

Energy Research & Social Science

“Hot-headed” students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries

--Manuscript Draft--

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Abstract:	<p>The growth in global climate protests by students challenge the status quo of policy makers and political leaders in mitigating the effects of climate change. These events suggest that young people are increasingly well-informed and aware of environmental issues and the impact of increases in greenhouse gases in the atmosphere. To investigate how well-informed students are on the issue of climate change, we have used secondary data from the Programme of International Student Assessment (PISA) [1], a cross-national study involving 540,000 students in 72 OECD and partner countries to explore students' responses. Our analysis of these data provides unparalleled insight into fifteen-year-old students' self-reported awareness about greenhouse gases and how this varies by achievement, enjoyment of and interest in science, students' socio-economic status and country of origin. We find there are substantial global variations in students' awareness of greenhouse gases, which is independent of the international ranking of PISA scores. Measures of scientific literacy have the greatest association with students' awareness about greenhouse gases, although enjoyment of science and interest in broad scientific topics suggests that school science courses that are rigorous in content and enjoyable for students prepare them to be well-informed citizens about climate change. Given the global interest in issues of equity, we argue that both schools and curriculum designers have the ability to cultivate enjoyment and interest to build positive attitudes, awareness and responsibility towards the environment alongside the development of scientific literacy.</p>
Suggested Reviewers:	<p>Marcus M Grace, PhD Professor of Science Education, University of Southampton M.M.Grace@soton.ac.uk Professor Grace is chair of BERG (Biology Education Research Group), affiliated with the Royal Society of Biology.</p> <p>Jake Anders, PhD Associate Professor of Educational and Social Statistics, University College, London jake.anders@ucl.ac.uk Dr Anders is able to offer insight into methodological choices and analysis, is experienced in enabling research to policy formation and experienced in educational research.</p> <p>Nano Teig, PhD Universitetet i Oslo nani.teig@ils.uio.no Nani's research in science education uses large scale data sets</p> <p>David Treagust, PhD Professor of Education, Curtin University D.Treagust@curtin.edu.au Professor Treagust is one of the world's eminent researchers in science education.</p>

	<p>Dean Cairns, BSc Assistant Professor, Emirates College for Advanced Education DCairns@ecae.ac.ae Dean has undertake a large number of analyses of large data sets, is an experienced science education teacher and researcher</p>
	<p>Dawson Vaille, PhD Professor of Science Education, University of Western Australia vaille.dawson@uwa.edu.au Profressor Dawson's research and expertise in science education is renowned. She has written a book about climate change and the greenhouse effect.</p>
<p>Opposed Reviewers:</p>	
<p>Response to Reviewers:</p>	

Dear Professor Sovacool,

Firstly, our sincere apologies for the error in the title – this was an oversight on our part.

We will provide all statistical codes (see footnote1)

1. The new title is indeed improved, but we had painstakingly discussed this via email and you altered it again after our discussion and agreement. Your current title is not as good as the one we suggested; it's also against journal style by having single quotation brackets (rather than double) and the "students'" awareness reads oddly, most people would put "student awareness." I again maintain you should revert back to the title we agreed on:

"Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries.

Once again, our apologies.

2. If you haven't already, now is also the time to format the manuscript fully to journal style. I think you can still keep tables and figures embedded in the text, and not submitted separately, but you will have to make sure you follow our requirements for references. Look at any published ERSS article to see how we format references to numbered endnotes. We used to do this for authors, but a change in typesetters means that is no longer possible. The journal is using a numeric reference style. References must be cited by numbers running consecutively in the text, e.g., ".. some studies have examined the influence of participation [1,2,3]" or "As Dawes et al. [4] point out ..". The References section should list the references in numeric order, i.e. in the order in which they first appear in the text. Before submitting the revised, final version of your paper please ensure that the manuscript follows the journal's numeric reference style.

Thank you, we have tried to adjust the references to suit the journal.

The urls for the PISA data and codes for model building, CAIT, climate data and climate change performance index are provided in the text.

We have amended all the references of the websites used, provided urls in the reference list and updated the text using numeric format.

We will provide all statistical codes (see footnote1)

3. Presentation: if you have figures and graphics, Elsevier will do very little to modify these. So take extra care to ensure that all of them have properly legible legends and titles, and perhaps spend a few moments tweaking them so that they look the best they possibly can. Same with headings and subheadings, which can really enhance the structure and style of a piece.

We have provided tiff images for the figures embedded in the text and attached high resolution pdf versions of these as well

We have put the figures and table captions below each

Each of the figures are two columns. Each table is two columns wide

4. Proofing: the days where journals tended to do this well are behind us. It is on authors to ensure everything is properly copy edited and proofed for English language proficiency. I remind you of this only because around one in every four published articles in the journal end up having easily identifiable grammatical mistakes we catch after publication (even in titles, abstracts, and keywords). So make sure to carefully proofread all parts of the manuscript.

We think we have proofread carefully this now and updated the manuscript.

5. Also, something that confuses people: when you resubmit, only include all of the new files, i.e. the latest manuscript clean, the latest manuscript tracked changes from the last version, a final (short) response to reviewers document, a final title page. Remove everything else, especially older versions of the manuscript. Production has been known to get confused and typeset the wrong one ...

We will do our best.

Reviewer #2: First of all, I want to thank the author(s) who have carefully considered my comments in their revisions and thus resolved almost all of the issues I raised with the previous version of the manuscript. I think the author(s) have done a really good work in communicating their research project in the current manuscript. However, I would like to propose a few minor suggestions to further improve the clarity of the manuscript.

1. Sample size and missing values

I might have commented about this issue on my previous feedback. I suggest moving the information about the sample size and missing values from the Appendix to 2.1 PISA Data on page 3. **This is done**
This information includes the final number of students and countries included in the final model as well as the name of the PISA participating countries that were excluded from the analyses. I think it should be clear that not all participating countries in PISA 2015 are shown in Figures 2 and 3; only those countries that were included in the final model.

We think this is more explicit (2.2) as part of the main text.

I agree with the author(s) that the model specifications and weights should be placed in the Appendix.

Thank you

2. Findings on RQ3

Could you check the values for odds ratio on interest in broad science topics page 8 line 23-24? Isn't supposed to be 1.36 to 1.39 (Table 2)?

These are checked and can confirm these are correct. Is the reviewer querying the odds ratio or / and intervals? There is a small difference between the values of these two coefficients after 2dp.

3. RQ5

Findings for RQ5 explore more than just answering whether there is a gender gap with regards to students' awareness of greenhouse gases (page 11 line 12-25). I suggest revising RQ5 to reflect these important findings, for example, "Is there a gender gap in students' awareness of greenhouse gases? If yes, how does the gender gap vary by OECD and partner countries?"

Thanks – we have updated the question itself to reflect the focus

Regarding plausible values (PVs), I have read far too many articles who ignored the importance of using correct analyses for PVs, such as by using only one PV or averaging the values of PVs. Thank you for clarifying how the PVs were integrated into the analyses in this study.

Thanks ☺

Reviewer #3: Thank you for your attention to my recommendations in my initial review. I thought it was a good article to start with and you appropriately addressed the few items I raised. My only concern was that none of the issues I raised in my review were addressed whatsoever in the response letter that you submitted with the edited manuscript. I had to dig through the track changes version of the article to see if I could find the respective edits. This caused me to put off notably my response; I would have submitted my suggestion to accept the article at least three weeks earlier, had your letter to the reviewers highlighted the changes that you made in response to my comments.

We apologise for this oversight. Originally, we had constructed a table to ensure that we had addressed each point properly / provided what we thought was an adequate rebuttal.

Actually, we later then wrote the letter for ease of overview and as many of the points were overlapping. For coherence, we summarised these in the letter. Perhaps we should have been better to include both.

With thanks to you, the reviewers and the team at ERSS.

Mary & Mike

“Hot-headed” students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries

Abstract

The growth in global climate protests by students challenge the *status quo* of policy makers and political leaders in mitigating the effects of climate change. These events suggest that young people are increasingly well-informed and aware of environmental issues and the impact of increases in greenhouse gases in the atmosphere. To investigate how well-informed students are on the issue of climate change, we have used secondary data from the Programme of International Student Assessment (PISA) [1], a cross-national study involving 540,000 students in 72 OECD and partner countries to explore students' responses. Our analysis of these data provides unparalleled insight into fifteen-year-old students' self-reported awareness about greenhouse gases and how this varies by achievement, enjoyment of and interest in science, students' socio-economic status and country of origin. We find there are substantial global variations in students' awareness of greenhouse gases, which is independent of the international ranking of PISA scores. Measures of scientific literacy have the greatest association with students' awareness about greenhouse gases, although enjoyment of science and interest in broad scientific topics suggests that school science courses that are rigorous in content and enjoyable for students prepare them to be well-informed citizens about climate change. Given the global interest in issues of equity, we argue that both schools and curriculum designers have the ability to cultivate enjoyment and interest to build positive attitudes, awareness and responsibility towards the environment alongside the development of scientific literacy.

“Hot-headed” students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries

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Abstract

The growth in global climate protests by students challenge the *status quo* of policy makers and political leaders in mitigating the effects of climate change. These events suggest that young people are increasingly well-informed and aware of environmental issues and the impact of increases in greenhouse gases in the atmosphere. To investigate how well-informed students are on the issue of climate change, we have used secondary data from the Programme of International Student Assessment (PISA) [1], a cross-national study involving 540,000 students in 72 OECD and partner countries to explore students’ responses. Our analysis of these data provides unparalleled insight into fifteen-year-old students’ self-reported awareness about greenhouse gases and how this varies by achievement, enjoyment of and interest in science, students’ socio-economic status and country of origin. We find there are substantial global variations in students’ awareness of greenhouse gases, which is independent of the international ranking of PISA scores. Measures of scientific literacy have the greatest association with students’ awareness about greenhouse gases, although enjoyment of science and interest in broad scientific topics suggests that school science courses that are rigorous in content and enjoyable for students prepare them to be well-informed citizens about climate change. Given the global interest in issues of equity, we argue that both schools and curriculum designers have the ability to cultivate enjoyment and interest to build positive attitudes, awareness and responsibility towards the environment alongside the development of scientific literacy.

1. Introduction

1.1 Environmental awareness

Activism in response to climate change is global and has been led by young people, inspired by protests in Sweden by Greta Thunberg. As future leaders, informed and active citizens, it is important that they understand and respond to effects of a changing climate. Young people’s knowledge of science and perceptions about climate change are rarely examined in large-scale studies and even fewer use cross-cultural analyses. In a cross-country study of 13-16 year olds (n=760) in Austria and Germany [2], researchers found students’ knowledge, awareness and willingness to act varies considerably and even the group of ‘concerned activists’ were not very knowledgeable about climate change. A survey administered to young secondary students in New South Wales, Australia (n=500) and England (n=785) explored ‘degree of willingness to act’ and ‘believed usefulness of action’ in respect of ameliorating climate change [3], reporting a discrepancy in students’ self-reports about being well-informed and their ‘beliefs about the effectiveness of actions in reducing climate change’. Encouraging students to ‘take action’ [3] may thus not reflect the knowledge needed to explain climate change even if motivation and behavioural change suggests otherwise. It is long assumed that being armed with appropriate knowledge predicates behavioural change.

One longitudinal survey has reported that adults’ trust in climate scientists is associated with interest in science as measured in 12-14 year olds [4] supporting the notion that school science courses that foster interest and curiosity may have long-lasting consequences for confidence in climate scientists. Schools and universities have been urged to use education to promote the message of sustainability, action and collaboration [5], climate change [6, 7], help ‘adaptation literacy’ to be creative in responding to climate change [8], and address risks and stresses from climate change in schools[9].

1 The relationship between climate change mechanistic knowledge and acceptance [10] suggest
2 that education and interventions can bring about changes in the understanding of the causes of
3 climate change, regardless of political orientation, religious and worldviews [11-13]. For
4 example, first year university students (n=24) showed large gains (ES=.53) in being informed
5 about the earth’s climate systems following a semester long introductory geology course [14].
6 Student activism is now global, beliefs and knowledge about climate change and behaviours to
7 mitigate climate change have been explored, but how confident are students in their ability to
8 explain? Is this likely to be associated with their school education, academic achievement in
9 science or reflective of their wider socio-cultural environment? This paper addresses a gap in
10 the literature about students’ environmental awareness in respect of greenhouse gases in
11 exploring how informed they think they are.
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17 1.2 Scientific literacy and PISA

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19 One of the goals of science education in schools is to develop scientific literacy. For example,
20 the Organisation for Economic Co-operation and Development’s (OECD) Programme for
21 International Student Assessment (PISA) defined this as:
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25 *...the ability to engage with science-related issues, and with the ideas of science, as a*
26 *reflective citizen. A scientifically literate person is willing to engage in reasoned*
27 *discourse about science and technology, which requires the competencies to explain*
28 *phenomena scientifically, evaluate and design scientific enquiry, and interpret data and*
29 *evidence scientifically [15]*
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32 Measurement of scientific literacy (PISA scores) amongst 15-year olds provides a global
33 snapshot and focus for educators, researchers and policy makers. School science is important
34 in supporting the development of students’ attitudes, responsibility towards environmental
35 awareness, their interest, motivation, and engagement in science. PISA uses a stratified two-
36 stage sample design [16] in each country to identify and select schools and students to ensure
37 valid representative sample, testing students’ ability to apply their knowledge to real world
38 problems in mathematics, reading and science, along with trials in an innovative area which in
39 2015 was collaborative problem solving and financial literacy. The 2015 data from a 540,000
40 student sample represents the 29 million 15-year olds, and therefore comprises one of the
41 largest cross-country study of education [17], providing a cross-sectional report every three
42 years with a focus on literacies (reading, scientific and mathematical) independent from OECD
43 countries’ curricula with a rotating focus on subjects. The official OECD and country reports
44 on students’ achievement are used to inform policies [17-19], stimulate debate about
45 approaches to teaching and learning [20-23], and create headlines in national media, where the
46 ranking of countries can be prioritised over other aspects of education [19, 24]. Linking PISA
47 scores with associated economic gains is contentious at best [25, 26] but the negative
48 association between interest in and achievement in science is evident at the country level and
49 student level of analysis [17], which is both counterintuitive and problematic. Much of the
50 secondary analyses undertaken by researchers explores relationships using student and school
51 level variables including achievement (or scientific literacy, the ‘score’), socioeconomic status,
52 gender, and affective dispositions. These are disseminated through professional and subject-
53 specific research avenues [21, 24]. This research provides a unique opportunity to undertake
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substantial ‘cross-cultural field work’ [25] from OECD and partner countries, of varying different geo-political persuasions with respect to climate change.

1.3 Objectives of the study

While PISA does not measure environmental literacy directly, questions focused on students’ reported self-awareness of environmental issues enable exploration of associations between measures of scientific literacy, affective dispositions of students and broader factors influencing environmental literacy [26]. In 2006 (the last time these items were used prior to 2015), for example, 58% of students reported an awareness of greenhouse gases compared with 73% of students who were aware of the consequences of forest clearing [27]. Importantly, the relationship between students’ awareness and scientific knowledge of environmental issues was reported to be linear in Australia [28], and also was robust using released 2006 test items about the greenhouse [29] and globally awareness of environmental issues was associated with socioeconomic background [30]. In another small study exploring Turkish students’ scientific literacy scores and environmental awareness [31], the relationship again was linear.

In view of the political discourse surrounding climate change, greenhouse gases and means to mitigate these, we have used the 2015 PISA data set to carry out an exploratory analysis of the relationship between achievement, affective measures and awareness (being informed) of the increase of greenhouse gases, as well as the relative influence of home background indices (wealth, cultural possessions, home educational and ICT resources [16]).

Our primary research question is therefore:

1. *What is the level of awareness of greenhouse gases in PISA 2015 students?*

In addition, we explore associations between scientific literacy, student level variables and affective measures, and consider the following secondary questions:

2. *How is awareness of greenhouse gases associated with scientific literacy?*
3. *How are student background variables and affective measures related to students’ reports of being informed about greenhouse gases?*
4. *How does awareness of greenhouse gases vary by OECD and partner countries?*
5. *Is there a gender gap in awareness of greenhouse gases and if so, how does this vary by OECD and partner countries?*

2. Materials and Methods

2.1 PISA data

PISA data are from a subset of the student questionnaire of the OECD’s 2015 Programme for International Student Assessment and combined with country-level environmental data. In 2015, science was the senior subject and the questionnaire was designed to explore student performance more widely, and importantly broad attitudes towards the study of science and scientific issues. The PISA dataset analysed during this study are available from the OECD [32].

1 PISA is targeted at 15-year olds attending educational institutions in grades 7 or higher, with
2 testing generally taking place between March 2015 and the end of August 2015, although some
3 countries could agree with the OECD to test outside of that period. In all but the Russian
4 Federation, the sampling process was of a two-stage stratified design. Firstly, a minimum of
5 150 schools were sampled from a national list on the basis of nationally determined school-
6 level strata – explicit and implicit – with the implicit strata used for sorting the schools uniquely
7 within each explicit stratum. For example, in the United States the explicit strata included
8 region, funding, whether or not the school was a public school and no modal grade. The implicit
9 strata included grade span, urbanisation, minority status, school gender composition and state.
10 In the United Kingdom this included country, school type, region, modal grade (in England),
11 school gender composition, and certainty selections, with the implicit strata being school
12 performance (England and Wales only), and local authority. This was followed by a second
13 stage where students were randomly sampled on the basis of equal probabilities within the
14 sampled school with a general target of 42 using the computer-based test and 35 for the paper-
15 based test [16]. Weights are included to allow inferences to be representative across
16 participating countries.
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21 2.2 Missing data

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23 Of the 519334 original observations from 69 countries, the final analysis contained 336396
24 students from 54 countries, losing participants from Argentina, Albania, Algeria, Georgia,
25 Indonesia, Jordan, Kosovo, Lebanon, Macedonia, Malta, Moldova, Romania, Vietnam,
26 Thailand, and Trinidad and Tobago,. A missing data pattern analysis highlighted several
27 covariates that reduced the sample size considerably. In particular, interest in broad science
28 reduced the available sample by approximately 52000, and highest occupational status of
29 parents reduced the sample further by approximately 22000. In addition, the interaction of
30 missing data across four covariates – enjoyment of science, climate-ordered, instrumental
31 motivation to science, and interest in broad science – reduced the sample by almost 19000
32 students.
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37 The analysis reported is the complete case analysis only. A three-level multiple imputation
38 procedure using Stat-JR’s n-level multiple imputation template was attempted [33, 34].
39 Unfortunately, the imputation did not converge. However, the sample size remains very large
40 across the majority of participating schools countries.
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45 2.3 Greenhouse Gas Emissions and Climate Policies

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47 For the country-level environmental data, the 2017 total Greenhouse gas emissions excluding
48 land use change and forestry, measured in millions of tonnes of carbon dioxide equivalent
49 (MtCO_{2e}) were downloaded from the World Resources Institute - CAIT climate data explorer
50 historical emissions database [35] and divided by the population of each territory to produce a
51 per capita measure. The Climate Change Performance Index reports on climate policies and
52 this enables a comparative analysis of the most recent national policies and enacted efforts to
53 protect the climate. These data [36] help us understand the wider context of the students’
54 responses in different countries.
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58 2.4 Outcome

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Our outcome variable formed part of a suite of questions to capture students’ awareness about selected environmental issues, some of which were used in earlier rounds of PISA. In PISA 2015, students were asked, ‘*How informed are you about the increase of greenhouse gases in the atmosphere?*’ (ST09201TA), each with four options: *I have never heard of this; I have heard about this but I would not be able to explain what it is really about; I know something about this and could explain the general issue; and I am familiar with this and I would be able to explain this well.*

2.5 Model building¹

Multilevel ordered logistic “proportional odds” regression was used to estimate the individual, school and country-level probability of being informed about the issue surrounding the increase in greenhouse gases in the atmosphere. Multiple models of increasing complexity were fitted, with the final model being adjusted on the basis of vectors of individual-level demographic and background variables (including the gender of respondent, immigration status, parental education, the highest occupational status of parents and economic and social resources); science affective measures – such as enjoyment, broad interest and motivation to study science; student performance on the science PISA test; and carbon dioxide equivalent per capita (see methods for further details). Taking full advantage of the multilevel nature of the data, we allowed the intercepts to vary by school and country, along with three coefficients which varied by country – female, student performance on Science PISA test, and a female*PISA score interaction. Several of the predictors are composite scores from multiple items (parental education, highest occupational status of parents) and some of these are further derived from IRT scaling using the generalised partial credit model (cultural possessions, home educational resources, wealth, ICT resources, enjoyment of science, interest in broad science topics, instrumental motivation to science). The scaling methodology is discussed in the technical report [16].

For the PISA science score this was designed to examine student competencies (explaining scientific phenomena, designing scientific enquiry as well as interpreting data), knowledge (which includes content knowledge of the natural world and technology, how such knowledge is produced and the rationale behind scientific procedures) and finally contexts (including personal contexts, and scientific issues at the local, national and global level)[16]. As the PISA questionnaire is so broad, each student is only ever asked a smaller subset of all available questions and so PISA have a procedure to impute the values producing 10 plausible values for each of the three main subject domains – Reading, Mathematics and Science (see [16] for a discussion on how these plausible values are generated).

For the purpose of modelling each plausible value added to the final model separately, the model was fit and the parameter simulations saved. Once all 10 plausible values had been fit, the parameter simulations were merged and quantities of interest were calculated [37].

Further details are available in the appendix.

3. Findings

¹ All codes used to create models are available at <https://doi.org/10.7910/DVN/JDCZA>

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We present the findings organised by research questions (RQ) below:

3.1 RQ1: *What is the level of awareness of greenhouse gases in PISA 2015 students??*

With the broad attitudes towards contemporary scientific issues, a subset of 4-item Likert questions asked student respondents on how informed they were about environmental issues.

How informed are you about the increase of greenhouse gases in the atmosphere?	N (%)
I have never heard of this	51090 (9.8%)
I have heard about this but I would not be able to explain what it is really about	127728 (24.6%)
I know something about this and could explain the general issue	182110 (35.1%)
I am familiar with this and I would be able to explain this well	107172 (20.6%)
Missing	51234 (9.9%)
Total	519334 (100%)

Table 1: *Distribution of the outcome variable*

The distribution of unweighted responses in table 1 shows that a baseline of 55.7% of students know ‘something about this’ or are ‘familiar with this and could explain it well’. It is concerning that such a large number of students do not feel well informed enough to explain this issue (24.6%) or have never heard of greenhouse gases in the atmosphere (9.8%). We now explore whether this patterning of responses is related to individual PISA scores or if these are associated with countries.

3.2 RQ2: *How is awareness of greenhouse gases associated with scientific literacy?*

The individual level weighted multilevel regressions results are presented in table 2. These show the average individual in the average school and in the average country (which have means of 0). All school and country-level effects are centred on zero. We can then easily see which positively or negatively deviate from the average probability. The coefficients are on the logit scale, but have also been converted to odds-ratios and probability for easier interpretation. Our comparison group is a student who is male, “native” to that country, whose parental education and highest occupational status are at the OECD average (mean centred at 0); home resources, such as cultural possessions, home educational resources, wealth and ICT resources are at the OECD average; enjoyment of science, interest in broad science and instrumental motivation towards science are at the OECD average; PISA score was again at the OECD average, and the student went to the average school in the average country with the average CO₂ emissions per capita.

Parameter	Posterior Mean (SD)	Posterior 95%	Odds-Ratio	Probability Scale 95%
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		Credible Intervals	95% Credible Intervals	Credible Interval
Sex of respondent	-0.14 (0.03)	-0.20,-0.08	0.82, 0.92	-0.05, -0.02
Immigrant (First generation)	0.11 (0.02)	0.07, 0.15	1.07, 1.16	0.02, 0.04
Immigrant (Second generation)	0.01 (0.02)	-0.02, 0.05	0.98, 1.05	-0.01, 0.01
Parental Education	0.01 (0.00)	0.01, 0.01	1.01, 1.01	0.02, 0.02
Highest Occupational Status of Parents	0.04 (0.01)	0.03, 0.05	1.03, 1.05	0.01, 0.01
Cultural Possessions	0.14 (0.01)	0.13, 0.15	1.14, 1.17	0.03, 0.04
Home Education Resources	0.08 (0.01)	0.07, 0.09	1.07, 1.09	0.02, 0.02
Wealth	0.03 (0.01)	0.01, 0.05	1.01, 1.05	0.00, 0.01
ICT Resources	-0.02 (0.01)	-0.04, -0.00	0.96, 1.00	-0.01, 0.00
Enjoyment of Science	0.32 (0.01)	0.31, 0.33	1.37, 1.40	0.08, 0.08
Interest in Broad Science	0.32 (0.01)	0.31, 0.33	1.36, 1.39	0.08, 0.08
Instrumental Motivation to Science	0.03 (0.00)	0.02, 0.04	1.02, 1.04	0.00, 0.01
PISA Score	1.69 (0.05)	1.59, 1.76	4.91, 5.96	0.33, 0.36
CO ₂ emissions per capita	-0.01 (0.01)	-0.03, 0.01	0.98, 1.01	-0.01, 0.00
Sex*PISA Score	-0.16 (0.02)	-0.20, -0.11	0.81, 0.90	-0.07, -0.05
Cutpoints:				
(I have never heard of this) (I have heard about this, but I would not be able to explain what it is really about)	-2.73 (0.06)	-2.86, -2.62		
(I have heard about this, but I would not be able to explain what it is really about) (I know something about this and could explain the general issue)	-0.57 (0.06)	-0.70, -0.46		
(I know something about this and could explain the general issue) (I	1.88 (0.06)	1.75, 2.00		

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am familiar with this and I would
be able to explain this well)

Table 2: Model of students' perceptions of being informed of the increase in greenhouse gas emissions

The largest coefficient is seen from the association between being well-informed and the PISA score, the measure of scientific literacy. In the PISA sample, males who scored one standard deviation higher were on average 34.5% more likely to perceive being more informed, whereas females were 6% lower than their male counterparts. This pattern is also illustrated in the Australian report, which showed a “positive relationship between environmental awareness and scientific literacy” [28].

3.3 RQ3: are student background variables and affective measures related to students' reports of being informed about greenhouse gases?

There are five key factors that have practical significance— i.e. whether the effect is of a sufficient magnitude given the context to be considered important (see the discussion in the supplementary materials) - on individual students being informed about greenhouse gases. These are sex of respondent (being female), cultural possessions, enjoyment of science, interest in broad science topics and the previously discussed PISA score. On average female students have an odds ratio interval of 0.82 to 0.92. When converted to the probability scale females were on average 4.7% less likely to perceive being informed than their male counterparts, although this varies considerably by country and this variation is addressed further below. For those students that on average were one standard deviation higher in terms of home cultural possessions (e.g. classical literature; books of poetry; works of art, books on art, music or design; and musical instruments), they had an odds ratio interval of 1.14 to 1.17. In probability terms, this means between three and four percentage greater likelihood of being more informed on the issue of the increase in greenhouse gases in the atmosphere.

Critically, positive coefficients on the affective measures show that they contribute considerably to the probability of being informed. For students that were one standard deviation higher in their enjoyment of science, they were approximately 8% more likely to perceive being more informed. This is a major shift for a social science based question and is something that teachers, schools and curriculum designers can influence and prioritise. This pattern is repeated for those who were one standard deviation higher than the OECD average regarding a broad interest in science topics, again being 8% more likely to be perceive being more informed (odds ratio of 1.37, 1.40).

3.4 RQ4: How does awareness of greenhouse gases vary by OECD and partner countries?

At the group-levels, knowledge about greenhouse gases in fifteen-year olds varies considerably by both school attended and country lived in. In a variance components analysis, 9% of the variance could be attributed to the school-level and 7% by country. In the final model the remaining unexplained variance was 4% at the school-level and 6% at the country-level. The school-level residuals (figure 3) mostly fell between ± 0.5 on the logit scale (0.61 and 1.65 on

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the odds-ratio scale, and $\pm 12\%$ on the percentage probability scale). The most extreme cases were -1.30 (UK) and 1.43 (Uruguay) logits from the baseline. On the odds ratio scale this is 0.27, and 4.18 respectively, and on the percentage probability scale this is -29% and +31% from the baseline. Once the country-level adjustments are taken account of the average student within these two schools sit -9% and +21% around the baseline. While these cases represent the extremes, and are subject to considerable uncertainty, the school-level is important: accounting for all other factors we have explored, schools’ contributions to student knowing about greenhouse gases cannot be overstated. In the case of the UK and Uruguayan education systems, both are both highly centralised, yet these two schools sit significantly away from the national averages. While we do have a lot of unmeasured variables here that can explain some of the variation, some of this will no doubt be down to school and subject leadership.

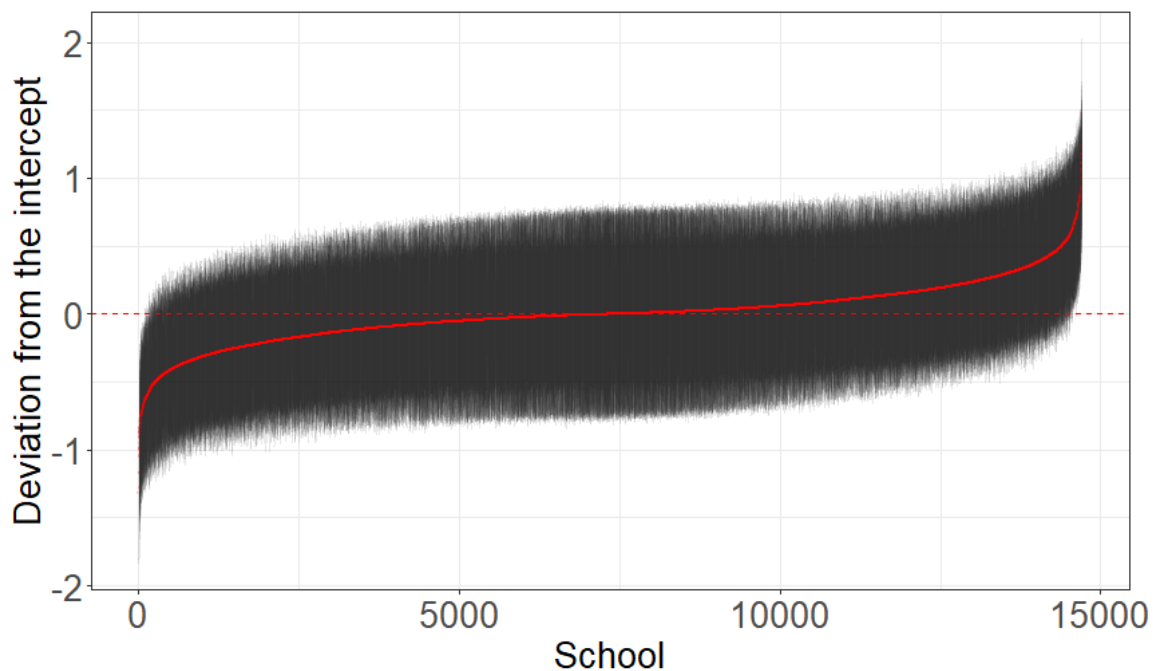


Figure 1: School-level residuals presenting the average deviation for each school from the intercept on the logit scale (Mean centred on 0)

With a focus on the country-level, while we did not see much of a relationship between country-level CO₂ emissions per capita, there is marked variation in intercept, showing students in some countries are much more knowledgeable than others (see figure 2). In particular, the average student in the average school in Sweden, Portugal, UK, and Ireland were 28%, 23%, 22%, and 21% more likely to report being more informed above the baseline respectively. Sweden has ambitious targets to be ‘carbon neutral’, leads the Climate Change Performance Index (CCPI). Portugal leads for both national and international policy performance, with renewable energy sources and commitment to be carbon neutral by 2050 and an aim to end coal use by 2030 [36]. It seems plausible to suggest that students in these countries are aware of climate change as a matter of global significance whether through education policy and school curricula or through wider societal and media discourse. For example, the UK Parliament (May 2019), Ireland’s

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Dáil (June 2019) Canada’s House of Commons and French government (July 2019) have declared a ‘climate emergency’.

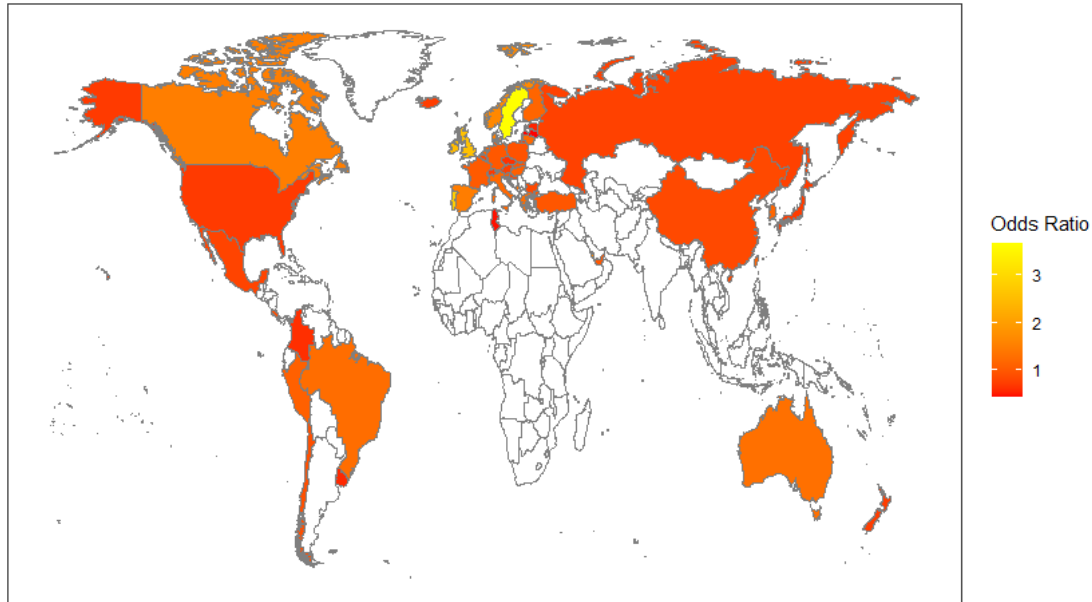


Figure 2: Country-level intercept variation on the probability of perceiving being informed about the increase of greenhouse gases in the atmosphere

Although the individual student PISA score is a predictor of environmental awareness, and in contrast to our earlier prediction, the relationship of PISA scientific literacy score to environmental awareness at the country level is less tenuous. East Asian countries (China, Chinese Taipei, Hong Kong, Japan, Korea, Macao, Singapore and Viet Nam) along with Canada, Estonia and Finland atop the international league table in achievement in science[1]. However, many students in these countries do not feel knowledgeable about greenhouse gases. China’s national policy and commitments to renewable energy, meet emissions targets and is considered to be an ‘improving’ country in respect of CCPI although a per capita high ‘net contributor’. At the lower end of the scale, probabilities of students feeling well-informed about greenhouse gases which are decreasing order from the baseline which include Latvia (19%), Israel (16%), Tunisia (15%), Estonia (15%), Uruguay (13%), Czech Republic (12%), Dominican Republic (11%), Columbia (11%), Luxembourg (10%), the USA (9%), New Zealand (8%), Russia (7%), Iceland (7%), and Croatia (6%). New Zealand is a medium-ranked CCPI country with respect to overall climate policy, a ‘top ranking’ country in PISA science, yet students there are not likely to feel well informed about the role of greenhouse gases. Indeed, the school curriculum lacks mandate to teach about climate change [38] except during the final years of high school. Being a geologically active country, with curriculum resources directed to address local and immediate environmental concerns may well explain the finding that New Zealand students do not feel well-informed about greenhouse gases. Contrary to the

1 findings drawn from adult populations, we do not find that levels of environmental awareness
2 were high in the US student population: quite the reverse. Even amongst 15-year olds, US
3 students were significantly less likely to feel well informed about greenhouse gases than those
4 in European countries (fig 4). This is a stark finding. Compared with other countries, the US
5 was identified in 2019 as ‘one of the worst-performing countries’ [36] and worsening in 2020
6 in regard to both national and international policy. The policies and practices of different states
7 and cities are thus not currently well aligned with the administration, which appears to promote
8 scepticism towards anthropogenic causes of climate change and the withdrawal from the Paris
9 agreement.
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14 *3.5 RQ5: Is there a gender gap in awareness of greenhouse gases and if so,*
15 *how does this vary by OECD and partner countries?*
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18 In the final model, the average gender difference highlighted that females were 4.7% less likely
19 to perceive being more informed about greenhouse gases than males, in contrast to the finding
20 reported in adults [39], where females show greater concern about environmental issues than
21 males. The sex and PISA score interaction demonstrated that those female students that scored
22 1 standard deviation higher on the PISA score were approximately 6% less (an odds-ratio
23 interval of 0.81,0.90 and probability interval of -0.07, -0.05) likely to informed on the issue of
24 greenhouse gases.
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28 Furthermore, we can explore the gender variation further by country as the slope has been
29 allowed to vary. As seen in Figure 3, there is considerable country-level variation in
30 probabilities. Female students on average in the following countries sit further below the -4.7%
31 probability: Iceland (-13.7%), the US (-12.7%), Chile (-11.7%), Latvia (-11.7%), Czech
32 Republic (-10.7%), Switzerland (-10.7%), New Zealand (-10.7%), and Poland (-9.7%). On the
33 other hand, in Turkey (4.5%), Macao (3.3%) South Korea (3.1%), Hong Kong (3.1%), Chinese
34 Taipei (2.47%), Montenegro (1.6%), Greece (0.60%) and mainland China (0.43%), females
35 were more likely than male peers to know about greenhouse gases. It is difficult to determine
36 whether this reflects differential emphasis in different schools, curriculum, or varying levels of
37 environmental awareness. While we are unable to identify causes for the gender gap, the school
38 science curricula, teachers and teaching are likely mediators to mitigate this.
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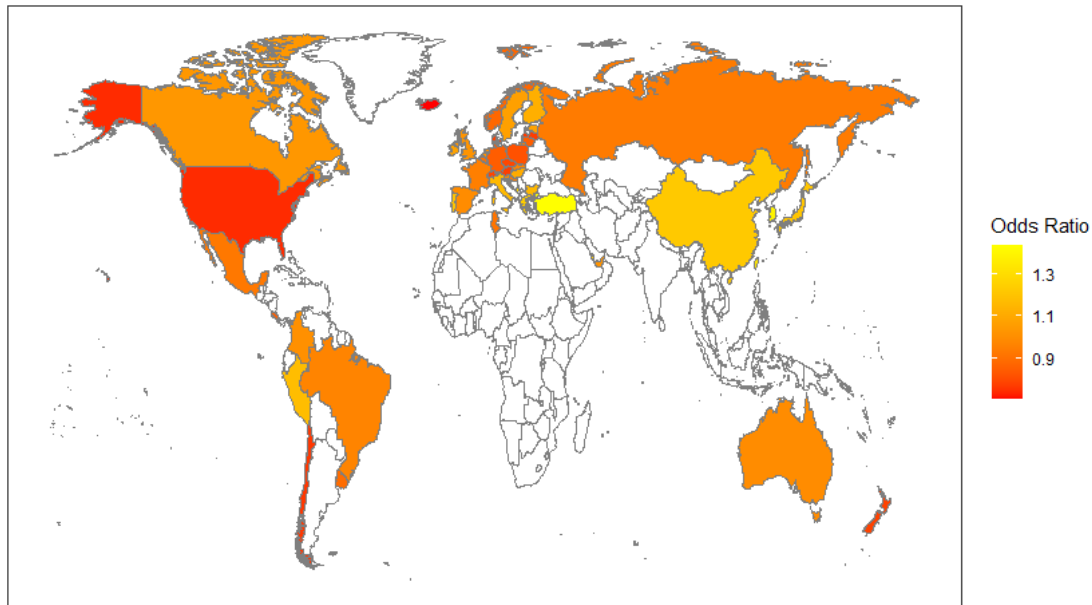


Figure 3: The varying country-level effect of being female on perceiving being more informed about greenhouse gases in the atmosphere

Positive effects are evident, especially between the variables of the PISA score and interest of, and enjoyment of science. These are large effects, likely to be reflective of the school environment, the curriculum content, teaching and learning.

Limitations

The OECD recognises that not all 15-year olds are enrolled in formal education across the world, so the data and analysis of these data need to be understood with this caveat in mind. Likewise, whether students’ responses across the world reflect the same understanding of attitudinal questions. We cannot know this but acknowledge this uncertainty in discussing the findings presented here. The use of student self-reported data such as PISA is subject to question and critique. We acknowledge this position and point to the use of the same questions across different rounds of the PISA cycle, refinements of constructs, questions and attention to survey design. Additionally, the self-reported nature has highlighted a gender gap that interestingly is not uniform across the all participating countries. It may be that ‘gaps’ are likely to be culturally dependent [40] and this is deserving of greater exploration.

5. Discussion

This analysis shows that students’ awareness of climate change is individually associated with their PISA score (achievement) and at the country level also likely to be shaped by local (national) policies and practices. Given the apparent mismatch in students’ environmental awareness of greenhouse gases and their achievement scores on PISA, we cannot assume all young people have equal access to scientifically informed materials about climate change and greenhouse gases at school [41]. High quality instruction in science can foster interest in

1 science and lead to improvement in knowledge and scientific literacy [12]. At the same time,
2 where schools promote science-related self-efficacy, or ‘build confidence in their students
3 abilities’ [42] students are likely to also have higher levels of achievement. Schools, the
4 curriculum, teaching and learning do not operate in a social vacuum. In part, this may well
5 reflect the emphasis on curriculum content, teachers’ confidence about teaching climate change
6 in school or wider societal attitudes. Education may help mitigate the consequences of political
7 inaction and address gaps in scientific and societal understanding of climate change [43, 44]
8 and greater priority needs to be given to environmental issues in schools. Students’ beliefs and
9 concerns about climate change may well be linked to local political and policy positions [45]
10 reflecting the public discourse or polarisation in adults’ views [46] and the global student-led
11 climate strikes.
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15 Sweden, for example, is identified by the CCPI as a ‘high-performing’ as a country, with falling
16 levels of greenhouse gas emissions and renewable energy as 40% of its total supply. Policies
17 in place to mitigate climate change are comprehensive, including energy, industry, agriculture,
18 etc. National legislation for climate and energy, policies aligned with international protocols
19 and the European Council mirror a country-wide approach to the environment. ‘Respect for the
20 environment’ is embedded from early years’ education [47] as a fundamental value throughout
21 schooling. Commitment to the United Nation’s Sustainable Development Goals is coordinated
22 across all government departments through the Minister for Public Administration within
23 Sweden and through the Ministry for Foreign Affairs. Specifically, the targets articulated to
24 ensure climate change measures through policy, planning including education.
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29 Girls’ education needs to be examined to ensure that they have equal access to the curriculum
30 and that they feel more informed about environmental issues. This is challenging for educators,
31 policy makers and political, business and industrial leaders. International cooperation and
32 commitment to align policies with a ‘green’ low-emission future will be essential to mitigate
33 the environmental emergency, reduce social inequalities and protect human societies [44]. With
34 the declaration of environmental emergencies, it appears that political leadership is not coming
35 fast enough, and from the analysis of these data that even young people do not feel well-
36 informed [45]. With inter-generational learning being one approach to rouse consciousness of
37 climate change [48], the siren voices to maintain the *status quo* are in sharp contrast to young
38 activist Greta Thunberg ‘*I want you to panic*’.
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Appendix

Weights

In the second stage of sampling all students within the school had an equal probability of selection. However, sampling probabilities at the first stage differed significantly across the participant countries. Some countries over or under-sampled specific sectors, explicit and implicit strata varied, school and student non-response differed across countries, and without available information to adjust for sample design and non-response for all countries, weighting becomes a necessity for appropriately modelling the outcome. Finally, schools are selected with a probability proportional to size. There are two methods to appropriately weight PISA data – via the final student weights or via the senate weights. Student weights scale up to the size of the population so larger countries carry more weight. Senate weights on the other hand allow each country to contribute equally to the analysis [52]. As the cross-country component of the research question was important, senate weights were used to adjust for the varying sample design and non-response.

Analysis strategy

As the outcome variable was a four ordered category variable where respondents expressed their level of awareness and ability to explain the environmental phenomenon, an ordered logistic “proportional odds” multilevel approach was used to model the data. This model assumes an underlying latent (and linear) variable that the ordered categorical variable maps on to via a series of (K-1) thresholds/cutpoints. The proportional odds assumption works on the basis of the linear predictor is assumed to explain the relationship in the same manner between all pairs of response categories, hence there are a single set of coefficients. When extending the model to adjust for group membership – in this case, the school attended by the student and the country in which the student and school are based. The varying intercept model allows for the thresholds/cut points to vary by school and country but maintaining the assumption of the same slope across all predictors, with the varying slope model further relaxing the assumption, by allowing some coefficients to vary by group membership.

A Calibrated Bayesian [53] approach was used, where frequentist methods were used for model development and model checking, but given the model complexity of the three-level model, logistic link function and multiple varying slopes, the analysis was conducted using Stan, a Bayesian Hamiltonian Markov Chain Monte Carlo sampler accessed through the R package brms [54]. The sampler was run on 10 chains for 5000 iterations to allow for the 10 plausible values to be modelled appropriately (1 per chain), and weakly informative priors – normal priors on the betas with 0 mean and standard deviations of 5, and half-cauchy priors on the variance parameters with means of 0 and standard deviations of 5. All parameters demonstrated convergence with rhat potential scale reduction factor values of ≤ 1.01 . Samples were then extracted to allow for post-processing and summary statistic calculations.

Model specification.

The final model reported here was as follows. The probability of the students perceiving themselves as being informed on the issue of the increase in greenhouse gases in the atmosphere was adjusted on the basis of a vector of individual-level demographic and background variables (sex of respondent, immigration status – “native”, “1st generation” and “second-generation”, parental education, and highest occupational status of parents); a vector

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of economic and social resources (Cultural possessions at home, Home educational resources, Family wealth, and ICT Resources); a vector of science affective measures (enjoyment of science, interest in broad science issues, instrumental motivation towards science; 10 plausible values of PISA overall science score; a group-level mean-centred indicator for the tonnes of carbon dioxide equivalent per capita; and a sex of respondent and PISA score interaction. The intercept was adjusted for school attended and country that the student resided in, and three of the covariates – sex of respondent, PISA score and the sex*PISA score interaction, were allowed to vary by country. This resulted in 5 additional parameters ($(U_{0jk}, v_{0k}, v_{1k}, v_{2k}, v_{3k})$), which provide the group membership adjustments.

The higher-level residuals were distributed as follows U_{0j} , the school-level residual is assumed to be normally distributed and centred on a mean of 0 with the variance parameter σ^2_u . The country-level residuals form a quadivariate normal distribution, with means of 0 and a variance-covariance matrix in which the diagonals are the four variance parameters for the intercept adjustment and 3 slope variances (and the oft-diagonals are used to provide the intercept-slope correlations). The model is presented below:

$$y_{ijk} = \begin{cases} 1 & \text{if } y_{ijk}^* \leq \theta_1 \\ 2 & \text{if } \theta_1 < y_{ijk}^* \leq \theta_2 \\ 3 & \text{if } \theta_2 < y_{ijk}^* \leq \theta_{K-1} \\ 4 & \text{if } \theta_{K-1} < y_{ijk}^* \end{cases}$$

$$y_{ijk}^* = \text{logistic}(\beta_{1k}Sex_{ij} + \beta_2Immig2_{ijk} + \beta_3Immig3_{ijk} + \beta_4Pared_{ijk} + \beta_5Hisei_{ijk} + \beta_6Cultposs_{ijk} + \beta_7Hedres_{ijk} + \beta_8Wealth_{ijk} + \beta_9Ictres_{ijk} + \beta_{10}Joyscie_{ijk} + \beta_{11}Intbrsci_{ijk} + \beta_{12}Instscie_{ijk} + \beta_{13k}Pisa.Score_{ij} + \beta_{14}co2e_k + \beta_{15k}Sex * Pisa.Score_{ij} + u_{0jk} + v_{0k} + v_{1k} + v_{2k} + v_{3k})$$

$$u_{0j} \sim N(0, \sigma_u^2) \text{ for } j = 1 \dots J$$

$$\begin{pmatrix} v_{0k} \\ v_{1k} \\ v_{2k} \\ v_{3k} \end{pmatrix} \sim N \left(\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{v_0}^2 & & & \\ \rho\sigma_{v_0}\sigma_{v_1} & \sigma_{v_1}^2 & & \\ \rho\sigma_{v_0}\sigma_{v_2} & \rho\sigma_{v_1}\sigma_{v_2} & \sigma_{v_2}^2 & \\ \rho\sigma_{v_0}\sigma_{v_3} & \rho\sigma_{v_1}\sigma_{v_3} & \rho\sigma_{v_2}\sigma_{v_3} & \sigma_{v_3}^2 \end{pmatrix} \right) \text{ for } k = 1 \dots K$$

Odds-Ratios

Ordinal Logistic regression returns coefficients which are the log of odds. These can be exponentiated to form odds ratios. Odds ratios are bounded at 0 at one end of the scale to positive infinity at the other. An odds ratio of 1 indicates a probability of .5, with anything

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under 1 indicating that the group has a lower probability than the comparison group and anything above 1 indicating that the group has a higher probability than the comparison group. To convert odds ratios to the probability scale, the following formula should be used:

$$\frac{odds}{(1 + odds)}$$

We have generally presented the results on the odds-ratio scale and probability scale to aid interpretation. Where we refer to probability we have re-centred a probability of 0.5 at 0 so that it provides a clear direction for the effect.

Practical and statistical significance

The analysis uses Bayesian inference to fit the ordinal logistic proportional odds multilevel model. Bayesian approaches do not rely on traditional null hypothesis significance testing, with the assumption of hypothetical repeated sampling and p-values. Parameters are represented as a probability distribution, with those that are more consistent with the data having higher probability and a narrower set of values, while those which are less consistent having lower probabilities and values that are more spread out [57]. 95% credible intervals are still judged in the same manner as 95% confidence intervals - as to whether they cross 0, however, the probability of a positive or negative effect can be directly calculated and where the distribution of an effect partially crosses 0, the weight of evidence for the direction and size of the effect can be judged.

An important distinction needs to be made between where an effect is bounded away from zero (statistical significance in the frequentist literature) and “practical significance” in which we consider the magnitude of the effect given the applied context. Often with a large enough sample size extremely small differences are “significant”, but if the effect size is small the impact of the covariate is much less relevant for understanding how our outcome variable varies.

Figure 1

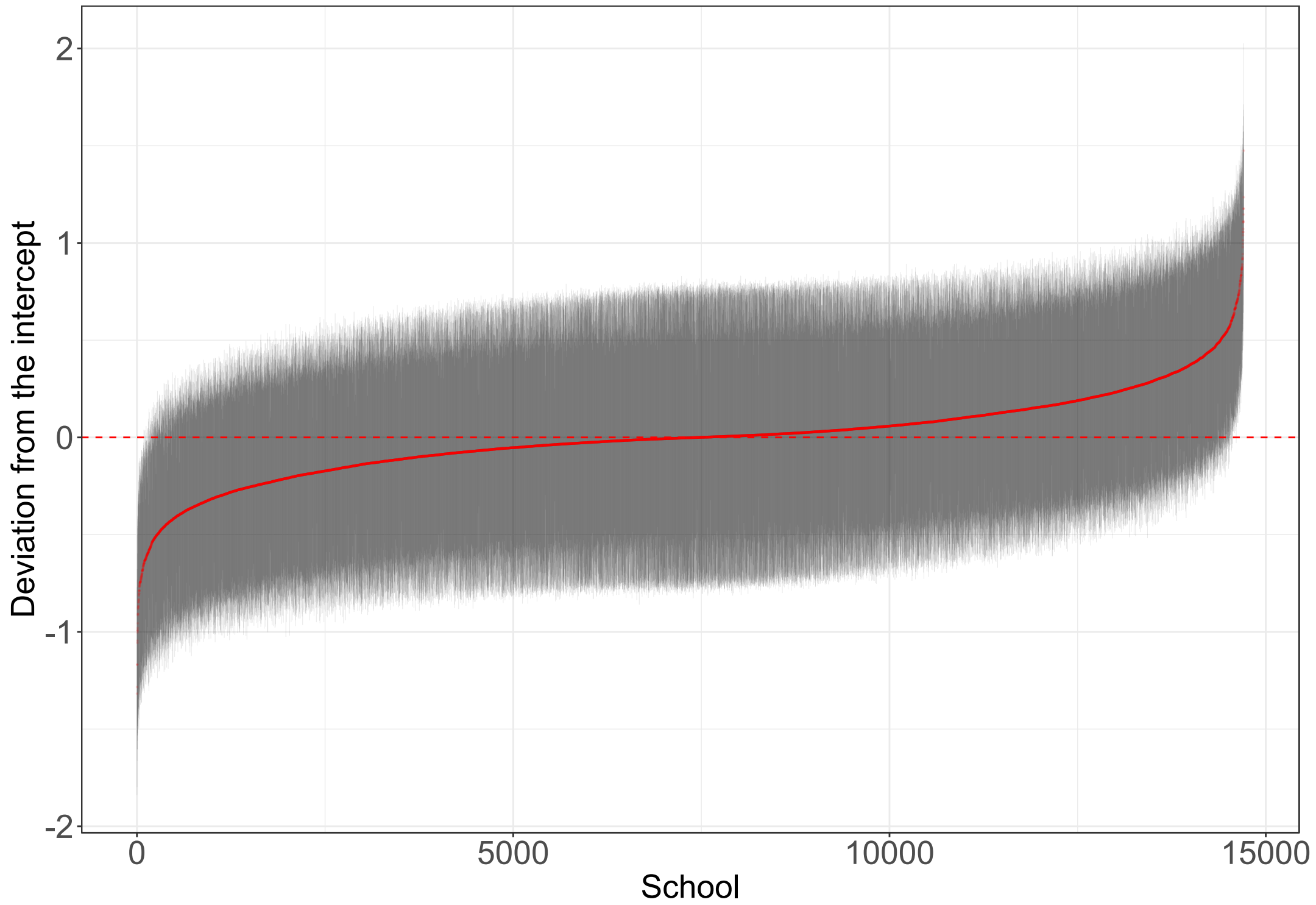
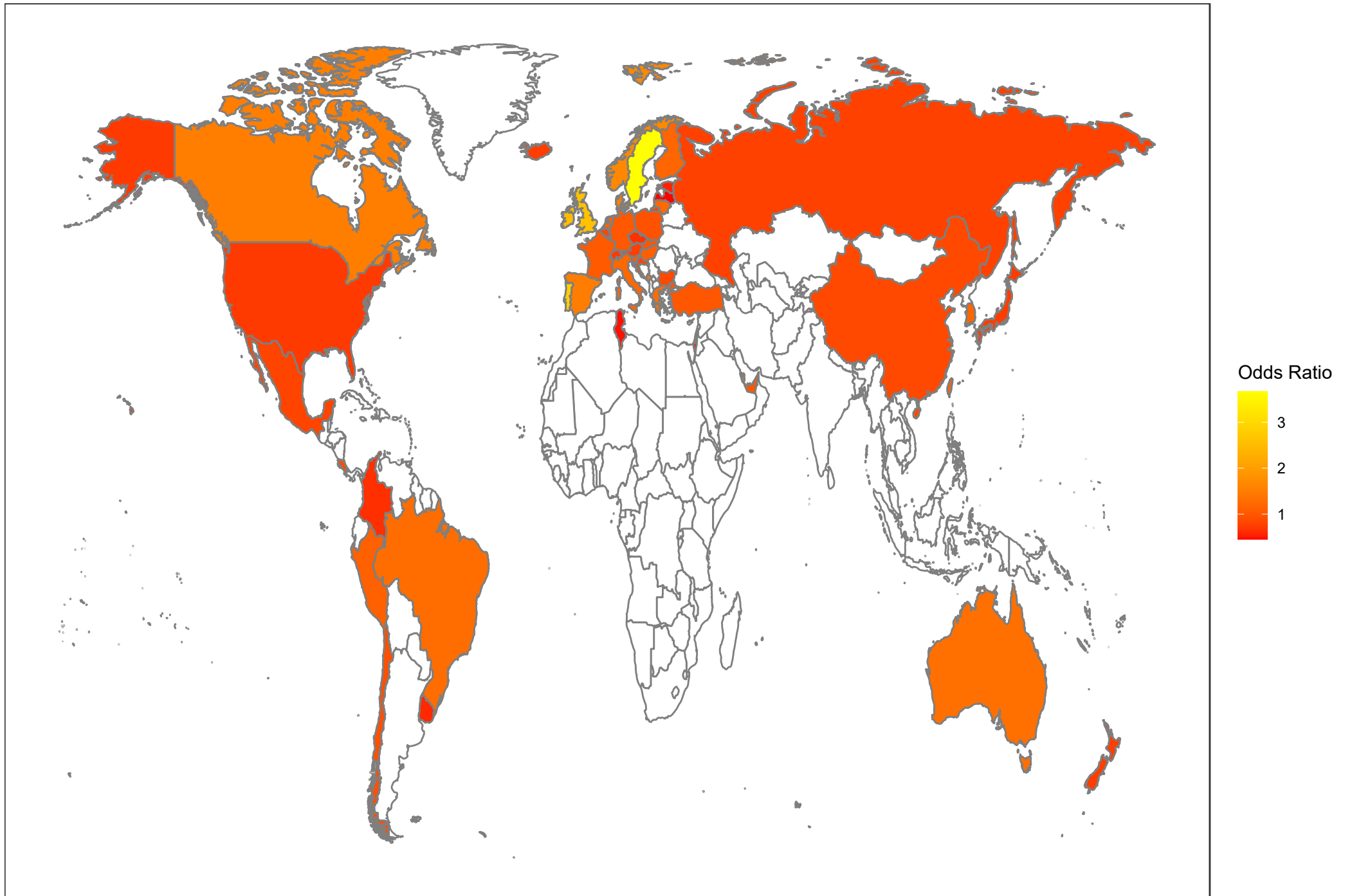


Figure 2



Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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"Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries
~~"Hot-headed students? A multi-level cross-country comparison of students' awareness of greenhouse gases"~~

Abstract

The growth in global climate protests by students challenge the *status quo* of policy makers and political leaders in mitigating the effects of climate change. These events suggest that young people are increasingly well-informed and aware of environmental issues and the impact of increases in greenhouse gases in the atmosphere. To investigate how well-informed students are on the issue of climate change, we have used secondary data from the Programme of International Student Assessment (PISA) [1], a cross-national study involving 540,000 students in 72 OECD and partner countries to explore students' responses. Our analysis of these data provides unparalleled insight into fifteen-year-old students' self-reported awareness about greenhouse gases and how this varies by achievement, enjoyment of and interest in science, students' socio-economic status and country of origin. We find there are substantial global variations in students' awareness of greenhouse gases, which is independent of the international ranking of PISA scores. Measures of scientific literacy have the greatest association with students' awareness about greenhouse gases, although enjoyment of science and interest in broad scientific topics suggests that school science courses that are rigorous in content and enjoyable for students prepare them to be well-informed citizens about climate change. Given the global interest in issues of equity, we argue that both schools and curriculum designers have the ability to cultivate enjoyment and interest to build positive attitudes, awareness and responsibility towards the environment alongside the development of scientific literacy.

1. Introduction
1.1 Environmental awareness

Activism in response to climate change is global and has been led by young people, inspired by protests in Sweden by Greta Thunberg. As future leaders, informed and active citizens, it is important that they understand and respond to effects of a changing climate. Young people's knowledge of science and perceptions about climate change are rarely examined in large-scale studies and even fewer use cross-cultural analyses. In a cross-country study of 13-16 year olds (n=760) in Austria and Germany [2], researchers found students' knowledge, awareness and willingness to act varies considerably and even the group of 'concerned activists' were not very knowledgeable about climate change. A survey administered to young secondary students in New South Wales, Australia (n=500) and England (n=785) explored 'degree of willingness to act' and 'believed usefulness of action' in respect of ameliorating climate change [3], reporting a discrepancy in students' self-reports about being well-informed and their 'beliefs about the effectiveness of actions in reducing climate change'. ~~(p.201)~~ Encouraging students to 'take action' ~~(p.191)~~ [3] may thus not reflect the knowledge needed to explain climate change even if motivation and behavioural change suggests otherwise. It is long assumed that being armed with appropriate knowledge predicates behavioural change.

One longitudinal survey has reported that adults' trust in climate scientists is associated with interest in science as measured in 12-14 year olds [4] supporting the notion that school science courses that foster interest and curiosity may have long-lasting consequences for confidence in climate scientists. Schools and universities have been urged to use education to promote the message of sustainability, action and collaboration [5], climate change [6, 7], help 'adaptation

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6 ~~'Hot-headed students? A multi-level cross-country comparison of students' awareness of greenhouse gases~~
7 literacy' to be creative in responding to climate change [8], and address risks and stresses from
8 climate change in schools[9].

9
10 The relationship between climate change mechanistic knowledge and acceptance [10] suggest
11 that education and interventions can bring about changes in the understanding of the causes of
12 climate change, regardless of political orientation, religious and worldviews [11-13]. For
13 example, first year university students (n=24) showed large gains (ES=.53) in being informed
14 about the earth's climate systems following a semester long introductory geology course [14].
15 Student activism is now global, beliefs and knowledge about climate change and behaviours to
16 mitigate climate change have been explored, but how confident are students in their ability to
17 explain? Is this likely to be associated with their school education, academic achievement in
18 science or reflective of their wider socio-cultural environment? This paper addresses a gap in
19 the literature about students' environmental awareness in respect of greenhouse gases in
20 exploring how informed they think they are.
21

22 23 1.2 Scientific literacy and PISA

24
25 One of the goals of science education in schools is to develop scientific literacy. For example,
26 the Organisation for Economic Co-operation and Development's (OECD) Programme for
27 International Student Assessment (PISA) defined this as:

28
29 *...the ability to engage with science-related issues, and with the ideas of science, as a*
30 *reflective citizen. A scientifically literate person is willing to engage in reasoned*
31 *discourse about science and technology, which requires the competencies to explain*
32 *phenomena scientifically, evaluate and design scientific enquiry, and interpret data and*
33 *evidence scientifically [15]*

34
35 Measurement of scientific literacy (PISA scores) amongst 15-year olds provides a global
36 snapshot and focus for educators, researchers and policy makers. School science is important
37 in supporting the development of students' attitudes, responsibility towards environmental
38 awareness, their interest, motivation, and engagement in science. PISA uses a stratified two-
39 stage sample design [16] in each country to identify and select schools and students to ensure
40 valid representative sample, testing students' ability to apply their knowledge to real world
41 problems in mathematics, reading and science, along with trials in an innovative area which in
42 2015 was collaborative problem solving and financial literacy. The 2015 data from a 540,000
43 student sample represents the 29 million 15-year olds, and therefore comprises one of the
44 largest cross-country study of education [17], providing a cross-sectional report every three
45 years with a focus on literacies (reading, scientific and mathematical) independent from OECD
46 countries' curricula with a rotating focus on subjects. The official OECD and country reports
47 on students' achievement are used to inform policies [17-19], stimulate debate about
48 approaches to teaching and learning [20-23], and create headlines in national media, where the
49 ranking of countries can be prioritised over other aspects of education [24] [19] 19, 24].
50 Linking PISA scores with associated economic gains is contentious at best [25] [26] 25, 26]
51 but the negative association between interest in and achievement in science is evident at the
52 country level and student level of analysis [17], which is both counterintuitive and problematic.
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8 ~~greenhouse gases~~

9 Much of the secondary analyses undertaken by researchers explores relationships using student
10 and school level variables including achievement (or scientific literacy, the 'score'),
11 socioeconomic status, gender, and affective dispositions. These are disseminated through
12 professional and subject-specific research avenues [21, 24]. This research provides a unique
13 opportunity to undertake substantial 'cross-cultural field work' [25] from OECD and partner
14 countries, of varying different geo-political persuasions with respect to climate change.

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15 16 1.3 Objectives of the study

17 While PISA does not measure environmental literacy directly, questions focused on students'
18 reported self-awareness of environmental issues enable exploration of associations between
19 measures of scientific literacy, affective dispositions of students and broader factors
20 influencing environmental literacy [26]. In 2006 (the last time these items were used prior to
21 2015), for example, 58% of students reported an awareness of greenhouse gases compared with
22 73% of students who were aware of the consequences of forest clearing [27]. Importantly, the
23 relationship between students' awareness and scientific knowledge of environmental issues
24 was reported to be linear in Australia [28], and also was robust using released 2006 test items
25 about the greenhouse [29] and globally awareness of environmental issues was associated with
26 socioeconomic background [30]. In another small study exploring Turkish students' scientific
27 literacy scores and environmental awareness [31], the relationship again was linear.

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29 In view of the political discourse surrounding climate change, greenhouse gases and means to
30 mitigate these, we have used the 2015 PISA data set to carry out an exploratory analysis of the
31 relationship between achievement, affective measures and awareness (being informed) of the
32 increase of greenhouse gases, as well as the relative influence of home background indices
33 (wealth, cultural possessions, home educational and ICT resources [16]).

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34 Our primary research question is therefore:

- 35
36 1. *What is the level of awareness of greenhouse gases in PISA 2015 students?*

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37
38 In addition, we explore associations between scientific literacy, student level variables and
39 affective measures, and consider the following secondary questions:

- 40 2. *How is awareness of greenhouse gases associated with scientific literacy?*
41 3. *How are student background variables and affective measures related to students'*
42 *reports of being informed about greenhouse gases?*
43 4. *How does awareness of greenhouse gases vary by OECD and partner countries?*
44 5. *Is there a gender gap in awareness of greenhouse gases and if so, how does this*
45 *vary by OECD and partner countries?*

46 47 48 2. Materials and Methods

49 2.1 PISA data

50
51 PISA data are from a subset of the student questionnaire of the OECD's 2015 Programme for
52 International Student Assessment and combined with country-level environmental data. In
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9 2015, science was the senior subject and the questionnaire was designed to explore student
10 performance more widely, and importantly broad attitudes towards the study of science and
11 scientific issues. The PISA dataset analysed during this study are available from the OECD
12 [32]. ~~<http://www.oecd.org/pisa/data/>~~

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13 PISA is targeted at 15-year olds attending educational institutions in grades 7 or higher, with
14 testing generally taking place between March 2015 and the end of August 2015, although some
15 countries could agree with the OECD to test outside of that period. In all but the Russian
16 Federation, the sampling process was of a two-stage stratified design. Firstly, a minimum of
17 150 schools were sampled from a national list on the basis of nationally determined school-
18 level strata – explicit and implicit – with the implicit strata used for sorting the schools uniquely
19 within each explicit stratum. For example, in the United States the explicit strata included
20 region, funding, whether or not the school was a public school and no modal grade. The implicit
21 strata included grade span, urbanisation, minority status, school gender composition and state.
22 In the United Kingdom this included country, school type, region, modal grade (in England),
23 school gender composition, and certainty selections, with the implicit strata being school
24 performance (England and Wales only), and local authority. This was followed by a second
25 stage where students were randomly sampled on the basis of equal probabilities within the
26 sampled school with a general target of 42 using the computer-based test and 35 for the paper-
27 based test [54–[16]]. Weights are included to allow inferences to be representative across
28 participating countries.

29 2.2 Missing data

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30 Of the 519334 original observations from 69 countries, the final analysis contained 336396
31 students from 54 countries, losing participants from Argentina, Albania, Algeria, Georgia,
32 Indonesia, Jordan, Kosovo, Lebanon, Macedonia, Malta, Moldova, Romania, Vietnam,
33 Thailand, and Trinidad and Tobago.. A missing data pattern analysis highlighted several
34 covariates that reduced the sample size considerably. In particular, interest in broad science
35 reduced the available sample by approximately 52000, and highest occupational status of
36 parents reduced the sample further by approximately 22000. In addition, the interaction of
37 missing data across four covariates – enjoyment of science, climate-ordered, instrumental
38 motivation to science, and interest in broad science – reduced the sample by almost 19000
39 students.

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41 The analysis reported is the complete case analysis only. A three-level multiple imputation
42 procedure using Stat-JR's n-level multiple imputation template was attempted [33, 34].
43 Unfortunately, the imputation did not converge. However, the sample size remains very large
44 across the majority of participating schools countries.

45 46 47 2.2.3 Greenhouse Gas Emissions and Climate Policies

48 For the country-level environmental data, the 2017 total Greenhouse gas emissions excluding
49 land use change and forestry, measured in millions of tonnes of carbon dioxide equivalent
50 (MtCO₂e) were downloaded from the World Resources Institute - CAIT climate data explorer
51 historical emissions database [35] (~~<https://cait.wri.org/>~~), and divided by the population of each
52 territory to produce a per capita measure. The Climate Change Performance Index ~~(2019)~~

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9 reports on climate policies and this enables a comparative analysis of the most recent national
10 policies and enacted efforts to protect the climate. These data [36] ~~are available at~~
11 ~~<https://www.climate-change-performance-index.org> and together~~ help us understand the wider
12 context of the students' responses in different countries.

13 2.3.4 Outcome

14 Our outcome variable formed part of a suite of questions to capture students' awareness about
15 selected environmental issues, some of which were used in earlier rounds of PISA. In PISA
16 2015, students were asked, 'How informed are you about the increase of greenhouse gases in
17 the atmosphere?' (ST09201TA), each with four options: *I have never heard of this; I have*
18 *heard about this but I would not be able to explain what it is really about; I know something*
19 *about this and could explain the general issue; and I am familiar with this and I would be able*
20 *to explain this well.*

21 2.4.5 Model building¹

22
23 Multilevel ordered logistic "proportional odds" regression was used to estimate the individual,
24 school and country-level probability of being informed about the issue surrounding the increase
25 in greenhouse gases in the atmosphere. Multiple models of increasing complexity were fitted,
26 with the final model being adjusted on the basis of vectors of individual-level demographic and
27 background variables (including the gender of respondent, immigration status, parental
28 education, the highest occupational status of parents and economic and social resources);
29 science affective measures – such as enjoyment, broad interest and motivation to study science;
30 student performance on the science PISA test; and carbon dioxide equivalent per capita (see
31 methods for further details). Taking full advantage of the multilevel nature of the data, we
32 allowed the intercepts to vary by school and country, along with three coefficients which varied
33 by country – female, student performance on Science PISA test, and a female*PISA score
34 interaction. Several of the predictors are composite scores from multiple items (parental
35 education, highest occupational status of parents) and some of these are further derived from
36 IRT scaling using the generalised partial credit model (cultural possessions, home educational
37 resources, wealth, ICT resources, enjoyment of science, interest in broad science topics,
38 instrumental motivation to science). The scaling methodology is discussed in the technical
39 report [16].

40
41 For the PISA science score this was designed to examine student competencies (explaining
42 scientific phenomena, designing scientific enquiry as well as interpreting data), knowledge
43 (which includes content knowledge of the natural world and technology, how such knowledge
44 is produced and the rationale behind scientific procedures) and finally contexts (including
45 personal contexts, and scientific issues at the local, national and global level)[16]. As the PISA
46 questionnaire is so broad, each student is only ever asked a smaller subset of all available
47 questions and so PISA have a procedure to impute the values producing 10 plausible values for
48 each of the three main subject domains – Reading, Mathematics and Science ~~[see [16], [34](see~~
49 ~~OECD, 2015, p181~~ for a discussion on how these plausible values are generated).

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53 ¹ All codes used to create models are available at <https://doi.org/10.7910/DVN/JDCZA>
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9 For the purpose of modelling each plausible value added to the final model separately, the
10 model was fit and the parameter simulations saved. Once all 10 plausible values had been fit,
11 the parameter simulations were merged and quantities of interest were calculated [37].

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12 Further details are available in the appendix.

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15 3. Findings

16 We present the findings organised by research questions (RQ) below:

17 3.1 RQ1: *What is the level of awareness of greenhouse gases in PISA 2015 students??*

18 With the broad attitudes towards contemporary scientific issues, a subset of 4-item Likert
19 questions asked student respondents on how informed they were about environmental issues.

20
21 Table 1: Distribution of the outcome variable

22
23

How informed are you about the increase of greenhouse gases in the atmosphere?	N (%)
I have never heard of this	51090 (9.8%)
I have heard about this but I would not be able to explain what it is really about	127728 (24.6%)
I know something about this and could explain the general issue	182110 (35.1%)
I am familiar with this and I would be able to explain this well	107172 (20.6%)
Missing	51234 (9.9%)
Total	519334 (100%)

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36 Table 1: Distribution of the outcome variable

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37 The distribution of unweighted responses in table 1 shows that a baseline of 55.7% of students
38 know 'something about this' or are 'familiar with this and could explain it well'. It is
39 concerning that such a large number of students do not feel well informed enough to explain
40 this issue (24.6%) or have never heard of greenhouse gases in the atmosphere (9.8%). We now
41 explore whether this patterning of responses is related to individual PISA scores or if these are
42 associated with countries.

43
44 3.2 RQ2: *How is awareness of greenhouse gases associated with scientific literacy?*

45 The individual level weighted multilevel regressions results are presented in table 2. These
46 show the average individual in the average school and in the average country (which have
47 means of 0). All school and country-level effects are centred on zero. We can then easily see
48 which positively or negatively deviate from the average probability. The coefficients are on the
49 logit scale, but have also been converted to odds-ratios and probability for easier interpretation.
50 Our comparison group is a student who is male, "native" to that country, whose parental
51 education and highest occupational status are at the OECD average (mean centred at 0); home
52 resources, such as cultural possessions, home educational resources, wealth and ICT resources

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9 are at the OECD average; enjoyment of science, interest in broad science and instrumental
10 motivation towards science are at the OECD average; PISA score was again at the OECD
11 average, and the student went to the average school in the average country with the average
12 CO₂ emissions per capita.

13 ~~Table 2- Model of students' perceptions of being informed of the increase in greenhouse gas~~
14 ~~emissions~~

Parameter	Posterior Mean (SD)	Posterior 95% Credible Intervals	Odds- Ratio 95% Credible Intervals	Probability Scale 95% Credible Interval
Sex of respondent	-0.14 (0.03)	-0.20,-0.08	0.82, 0.92	-0.05, -0.02
Immigrant (First generation)	0.11 (0.02)	0.07, 0.15	1.07, 1.16	0.02, 0.04
Immigrant (Second generation)	0.01 (0.02)	-0.02, 0.05	0.98, 1.05	-0.01, 0.01
Parental Education	0.01 (0.00)	0.01, 0.01	1.01, 1.01	0.02, 0.02
Highest Occupational Status of Parents	0.04 (0.01)	0.03, 0.05	1.03, 1.05	0.01, 0.01
Cultural Possessions	0.14 (0.01)	0.13, 0.15	1.14, 1.17	0.03, 0.04
Home Education Resources	0.08 (0.01)	0.07, 0.09	1.07, 1.09	0.02, 0.02
Wealth	0.03 (0.01)	0.01, 0.05	1.01, 1.05	0.00, 0.01
ICT Resources	-0.02 (0.01)	-0.04, -0.00	0.96, 1.00	-0.01, 0.00
Enjoyment of Science	0.32 (0.01)	0.31, 0.33	1.37, 1.40	0.08, 0.08
Interest in Broad Science	0.32 (0.01)	0.31, 0.33	1.36, 1.39	0.08, 0.08
Instrumental Motivation to Science	0.03 (0.00)	0.02, 0.04	1.02, 1.04	0.00, 0.01
PISA Score	1.69 (0.05)	1.59, 1.76	4.91, 5.96	0.33, 0.36
CO ₂ emissions per capita	-0.01 (0.01)	-0.03, 0.01	0.98, 1.01	-0.01, 0.00
Sex*PISA Score	-0.16 (0.02)	-0.20, -0.11	0.81, 0.90	-0.07, -0.05

47 **Cutpoints:**

48 (I have never heard of this) (I have
49 heard about this, but I would not be
50 able to explain what it is really
51 about)
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9
10 (I have heard about this, but I
11 would not be able to explain what
12 it is really about) (I know
13 something about this and could -0.57 (0.06) -0.70, -0.46
14 explain the general issue)

15
16 (I know something about this and
17 could explain the general issue) (I
18 am familiar with this and I would 1.88 (0.06) 1.75, 2.00
19 be able to explain this well)
20
21

22
23 Table 2: Model of students' perceptions of being informed of the increase in greenhouse gas
24 emissions

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26
27 The largest coefficient is seen from the association between being well-informed and the PISA
28 score, the measure of scientific literacy. In the PISA sample, males who scored one standard
29 deviation higher were on average 34.5% more likely to perceive being more informed, whereas
30 females were 6% lower than their male counterparts. This pattern is also illustrated in the
31 Australian report, which showed a "positive relationship between environmental awareness
32 and scientific literacy" [28], p. 235).

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34 3.3 RQ3: are student background variables and affective measures related to students'
35 reports of being informed about greenhouse gases?

36 There are five key factors that have practical significance– i.e. whether the effect is of a
37 sufficient magnitude given the context to be considered important (see the discussion in the
38 supplementary materials) - on individual students being informed about greenhouse gases.
39 These are sex of respondent (being female), cultural possessions, enjoyment of science, interest
40 in broad science topics and the previously discussed PISA score. On average female students
41 have an odds ratio interval of 0.82 to 0.92. When converted to the probability scale females
42 were on average 4.7% less likely to perceive being informed than their male counterparts,
43 although this varies considerably by country and this variation is addressed further below. For
44 those students that on average were one standard deviation higher in terms of home cultural
45 possessions (e.g. classical literature; books of poetry; works of art, books on art, music or
46 design; and musical instruments), they had an odds ratio interval of 1.14 to 1.17. In probability
47 terms, this means between three and four percentage greater likelihood of being more informed
48 on the issue of the increase in greenhouse gases in the atmosphere.

49 Critically, positive coefficients on the affective measures show that they contribute
50 considerably to the probability of being informed. For students that were one standard deviation
51 higher in their enjoyment of science, they were approximately 8% more likely to perceive being
52 more informed. This is a major shift for a social science based question and is something that
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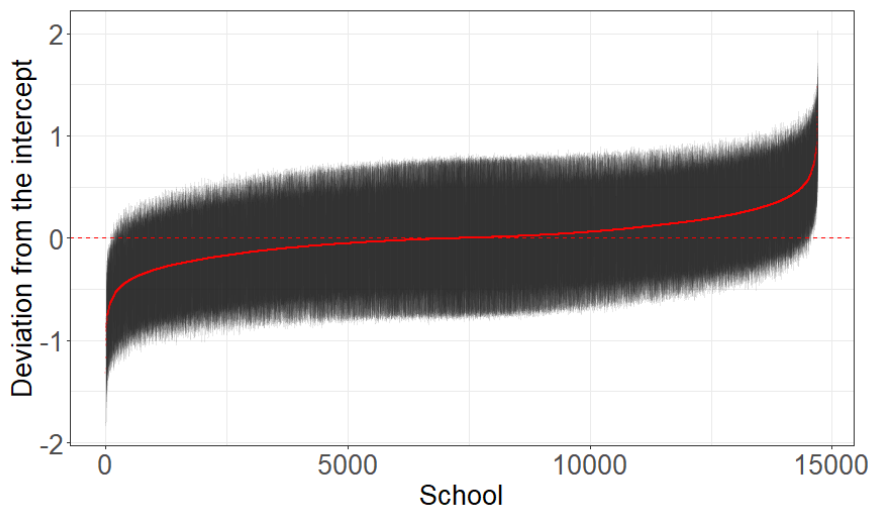
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8 ~~[greenhouse gases](#)~~

9 teachers, schools and curriculum designers can influence and prioritise. This pattern is repeated
10 for those who were one standard deviation higher than the OECD average regarding a broad
11 interest in science topics, again being 8% more likely to be perceive being more informed (odds
12 ratio of 1.37, 1.40).

13 3.4 RQ4: *How does awareness of greenhouse gases vary by OECD and partner*
14 *countries?*

15 At the group-levels, knowledge about greenhouse gases in fifteen-year olds varies considerably
16 by both school attended and country lived in. In a variance components analysis, 9% of the
17 variance could be attributed to the school-level and 7% by country. In the final model the
18 remaining unexplained variance was 4% at the school-level and 6% at the country-level. The
19 school-level residuals (figure 3) mostly fell between ± 0.5 on the logit scale (0.61 and 1.65 on
20 the odds-ratio scale, and $\pm 12\%$ on the percentage probability scale). The most extreme cases
21 were -1.30 (UK) and 1.43 (Uruguay) logits from the baseline. On the odds ratio scale this is
22 0.27, and 4.18 respectively, and on the percentage probability scale this is -29% and +31%
23 from the baseline. Once the country-level adjustments are taken account of the average student
24 within these two schools sit -9% and +21% around the baseline. While these cases represent
25 the extremes, and are subject to considerable uncertainty, the school-level is important:
26 accounting for all other factors we have explored, schools' contributions to student knowing
27 about greenhouse gases cannot be overstated. In the case of the UK and Uruguayan education
28 systems, both are both highly centralised, yet these two schools sit significantly away from the
29 national averages. While we do have a lot of unmeasured variables here that can explain some
30 of the variation, some of this will no doubt be down to school and subject leadership.

31 *Figure 1: School-level residuals presenting the average deviation for each school from the*
32 *intercept on the logit scale (Mean centred on 0)*



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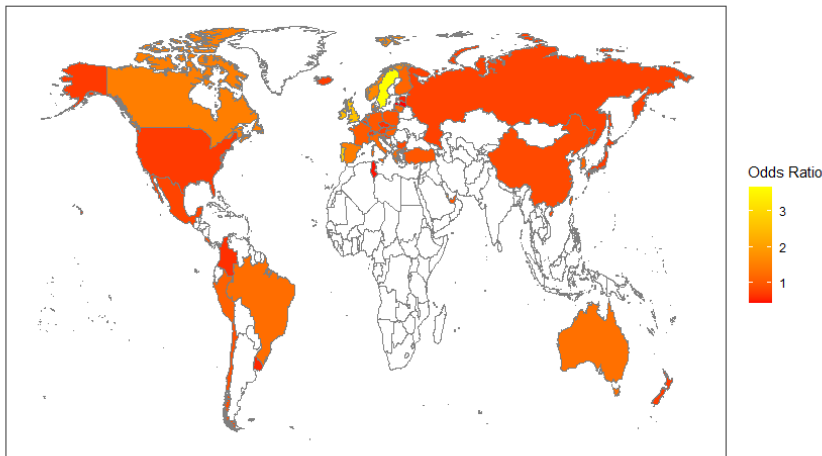
9 Figure 1: School-level residuals presenting the average deviation for each school from the
10 intercept on the logit scale (Mean centred on 0)

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12 With a focus on the country-level, while we did not see much of a relationship between country-
13 level CO₂ emissions per capita, there is marked variation in intercept, showing students in some
14 countries are much more knowledgeable than others (see figure 2). In particular, the average
15 student in the average school in Sweden, Portugal, UK, and Ireland were 28%, 23%, 22%, and
16 21% more likely to report being more informed above the baseline respectively. Sweden has
17 ambitious targets to be 'carbon neutral', leads the Climate Change Performance Index (CCPI).
18 Portugal leads for both national and international policy performance, with renewable energy
19 sources and commitment to be carbon neutral by 2050 and an aim to end coal use by 2030 [36].
20 It seems plausible to suggest that students in these countries are aware of climate change as a
21 matter of global significance whether through education policy and school curricula or through
22 wider societal and media discourse. For example, the UK Parliament (May 2019), Ireland's
23 Dáil (June 2019) Canada's House of Commons and French government (July 2019) have
24 declared a 'climate emergency'.
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27 ~~Figure 2: Country-level intercept variation on the probability of perceiving being informed~~
28 ~~about the increase of greenhouse gases in the atmosphere~~



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9 Although the individual student PISA score is a predictor of environmental awareness, and in
10 contrast to our earlier prediction, the relationship of PISA scientific literacy score to
11 environmental awareness at the country level is less tenuous. East Asian countries (China,
12 Chinese Taipei, Hong Kong, Japan, Korea, Macao, Singapore and Viet Nam) along with
13 Canada, Estonia and Finland atop the international league table in achievement in science[1].
14 However, many students in these countries do not feel knowledgeable about greenhouse gases.
15 China's national policy and commitments to renewable energy, meet emissions targets and is
16 considered to be an 'improving' country in respect of CCPI although a per capita high 'net
17 contributor'. At the lower end of the scale, probabilities of students feeling well-informed about
18 greenhouse gases which are decreasing order from the baseline which include Latvia (19%),
19 Israel (16%), Tunisia (15%), Estonia (15%), Uruguay (13%), Czech Republic (12%),
20 Dominican Republic (11%), Columbia (11%), Luxembourg (10%), the USA (9%), New
21 Zealand (8%), Russia (7%), Iceland (7%), and Croatia (6%). New Zealand is a medium-ranked
22 CCPI country with respect to overall climate policy, a 'top ranking' country in PISA science,
23 yet students there are not likely to feel well informed about the role of greenhouse gases.
24 Indeed, the school curriculum lacks mandate to teach about climate change [38] except during
25 the final years of high school. Being a geologically active country, with curriculum resources
26 directed to address local and immediate environmental concerns may well explain the finding
27 that New Zealand students do not feel well-informed about greenhouse gases. Contrary to the
28 findings drawn from adult populations, we do not find that levels of environmental awareness
29 were high in the US student population: quite the reverse. Even amongst 15-year olds, US
30 students were significantly less likely to feel well informed about greenhouse gases than those
31 in European countries (fig 4). This is a stark finding. Compared with other countries, the US ~~is~~
32 was identified in 2019 as 'one of the worst-performing countries' [38 [36]] and worsening in
33 2020 (p.14) in regard to both national and international policy. The policies and practices of
34 different states and cities are thus not currently well aligned with the administration, which
35 appears to promote scepticism towards anthropogenic causes of climate change and the
36 withdrawal from the Paris agreement.

37
38 3.5 RQ5: Is there a gender gap in awareness of greenhouse gases, gases and if so,
39 how does this vary by OECD and partner countries?

40 In the final model, the average gender difference highlighted that females were 4.7% less likely
41 to perceive being more informed about greenhouse gases than males, in contrast to the finding
42 reported in adults [39], where females show greater concern about environmental issues than
43 males. The sex and PISA score interaction demonstrated that those female students that scored
44 1 standard deviation higher on the PISA score were approximately 6% less (an odds-ratio
45 interval of 0.81,0.90 and probability interval of -0.07, -0.05) likely to informed on the issue of
46 greenhouse gases.

47
48 Furthermore, we can explore the gender variation further by country as the slope has been
49 allowed to vary. As seen in Figure 3, there is considerable country-level variation in
50 probabilities. Female students on average in the following countries sit further below the -4.7%
51 probability: Iceland (-13.7%), the US (-12.7%), Chile (-11.7%), Latvia (-11.7%), Czech
52 Republic (-10.7%), Switzerland (-10.7%), New Zealand (-10.7%), and Poland (-9.7%). On the
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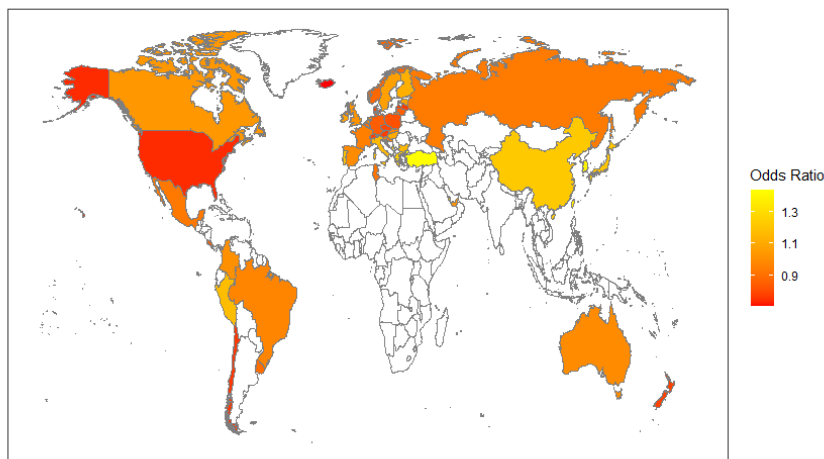
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9 other hand, in Turkey (4.5%), Macao (3.3%) South Korea (3.1%), Hong Kong (3.1%), Chinese
10 Taipei (2.47%), Montenegro (1.6%), Greece (0.60%) and mainland China (0.43%), females
11 were more likely than male peers to know about greenhouse gases. It is difficult to determine
12 whether this reflects differential emphasis in different schools, curriculum, or varying levels of
13 environmental awareness. While we are unable to identify causes for the gender gap, the school
14 science curricula, teachers and teaching are likely mediators to mitigate this.

15
16 Figure 3: The varying country-level effect of being female on perceiving being more informed
17 about greenhouse gases in the atmosphere



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38 Figure 3: The varying country-level effect of being female on perceiving being more informed
39 about greenhouse gases in the atmosphere

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42 Positive effects are evident, especially between the variables of the PISA score and interest of,
43 and enjoyment of science. These are large effects, likely to be reflective of the school
44 environment, the curriculum content, teaching and learning.

45 Limitations

46
47 The OECD recognises that not all 15-year olds are enrolled in formal education across the
48 world, so the data and analysis of these data need to be understood with this caveat in mind.
49 Likewise, whether students' responses across the world reflect the same understanding of
50 attitudinal questions. We cannot know this but acknowledge this uncertainty in discussing the
51 findings presented here. The use of student self-reported data such as PISA is subject to
52 question and critique. We acknowledge this position and point to the use of the same questions
53 across different rounds of the PISA cycle, refinements of constructs, questions and attention to
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9 survey design. Additionally, the self-reported nature has highlighted a gender gap that
10 interestingly is not uniform across the all participating countries. It may be that 'gaps' are likely
11 to be culturally dependent [40] [40] and this is deserving of greater exploration.

12 5. Discussion

13 This analysis shows that students' awareness of climate change is individually associated with
14 their PISA score (achievement) and at the country level also likely to be shaped by local
15 (national) policies and practices. Given the apparent mismatch in students' environmental
16 awareness of greenhouse gases and their achievement scores on PISA, we cannot assume all
17 young people have equal access to scientifically informed materials about climate change and
18 greenhouse gases at school [41]. High quality instruction in science can foster interest in
19 science and lead to improvement in knowledge and scientific literacy [12]. At the same time,
20 where schools promote science-related self-efficacy, or 'build confidence in their students
21 abilities' [42] (p.938) students are likely to also have higher levels of achievement. Schools,
22 the curriculum, teaching and learning do not operate in a social vacuum. In part, this may well
23 reflect the emphasis on curriculum content, teachers' confidence about teaching climate change
24 in school or wider societal attitudes. Education may help mitigate the consequences of political
25 inaction and address gaps in scientific and societal understanding of climate change [43, 44]
26 and greater priority needs to be given to environmental issues in schools. Students' beliefs and
27 concerns about climate change may well be linked to local political and policy positions [45]
28 reflecting the public discourse or polarisation in adults' views [46] and the global student-led
29 climate strikes.

30 Sweden, for example, is identified by the CCPI as a 'high-performing' as a country, with falling
31 levels of greenhouse gas emissions and renewable energy as 40% of its total supply. Policies
32 in place to mitigate climate change are comprehensive, including energy, industry, agriculture,
33 etc. National legislation for climate and energy, policies aligned with international protocols
34 and the European Council mirror a country-wide approach to the environment. 'Respect for the
35 environment' is embedded from early years' education [47] as a fundamental value throughout
36 schooling. Commitment to the United Nation's Sustainable Development Goals is coordinated
37 across all government departments through the Minister for Public Administration within
38 Sweden and through the Ministry for Foreign Affairs. Specifically, the targets articulated to
39 ensure climate change measures through policy, planning including education.

40
41 Girls' education needs to be examined to ensure that they have equal access to the curriculum
42 and that they feel more informed about environmental issues. This is challenging for educators,
43 policy makers and political, business and industrial leaders. International cooperation and
44 commitment to align policies with a 'green' low-emission future will be essential to mitigate
45 the environmental emergency, reduce social inequalities and protect human societies [44] [44].
46 With the declaration of environmental emergencies, it appears that political leadership is not
47 coming fast enough, and from the analysis of these data that even young people do not feel
48 well-informed [45]. With inter-generational learning being one approach to rouse
49 consciousness of climate change [48], the siren voices to maintain the *status quo* are in sharp
50 contrast to young activist Greta Thunberg '*I want you to panic*'.

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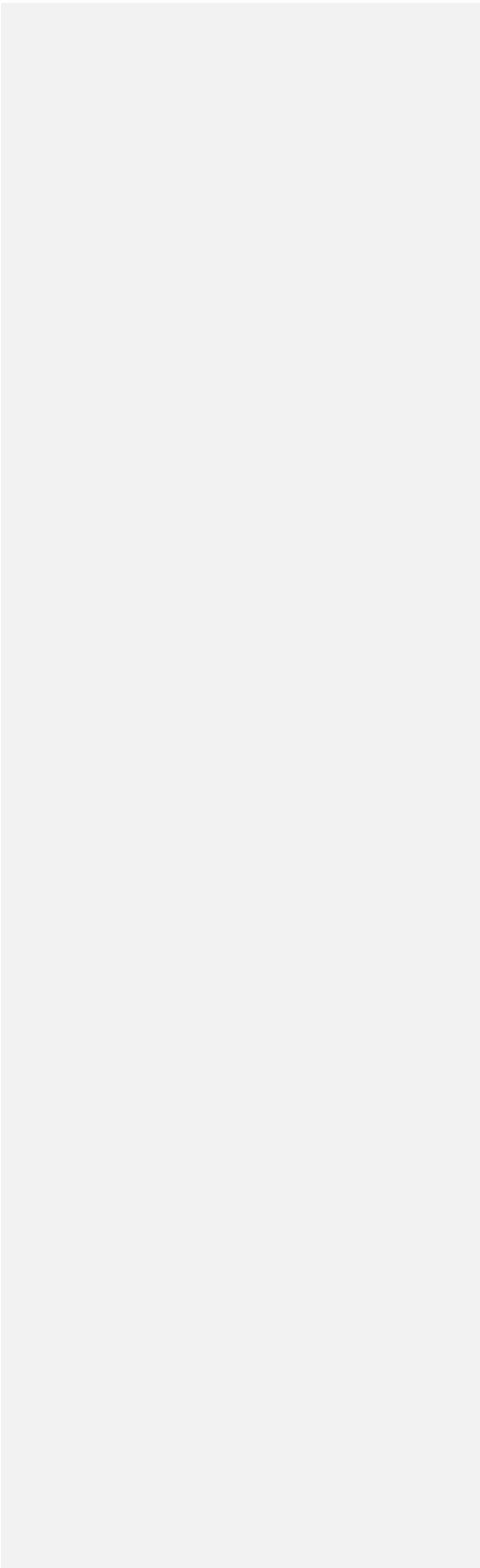
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"Hot-headed" students? Scientific literacy, perceptions and awareness of climate change in 15-year olds across 54 countries
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9 **Appendix**

10 **Weights**

11 In the second stage of sampling all students within the school had an equal probability of
12 selection. However, sampling probabilities at the first stage differed significantly across the
13 participant countries. Some countries over or under-sampled specific sectors, explicit and
14 implicit strata varied, school and student non-response differed across countries, and without
15 available information to adjust for sample design and non-response for all countries, weighting
16 becomes a necessity for appropriately modelling the outcome. Finally, schools are selected
17 with a probability proportional to size. There are two methods to appropriately weight PISA
18 data – via the final student weights or via the senate weights. Student weights scale up to the
19 size of the population so larger countries carry more weight. Senate weights on the other hand
20 allow each country to contribute equally to the analysis [52]. As the cross-country component
21 of the research question was important, senate weights were used to adjust for the varying
22 sample design and non-response.

23 **Analysis strategy**

24
25 As the outcome variable was a four ordered category variable where respondents expressed
26 their level of awareness and ability to explain the environmental phenomenon, an ordered
27 logistic “proportional odds” multilevel approach was used to model the data. This model
28 assumes an underlying latent (and linear) variable that the ordered categorical variable maps
29 on to via a series of (K-1) thresholds/cutpoints. The proportional odds assumption works on
30 the basis of the linear predictor is assumed to explain the relationship in the same manner
31 between all pairs of response categories, hence there are a single set of coefficients. When
32 extending the model to adjust for group membership – in this case, the school attended by the
33 student and the country in which the student and school are based. The varying intercept model
34 allows for the thresholds/cut points to vary by school and country but maintaining the
35 assumption of the same slope across all predictors, with the varying slope model further
36 relaxing the assumption, by allowing some coefficients to vary by group membership.

37
38 A Calibrated Bayesian [53] approach was used, where frequentist methods were used for model
39 development and model checking, but given the model complexity of the three-level model,
40 logistic link function and multiple varying slopes, the analysis was conducted using Stan, a
41 Bayesian Hamiltonian Markov Chain Monte Carlo sampler accessed through the R package
42 brms [54]. The sampler was run on 10 chains for 5000 iterations to allow for the 10 plausible
43 values to be modelled appropriately (1 per chain), and weakly informative priors – normal
44 priors on the betas with 0 mean and standard deviations of 5, and half-cauchy priors on the
45 variance parameters with means of 0 and standard deviations of 5. All parameters demonstrated
46 convergence with rhat potential scale reduction factor values of ≤ 1.01 . Samples were then
47 extracted to allow for post-processing and summary statistic calculations.

48 **Model specification.**

49 The final model reported here was as follows. The probability of the students perceiving
50 themselves as being informed on the issue of the increase in greenhouse gases in the
51 atmosphere was adjusted on the basis of a vector of individual-level demographic and
52 background variables (sex of respondent, immigration status – “native”, “1st generation” and
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9 "second-generation", parental education, and highest occupational status of parents); a vector
10 of economic and social resources (Cultural possessions at home, Home educational resources,
11 Family wealth, and ICT Resources); a vector of science affective measures (enjoyment of
12 science, interest in broad science issues, instrumental motivation towards science; 10 plausible
13 values of PISA overall science score; a group-level mean-centred indicator for the tonnes of
14 carbon dioxide equivalent per capita; and a sex of respondent and PISA score interaction. The
15 intercept was adjusted for school attended and country that the student resided in, and three of
16 the covariates – sex of respondent, PISA score and the sex*PISA score interaction, were
17 allowed to vary by country. This resulted in 5 additional parameters ((U_{0jk} , v_{0k} , v_{0k} , v_{0k} , v_{0k}),
18 which provide the group membership adjustments.

19 The higher-level residuals were distributed as follows U_{0j} , the school-level residual is assumed
20 to be normally distributed and centred on a mean of 0 with the variance parameter σ^2_u . The
21 country-level residuals form a quadivariate normal distribution, with means of 0 and a variance-
22 covariance matrix in which the diagonals are the four variance parameters for the intercept
23 adjustment and 3 slope variances (and the off-diagonals are used to provide the intercept-slope
24 correlations). The model is presented below:

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$$y_{ijk} = \begin{cases} 1 & \text{if } y_{ijk}^* \leq \theta_1 \\ 2 & \text{if } y_{ijk}^* \leq \theta_2 \\ 3 & \text{if } \theta_{K-1} < y_{ijk}^* \end{cases}$$

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$$y_{ijk}^* = \text{logistic}(\beta_{1k} \text{Sex}_{ij} + \beta_2 \text{Immig}2_{ijk} + \beta_3 \text{Immig}3_{ijk} + \beta_4 \text{Pared}_{ijk} + \beta_5 \text{Hise}i_{ijk}$$

35
$$+ \beta_6 \text{Cultposs}_{ijk} + \beta_7 \text{Hedres}_{ijk} + \beta_8 \text{Wealth}_{ijk} + \beta_9 \text{Ictres}_{ijk}$$

36
$$+ \beta_{10} \text{Joyscie}_{ijk} + \beta_{11} \text{Intbrsci}_{ijk} + \beta_{12} \text{Instscie}_{ijk} + \beta_{13k} \text{Pisa.Score}_{ij}$$

37
$$+ \beta_{14} \text{co}2e_k + \beta_{15k} \text{Sex} * \text{Pisa.Score}_{ij} + u_{0jk} + v_{0k} + v_{1k} + v_{2k} + v_{3k})$$

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39
$$u_{0j} \sim N(0, \sigma_u^2) \text{ for } j = 1 \dots J$$

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41
42
$$\begin{pmatrix} v_{0k} \\ v_{1k} \\ v_{2k} \\ v_{3k} \end{pmatrix} \sim N \left(\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{v_0}^2 & & & \\ \rho \sigma_{v_0} \sigma_{v_1} & \sigma_{v_1}^2 & & \\ \rho \sigma_{v_0} \sigma_{v_2} & \rho \sigma_{v_1} \sigma_{v_2} & \sigma_{v_2}^2 & \\ \rho \sigma_{v_0} \sigma_{v_3} & \rho \sigma_{v_1} \sigma_{v_3} & \rho \sigma_{v_2} \sigma_{v_3} & \sigma_{v_3}^2 \end{pmatrix} \right) \text{ for } k = 1 \dots K$$

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48 **Missing data**

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50 ~~Of the 519334 original observations from 69 countries, the final analysis contained 336396~~
51 ~~students from 54 countries, losing participants from Argentina, Albania, Algeria, Georgia,~~
52 ~~Indonesia, Jordan, Kosovo, Lebanon, Malta, Moldova, Romania, Vietnam, Thailand, Trinidad~~
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5 "Hot-headed" students? Scientific literacy, perceptions and awareness of climate change
6 in 15-year olds across 54 countries
7 ~~'Hot-headed students'? A multi-level cross-country comparison of students' awareness of~~
8 ~~greenhouse gases~~
9 ~~and Tobago, and Macedonia. A missing data pattern analysis highlighted several covariates~~
10 ~~that reduced the sample size considerably. In particular, interest in broad science reduced the~~
11 ~~available sample by approximately 52000, and highest occupational status of parents reduced~~
12 ~~the sample further by approximately 22000. In addition, the interaction of missing data across~~
13 ~~four covariates—enjoyment of science, climate ordered, instrumental motivation to science,~~
14 ~~and interest in broad science—reduced the sample by almost 19000 students.~~

15 ~~The analysis reported is the complete case analysis only. A three-level multiple imputation~~
16 ~~procedure using Stat JR's n-level multiple imputation template was attempted [55, 56].~~
17 ~~Unfortunately, the imputation did not converge. However, the sample size remains very large~~
18 ~~across the majority of participating schools/countries.~~

20 Odds-Ratios

21
22 Ordinal Logistic regression returns coefficients which are the log of odds. These can be
23 exponentiated to form odds ratios. Odds ratios are bounded at 0 at one end of the scale to
24 positive infinity at the other. An odds ratio of 1 indicates a probability of .5, with anything
25 under 1 indicating that the group has a lower probability than the comparison group and
26 anything above 1 indicating that the group has a higher probability than the comparison group.
27 To convert odds ratios to the probability scale, the following formula should be used:

$$\frac{\text{odds}}{(1 + \text{odds})}$$

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34 We have generally presented the results on the odds-ratio scale and probability scale to aid
35 interpretation. Where we refer to probability we have re-centred a probability of 0.5 at 0 so that
36 it provides a clear direction for the effect.

37 Practical and statistical significance

38
39 The analysis uses Bayesian inference to fit the ordinal logistic proportional odds multilevel
40 model. Bayesian approaches do not rely on traditional null hypothesis significance testing, with
41 the assumption of hypothetical repeated sampling and p-values. Parameters are represented as
42 a probability distribution, with those that are more consistent with the data having higher
43 probability and a narrower set of values, while those which are less consistent having lower
44 probabilities and values that are more spread out [57]. 95% credible intervals are still judged
45 in the same manner as 95% confidence intervals - as to whether they cross 0, however, the
46 probability of a positive or negative effect can be directly calculated and where the distribution
47 of an effect partially crosses 0, the weight of evidence for the direction and size of the effect
48 can be judged.

49
50 An important distinction needs to be made between where an effect is bounded away from zero
51 (statistical significance in the frequentist literature) and "practical significance" in which we
52 consider the magnitude of the effect given the applied context. Often with a large enough
53 sample size extremely small differences are "significant", but if the effect size is small the
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5 "Hot-headed" students? Scientific literacy, perceptions and awareness of climate change
6 in 15-year olds across 54 countries
7 'Hot-headed students'? A multi-level cross-country comparison of students' awareness of
8 greenhouse gases
9 impact of the covariate is much less relevant for understanding how our outcome variable
10 varies.

11 **References for methods**

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