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# A Structural Model of Future-Oriented Climate Change Optimism in Science Education: PISA Evidence from Countries with Top Environmental Protection Index

**Kason Ka Ching Cheung**[1]

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**Abstract**
The purpose of this study is to examine the predictive effects of epistemological beliefs about science and informal reading of scientific texts on students' future-oriented optimism on the issue of climate change. Future-oriented climate change optimism is defined as encompassing *hope* and *anticipation* about the climate future. To identify the relationships among variables, structural equation modelling was conducted on the PISA dataset on 15-year-old students from Denmark, the UK and Finland which have the top three Environmental Protection Index. Students of all three countries demonstrated a consistently low optimism about the future of climate change. Also, the findings indicated that students' epistemological beliefs about science had a significantly negative predicting effect on their future-oriented climate change optimism across all three countries, while their informal reading of scientific texts had a significantly positive predictive effect on their future-oriented climate change optimism in Denmark and the UK. Across all three countries, 15-year-old students' awareness of the issue of climate change plays a significantly negative mediating role between their epistemological beliefs about science and their optimism in the future climate, as well as their informal reading of scientific texts and their optimism in the future climate. This calls for a new curricular environmental-science education model that addresses how students' informal science reading and epistemological beliefs about science can address future-oriented climate change optimism which might in turn impact young people's action competence to address the issues of climate change.

**Keywords** Epistemological beliefs · Informal science reading · Future-oriented science education · Climate change · Environmental Protection Index

✉ Kason Ka Ching Cheung
ka.cheung@education.ox.ac.uk

[1] Department of Education, University of Oxford, 15 Norham Gardens, Oxford OX2 6PY, UK

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## Introduction

In the era of the climate change crisis, our next generation needs to critically analyse the present situation of climate change and anticipate the climate future (Hickman et al., 2021; Ojala, 2012c). Students' climate optimism is related to their collective engagement in pro-environmental behaviour, such as cycling to schools and communicating to their peers the importance of doing something to reduce greenhouse gas emissions (Ojala, 2012b, 2012c). However, to promote young people's engagement in actions related to climate change, it is important to understand structural factors in science education on their optimism in climate future (Nairn, 2019; Ojala, 2012a) so science educators can develop a related pedagogical framework to harness their optimism to promote young people's collective engagement in climate issues.

As framed in this article, *future-oriented climate change optimism* refers to how our young generation hopes and anticipates the causes and effects of climate change, such as an increase in greenhouse gas emissions and water shortage by drawing on their future thinking. As argued in OECD's (2018) paper, it is important for students to reflect on the present situation and project future trends (Cuzzocrea & Mandich, 2016). In particular, students need to understand the present situation on climate change and develop their hope in changing the climate future. As science education and climate change are intertwined and inseparable (Skamp et al., 2019), students' future-oriented climate change optimism draws on their epistemological beliefs about science, informal reading of scientific texts and environmental awareness. The inter-relations between these factors are under-researched in the field of science education.

Our young generation's optimism about the climate future depends on their awareness and concerns about issues (Lorenzoni et al., 2007). Their awareness on climate change issues is often shaped by reading media coverage (Jiménez-Castillo & Ortega-Egea, 2015) and their epistemic understanding of how scientists know the causes and effects of climate change (Holthuis et al., 2014). These two factors, namely epistemological beliefs about science and informal reading in science, have been demonstrated to be related to their climate change awareness (Xie et al., 2023). Hence, this study hypothesises two key factors that potentially predict students' future-oriented climate change optimism, namely epistemological beliefs about science, and informal science reading activities. In emerging science education literature, it is argued that epistemological beliefs about science are closely related to students' future-oriented thinking (Levrini et al., 2021). Specifically, students who believe in the tentative and empirical nature of scientific knowledge tend to acquire positive epistemic emotions in learning the complexities of climate change (Muis et al., 2015). On the other hand, students read socio-scientific texts to learn about climate change (Dawson, 2015; Cheung et al., 2023b). For example, students can participate in informal science learning activities (Choi et al., 2021), such as reading online materials and watching videos, to develop their perception of climate change. Importantly, epistemological belief and informal science activities were found to be correlated with students' environmental awareness in one recent study (Xie et al., 2023). It is unknown if the role of climate change awareness mediates the relationship between epistemological beliefs and future-oriented climate change optimism, as well as that between informal science reading activities and future-oriented climate change optimism.

Based on the PISA 2015 dataset, a structural model was built so the relationships between epistemological beliefs about science, future-oriented climate change optimism, awareness on climate change and informal science reading activities can be investigated using 15-year-old

students' data from Denmark, England and Finland. These three countries were chosen because they had the highest Environmental Performance Index (EPI) in 2022 (EPI, 2022). Also, it would be of interest to learn how future-oriented climate change optimism of the young generation from countries with the best EPI is impacted by factors related to science learning; therefore, such a structural model can be turned into a pedagogical framework to influence climate change awareness and future-oriented climate change optimism worldwide. Three main research questions were asked: (1) whether students' epistemological beliefs about science and informal science reading predict their future-oriented climate change optimism, (2) whether their awareness on climate change mediates the relationship between their epistemological beliefs about science and future-oriented climate change optimism, as well as that between their informal science reading and future-oriented climate change optimism and (3) are these relationships similar across the three countries with the highest EPI?

## Conceptual Framework

### Future-Oriented Optimism in Climate Change in Science Education

Environment optimism is well researched across different fields of study, but not in the field of science education. Optimism is defined as an expectation of a positive outcome (Carver & Scheier, 2014), while environmental optimism refers to how individuals maintain hope about environmental issues (McAfee et al., 2019). The study of environmental optimism has proliferated in recent decades. Individuals with a persistently lower environment optimism about the environment were likely to experience fatigue and less likely to initiate change in personal actions (Landry et al., 2018; O'neill and Nicholson-Cole, 2009). On the other hand, individuals who perceived negative consequences were related to their pro-environmental behaviour (Hornsey et al., 2016). Departing from this line of literature, how school-related factors or science education factors related to science epistemological beliefs and informal activities predict students' environmental optimism was underresearched in the field of science education. Initial works have already demonstrated the role of school science education in shaping students' environmental awareness (Coertjens et al., 2010; Lin & Shi, 2014).

The theoretical framing that grounds this study is *future-oriented optimism in climate change* that replaces the common framing of environmental optimism. Science educators have been increasingly interested in exploring students' future-oriented dimensions of learning (Laherto et al., 2023; Levrini et al., 2019, 2021). When students predict how issues of climate change impact a forest ecosystem under 0.5 °C increase over 25 years, they craft their explanations based on a range of ecological processes (Clabaugh Howell & Holt, 2024). As the climate issue is multifaceted and involves scientific cause-and-effect relationships (Eilam, 2022), future-oriented climate optimism comprises hope and anticipation of ecological processes in the next few decades (Cuzzocrea & Mandich, 2016). In literature related to cognitive psychology, although hope refers to feeling about a positive goal (Snyder & Lopez, 2001), hope can also comprise ideas about the future as it manifests both emotive and cognitive elements.

Such framing of future-oriented climate optimism aligns with the notion of critical hope by Freire (2021) which argues that students can develop hope by analysing the present situation (Levitas, 1990). Future-oriented climate optimism does not merely encompass positive emotions, as an exclusive focus on positive emotions might exclude some students who

have the wrong feelings and emotions from environmental and sustainability education (Ideland, 2016). More importantly, developing students' optimism about climate change should not focus on relieving students' worrying and negative emotions, as this approach might result in social unrest and make it harder to render our next generation's collective engagement (Ojala, 2021) in ecological processes of climate change.

## Predictors of Future-Oriented Climate Change Optimism: Epistemological Beliefs and Informal Science Reading

Previous research studies did not explore how students' epistemological beliefs about science and informal science learning predicted their future-oriented climate change optimism. School-level factors such as student investigation and student-level factors such as gender have a significant predicting effect on students' environmental optimism (Lin & Shi, 2014). Drawing on PISA 2006 data, after controlling school characteristics at science characteristics, science hands-on activities and scientific investigation significantly predicted Columbia students' environmental optimism (Edsand & Broich, 2020). Nevertheless, as climate change is a type of socio-scientific issue (Eggert et al., 2017), epistemological beliefs about science and informal science reading might have a more direct effect compared to other science instructional factors.

Climate change is a socio-scientific issue because it is complex conceptually and ethically, with an ill-structured issue that does not have a clear solution and cannot be solved with simple reasoning (Dawson, 2015; Sadler et al., 2007). In the context of becoming more aware of and discussing the issue of climate change, students' epistemological beliefs are likely to be elicited (Eggert et al., 2017). While students were exposed to socio-scientific issues like climate change, students' emotions were likely to be elicited (Herman et al., 2020). One study related to university students' epistemological beliefs significantly positively predicted their positive emotions when they were engaged in the issue of climate change (Trevors et al., 2017). Likewise, in another study on post-secondary students in Canada, the USA and Germany, post-secondary students who hold an informed view of the justification of knowledge about climate change demonstrated a higher level of enjoyment and curiosity about the issue (Muis et al., 2015). Although these studies on epistemic emotions did not articulate hope for the climate change future, they provided preliminary evidence on the connections between students' emotive elements (such as future-oriented climate change optimism) and epistemological beliefs in encountering the issue of climate change.

From another perspective, future-oriented climate change optimism does not only comprise epistemic emotions, but it also encompasses *anticipation* of the climate crisis by students. More sophisticated beliefs were found to be significant predictors of informal reasoning (Wu & Tsai, 2011) and forming arguments (Baytelman et al., 2020) about socio-scientific issues. Sophisticated epistemological beliefs about science consist of understanding the tentative nature of science, and scientific knowledge is justified by multiple sources of evidence and experiments (Tsai et al., 2011). In *anticipating* the future of climate change, it is likely that students draw on these informal reasonings and arguments (Visintainer & Linn, 2015).

Apart from epistemological beliefs, informal science reading might be related to students' future-oriented climate change optimism. Contrasting with formal science reading, informal science reading takes place outside classroom contexts (Xie et al., 2023). To develop students' awareness and optimism about climate change, students read multiple information sources (Bråten et al., 2011). As Tang et al. (2022) argue, informal science reading is not limited to merely comprehending hard-copy extra-curricular books, but it can

consist of digital texts such as websites, blogs, videos and TV programs. Students reading scientific texts were evidenced to trigger their emotive elements (Muis et al., 2015; Trevors et al., 2017) and hence could be related to their future-oriented climate change optimism.

## A Structural Model Accounting for Epistemological Beliefs, Informal Science Reading, Awareness of Climate Change and Future-Oriented Climate Change Optimism

In studies that draw on the PISA dataset, researchers mostly examined discursive factors related to environmental awareness (e.g. Coertjens et al., 2010; Xie et al., 2023), without building a structural model that understands relationships between epistemological beliefs, informal science reading activities, climate change awareness and future-oriented climate change optimism. Previous studies on the PISA dataset ran regression models to examine the factors predicting environmental awareness or environmental optimism (Coertjens et al., 2010; Edsand & Broich, 2020; Lin & Shi, 2014). To unpack the relationships between variables, a structural equation model is needed to identify both predicting and mediating effects (as stipulated in Fig. 1).

In the newly stipulated model, awareness on climate change is directly predicted by students' informal science reading and epistemological beliefs about science. After controlling for science characteristics, Colombian 15-year-old students' hands-on activities and scientific investigation showed a significantly negative relation with their environmental awareness, while such factors showed a positive relation with their optimism (Edsand & Broich, 2020). On the other side, drawing on PISA 2006 data, American students' scientific investigation negatively predicted their environmental awareness, while Canadian students' scientific investigation positively predicted their environmental awareness (Lin & Shi, 2014). Both American and Canadian students' scientific investigation positively predicted their environmental awareness (Lin & Shi, 2014). Since the scientific investigation is closely related to students' epistemological beliefs, there is a research gap in the epistemological beliefs about science that can predict students' awareness on climate change and future-oriented climate change optimism. In the opposite direction, based on the PISA 2015 data in China, Xie et al. (2023) reported that students' epistemological

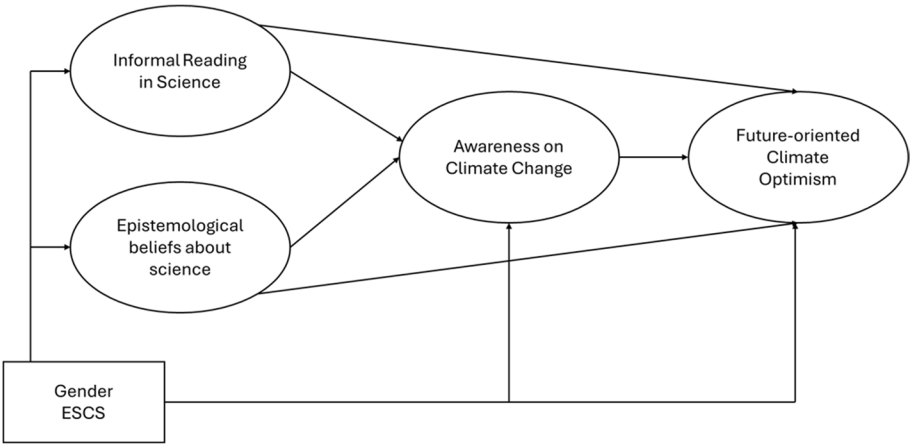


**Fig. 1** The hypothesised structural model of this study (ESCS = index of economic, social and cultural status)

beliefs about science were positively predicted by environmental awareness, moderated by higher informal science activities. However, students obtained information about climate change through reading different sources of texts such as websites and videos (Morote & Hernández, 2022). It is postulated that informal science activities, especially informal science reading, directly impacted students' awareness on climate change hence their future-oriented hope and anticipation about climate change.

### Environmental Index Performance and Science Education in Denmark, England and Finland

As argued in the introduction section, three countries, namely Denmark, England and Finland were chosen for analysis as they demonstrated the highest EPI (EPI, 2022). The EPI measures how countries perform in terms of establishing environmental policies and attaining environmental protection targets (EPI, 2022). As a country's environmental protection performance might impact individuals' environmental awareness (Li & Lv, 2021), this study sampled countries with similar socio-political contexts in terms of environmental protection to control its influence on structural relationships among variables in environmental science education. Moreover, as these three countries were world-leading in environmental protection, there might be lessons learnt from studying structural relationships between variables in environmental science education.

Importantly, although these three countries have a high environmental protection performance, efforts to promote environmental education appear to be insufficient. In Denmark, the government puts less emphasis on education for sustainable development; instead, it exerts more emphasis on science education (Breiting & Wickenberg, 2010). There was a small proportion of teachers who promoted students' environmental awareness (Breiting & Wickenberg, 2010), while in Finland, environmental education was underpinned by the ideology of "learning by doing", fostering education for sustainable development (Jeronen et al., 2009). Although Finnish students were also optimistic about the future climate (Ratinen & Uusiautti, 2020), school teachers perceived that students can only perform private actions (e.g. recycling rubbish) instead of achieving significant environmental citizenship (e.g. protest) (Aarnio-Linnanvuori, 2019). Also in England, climate change education has a low profile across the policy landscape (Greer, 2021), while some academics argued that climate change is embedded in science education instead of offering a broader vision for environmental education (Dunlop & Rushton, 2022).

## Methodology

### Data Sources and Samples

As delineated in the introduction of this paper, the present study examines the associations between students' epistemological beliefs about science, students' reports on informal science reading and students' awareness on climate change issues, as well as their future-oriented optimism in the climate change issue. Considering this, secondary data analysis on the Organisation for Economic Co-operation and Development's (OECD) PISA 2015 study was performed by drawing on datasets from Denmark, England and Finland. PISA is a large-scale triennial international assessment of 15-year-old students regarding their reading, mathematics and science literacy. Among reading, mathematics and science literacy,

each round of PISA assessment focuses on only one subject, such as a focus on science in PISA 2015. Instead of designing assessments according to each country's contexts, PISA design questions that measure students' disciplinary-specific literacy (OECD, 2016), coupled with background questionnaires surveying conditions of teaching and learning from students, teachers, parents and schools; therefore, a two-staged stratified sampling was used (OECD, 2017). In a two-stage stratified sampling, schools were sampled according to the probabilities related to their estimated size of 15-year-old students, followed by a random sampling of students within schools (OECD, 2017).

In Denmark, a total of 7161 students (male = 3559; female = 3602) from 333 schools participated in PISA 2015; in England, a total of 14,157 students (male = 7235; female = 6922) from 550 schools took part in PISA 2015; in Finland, a total of 5882 students (male = 3019; female = 2863) from 168 schools participated in PISA 2015.

## Measures

There are six variables in total, with two exogenous variables (informal science reading and epistemological beliefs about science), one mediating variable (climate change awareness) and one outcome variable (future-oriented climate change optimism), as well as two background control variables (gender and index of economic, social and cultural status (ESCS)).

### Informal Reading in Science

Six items were used to measure students' frequency in reading science in an informal context. These items were selected because they addressed a comprehensive view of reading scientific texts outside schooling, including multimodal and multimedia texts (Tang et al., 2022). Students do not simply decode scientific information from printed text (Tang et al., 2022), while they can decode scientific information from a range of sources outside classrooms such as websites and TV programs. These items encompass "Watch TV programmes about < broad science > " (IFR1), "Borrow or buy books on < broad science > topics" (IFR2), "Visit web sites about < broad science > topics" (IFR3), "Read < broad science > magazines or science articles in newspapers" (IFR4), "Visit web sites of ecology organisations" (IFR5) and "Follow news of science, environmental, or ecology organizations via blogs and microblogging" (IFR6) (OECD, 2017). Students were asked to give a response on a 4-point Likert scale, ranging from "very often" to "never or hardly ever", while their responses were reversely coded. The original scale consists of nine items in the PISA assessment. Error terms of IFR5 and IFR6 were correlated because both items were concerned with reading on the Internet. As this variable focuses on how students read to learn about climate change information, only six related items were included. According to confirmatory factor analysis (CFA) of data from individual countries, CFI and TFI yield above 0.95, while RMSEA yields below 0.05, and SRMR yields below 0.05. These indices indicate a high construct validity (Table 1).

### Epistemological Beliefs About Science

Six items were used to measure students' epistemological beliefs about science. These items included "A good way to know if something is true to do an experiment" (EPI1), "Idea in < broad science > sometimes change." (EP2), "Good answers are based on

**Table 1** Descriptive statistics, standard regression coefficient of items and model fit indices of latent variables

| Variables/items/model fit indices | Countries | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Denmark | | | | UK | | | | Finland | | | |
| | *M* | SD | *β* | SE | *M* | SD | *β* | SE | *M* | SD | *β* | SE |
| *Informal reading in science* | | | | | | | | | | | | |
| IFR1. Watch TV programmes about < broad science > | 1.991 | 0.831 | 0.667 | 0.012 | 1.857 | 0.843 | 0.664 | 0.011 | 1.828 | 0.755 | 0.631 | 0.013 |
| IFR2. Borrow or buy books on < broad science > topics | 1.330 | 0.649 | 0.726 | 0.013 | 1.533 | 0.764 | 0.750 | 0.011 | 1.290 | 0.611 | 0.817 | 0.012 |
| IFR3. Visit web sites about < broad science > topics | 1.846 | 0.858 | 0.800 | 0.009 | 1.866 | 0.848 | 0.746 | 0.009 | 1.438 | 0.699 | 0.873 | 0.007 |
| IFR4. Read < broad science > magazines or science articles in newspapers | 1.638 | 0.839 | 0.788 | 0.010 | 1.476 | 0.760 | 0.795 | 0.009 | 1.537 | 0.751 | 0.782 | 0.010 |
| IFR5. Visit web sites of ecology organisations | 1.360 | 0.666 | 0.584 | 0.018 | 1.307 | 0.644 | 0.661 | 0.015 | 1.263 | 0.603 | 0.720 | 0.016 |
| IFR6. Follow news of science, environmental, or ecology organizations via blogs and microblogging | 1.581 | 0.837 | 0.637 | 0.016 | 1.532 | 0.829 | 0.690 | 0.013 | 1.230 | 0.587 | 0.727 | 0.016 |
| CFI/TFI/RMESA/SRMR | **0.984/0.970/0.048/0.021** | | | | **0.989/0.980/0.028/0.015** | | | | **0.990/0.982/0.041/0.017** | | | |
| *Epistemological beliefs about science* | | | | | | | | | | | | |
| EP1. A good way to know if something is true is to do an experiment | 3.160 | 0.763 | 0.774 | 0.010 | 3.106 | 0.669 | 0.667 | 0.015 | 3.000 | 0.718 | 0.745 | 0.012 |
| EP2. Ideas in < broad science > sometimes change | 2.963 | 0.655 | 0.778 | 0.011 | 3.149 | 0.637 | 0.837 | 0.009 | 2.942 | 0.639 | 0.832 | 0.009 |
| EP3. Good answers are based on evidence from many different experiments | 3.193 | 0.752 | 0.829 | 0.010 | 3.189 | 0.670 | 0.758 | 0.012 | 3.096 | 0.706 | 0.800 | 0.010 |
| EP4. It is good to try experiments more than once to make sure of your findings | 3.192 | 0.776 | 0.787 | 0.009 | 3.341 | 0.693 | 0.754 | 0.012 | 3.133 | 0.732 | 0.755 | 0.012 |
| EP5. Sometimes < broad science > scientists change their minds about what is true in science | 3.190 | 0.740 | 0.844 | 0.007 | 3.064 | 0.666 | 0.713 | 0.012 | 2.856 | 0.671 | 0.717 | 0.014 |
| EP6. The ideas in < broad science > science books sometimes change | 2.953 | 0.712 | 0.724 | 0.013 | 3.047 | 0.657 | 0.717 | 0.013 | 2.884 | 0.655 | 0.756 | 0.013 |
| CFI/TFI/RMESA/SRMR | **0.979/0.956/0.073/0.022** | | | | **0.983/0.964/0.043/0.024** | | | | **0.987/0.972/0.061/0.021** | | | |
| *Climate change awareness* | | | | | | | | | | | | |
| ISS1. The increase of greenhouse gases in the atmosphere | 2.985 | 0.832 | 0.625 | 0.012 | 3.204 | 0.851 | 0.714 | 0.011 | 2.950 | 0.657 | 0.644 | 0.011 |
| ISS2. The consequences of clearing forests for other land use | 3.099 | 0.813 | 0.762 | 0.010 | 3.140 | 0.870 | 0.788 | 0.009 | 2.894 | 0.633 | 0.692 | 0.012 |
| ISS3. Air pollution | 3.117 | 0.752 | 0.785 | 0.010 | 3.220 | 0.769 | 0.827 | 0.008 | 3.223 | 0.452 | 0.843 | 0.007 |
| ISS4. Extinction of plants and animals | 2.957 | 0.769 | 0.745 | 0.011 | 3.195 | 0.788 | 0.775 | 0.009 | 3.140 | 0.526 | 0.801 | 0.009 |
| ISS5. Water shortage | 2.817 | 0.831 | 0.672 | 0.012 | 2.724 | 0.880 | 0.644 | 0.009 | 2.861 | 0.658 | 0.654 | 0.011 |

**Table 1** (continued)

| Variables/items/model fit indices | Countries | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Denmark | | | | UK | | | | Finland | | | |
| | *M* | SD | $\beta$ | SE | *M* | SD | $\beta$ | SE | *M* | SD | $\beta$ | SE |
| CFI/TFI/RMESA/SRMR | **0.978/0.956/0.067/0.025** | | | | **0.977/0.954/0.051/0.025** | | | | **0.975/0.951/0.081/0.024** | | | |
| *Future-oriented climate change optimism* | | | | | | | | | | | | |
| FUR1. Air pollution | 1.472 | 0.713 | 0.624 | 0.015 | 1.471 | 0.543 | 0.737 | 0.013 | 1.461 | 0.474 | 0.628 | 0.014 |
| FUR2. Extinction of plants and animals | 1.568 | 0.644 | 0.692 | 0.015 | 1.506 | 0.487 | 0.698 | 0.012 | 1.714 | 0.452 | 0.682 | 0.012 |
| FUR3. Clearing of forests for other land use | 1.503 | 0.688 | 0.626 | 0.015 | 1.450 | 0.504 | 0.710 | 0.012 | 1.536 | 0.434 | 0.652 | 0.014 |
| FUR4. Water shortages | 1.770 | 0.713 | 0.460 | 0.015 | 1.735 | 0.570 | 0.755 | 0.012 | 1.773 | 0.487 | 0.554 | 0.015 |
| FUR5. The increase of greenhouse gases in the atmosphere | 1.514 | 0.697 | 0.549 | 0.016 | 1.502 | 0.559 | 0.748 | 0.013 | 1.466 | 0.455 | 0.582 | 0.015 |
| CFI/TFI/RMESA/SRMR | **0.991/0.978/0.036/0.014** | | | | **0.994/0.984/0.026/0.013** | | | | **0.993/0.982/0.036/0.011** | | | |

evidence from many different experiments." (EP3), "It is good to try experiments more than once to make sure of your findings" (EP4), "Sometimes < broad science > scientists change their minds about what is true in science" (EP5) and "The ideas in < broad science > science books sometimes change." (EP6) (OECD, 2017). Students were asked to give a response on a 4-point Likert scale, ranging from "strongly disagree" to "strongly agree". As EPI3 and EP4 are concerned with multiple sources of evidence, while EPI5 and EPI6 are concerned with the tentative nature of knowledge, their error terms were correlated. According to CFA of data from individual countries, CFI and TFI yield above 0.95, while RMSEA yields below 0.08, and SRMR yields below 0.05. These indices indicate a high construct validity.

### Climate Change Awareness

Five items were used to measure students' self-reported awareness on climate change issues. Students were asked if they were informed of the five issues: "The increase of greenhouse gases in the atmosphere" (ISS1), "The consequences of clearing forests for other land use" (ISS2), "Air pollution" (ISS3), "Extinction of plants and animals" (ISS4) and "Water shortage" (ISS5) (OECD, 2017). The original scale has seven items, so we selected these items because they have direct inferences to students' awareness of the issue of climate change, which is the focus of this study. Students were asked to rate a 4-point scale ranging from "I have ever heard of this" to "I am familiar with this and I would be able to explain this well". Based on the CFA results of respective countries, CFI and TFI yield above 0.95, while RMSEA yields below 0.08, and SRMR yields below 0.05. These indices indicate a high construct validity.

### Future-Oriented Climate Change Optimism

Five items were used to measure students' future-oriented climate change optimism. They were asked to indicate whether five issues related to climate change will improve or get worse over the next 20 years. These items allow students to express their hope and anticipation about the climate future by critically analysing the present situation, while these five issues were related to cause-and-effect and ecological processes related to the climate future (e.g. Eilam, 2022). These issues comprise "Air pollution" (FUR1), "Extinction of plants and animals" (FUR2), "Clearing of forests for other land use" (FUR3), "Water shortage" (FUR4) and "The increase of greenhouse gases in the atmosphere" (FUR5) (OECD, 2017). The original scale has seven items, and we selected the five items that are directly related to climate change issues. Students were asked to rate a 3-point scale ranging from "Improve" to "Get worse". The error terms of two items, FUR1 and FUR5, were correlated because they were related to the emission of air pollutants. The CFA results revealed a high construct validity, as supported by CFI and TFI over 0.95, RMSEA below 0.08 and SMRR below 0.05.

### Gender and Economics, Social and Cultural Status (ESCS)

In the background questionnaire, students were asked to express their gender. Students were asked "are you female or male", with 1 representing female and 2 representing male. To control for students' socio-economic status, the ESCS Index of the PISA dataset was used.

### Data Analysis

Descriptive statistics were computed to identify the preliminary trend of variables in three countries (Table 1). Afterward, a correlation analysis was conducted to examine the correlation between variables. The hypothesised structural model was tested using a structural equation model approach in two stages using MPlus 8.3 (Muthén & Muthén, 2012). Despite the stratified random sampling design of PISA, multilevel structural equation modelling was not used because the null model indicated low intraclass correlation coefficients (6.15% for Denmark, 4.39% for the UK, 0.76% for Finland) which are below the 10% threshold (Raudenbush, 2004). In the first stage, a confirmatory factor analysis was conducted to examine the model fit of the measurement model of latent variables. The confirmatory factor model consists of four latent variables, namely informal reading in science, epistemological beliefs about science, climate change awareness and future-oriented climate change optimism. After specifying the measurement model, structural equation modelling (SEM) was carried out to identify relationships between latent variables and observed variables. The predicting effects of epistemological beliefs about science and informed science reading on future-oriented climate change optimism were specified, mediated by climate change awareness, while these relationships were controlled by gender and ESCS.

Owing to the complex sampling of PISA data (Liou & Hung, 2015), the function "Type = complex" was used to take into account design effects and weightings. The final student weight was used to specify the weight, while the data was clustered using the school ID. More importantly, the full information maximum likelihood estimation (FIML) was used as it can take into account non-normality and dependence of observations when MPlus 8.3 calculated standard errors and chi-square tests when it handled missing data (Muthén & Muthén, 2012). To assess the measurement models and SEM models in individual countries, the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the root-mean-squared error of approximation (RMSEA) and the standardized root-mean-squared residual (SRMR) were used. Both values of CFI and TFI > 0.90 indicate an acceptable fit, while > 0.95 indicates a good fit, while values of RMSEA and SRMR < 0.08 indicate a good fit (Hu & Bentler, 1999).

## Results

### Correlation Among Latent Variables and Model Fits for Measurement Models

According to Table 2, across three countries, students' informal reading in science (IFR) is positively correlated with their epistemological beliefs about science (EPI), awareness of climate change issues (ISS) and gender (GEN) at a significant level. Students' epistemological beliefs in science (EPI) are significantly negatively correlated with their future-oriented climate change optimism (FUR) across three countries. More importantly, across all three countries, future-oriented climate change optimism (FUR) was significantly positively associated with gender (GEN). This shows that males tend to have a higher future-oriented optimism on the issue of climate change.

Confirmatory factor analysis was carried out on the dataset of Denmark, the UK and Finland. For Denmark, the measurement model yielded a good model fit (CFI = 0.986, TLI = 0.984, RMSEA = 0.023; SRMR = 0.019); for the UK, the measurement model also

**Table 2** Correlation between variables

| Variables | Countries | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Denmark | | | | | | UK | | | | | | Finland | | | | | |
| | IFR | EPI | ISS | FUR | GEN | ESCS | IFR | EPI | ISS | FUR | GEN | ESCS | IFR | EPI | ISS | FUR | GEN | ESCS |
| Informal reading in science (IFR) | 1 | 0.019* | 0.095*** | 0.000 | 0.043*** | 0.016 | 1 | 0.100*** | 0.316*** | 0.07*** | 0.128*** | 0.027 | 1 | 0.007 | 0.037*** | 0.011* | 0.034*** | 0.162 |
| Epistemological beliefs about science (EPI) | | 1 | 0.083 | −0.039*** | −0.012** | −0.203 | | 1 | 0.314*** | −0.144*** | −0.016 | −0.041* | | 1 | 0.095*** | −0.033** | 0.020*** | −0.297 |
| Climate change awareness (ISS) | | | 1 | −0.050*** | 0.031*** | −0.116 | | | 1 | −0.181*** | 0.072* | −0.056** | | | 1 | −0.044*** | −0.019*** | 0.318 |
| Future-oriented climate change optimism (FUR) | | | | 1 | 0.013*** | 0.230 | | | | 1 | 0.088*** | 0.032 | | | | 1 | 0.034*** | −0.290 |
| Gender (GEN) | | | | | 1 | 0.111 | | | | | 1 | 0.044*** | | | | | 1 | 0.026 |

**Table 2** (continued)

| Variables | Countries | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Denmark | | | | | | UK | | | | | | Finland | | | | | |
| | IFR | EPI | ISS | FUR | GEN | ESCS | IFR | EPI | ISS | FUR | GEN | ESCS | IFR | EPI | ISS | FUR | GEN | ESCS |
| Index of economic, social and cultural status (ESCS) | | | | | | 1 | | | | | | 1 | | | | | | 1 |

***$p < 0.001$,**$p < 0.01$,*$p < 0.01$

resulted in a good fit (CFI = 0.991, TLI = 0.990, RMSEA = 0.011; SRMR = 0.016). For Finland, fit indices indicated a good fit for the measurement model (CFI = 0.990, TLI = 0.989, RMSEA = 0.018; SRMR = 0.017).

## Structural Equation Modelling

Table 3 presents a summary of all coefficient paths of 15-year-old students in Denmark, the UK and Finland. The structural models for all countries yielded a good fit, with most CFI and TFI values above 0.95, except for TFI in Finland's dataset which is slightly below 0.95. Also, RMSEA and SRMR values were also below 0.05 which supported a perfect fit.

## Predicting Effects of Students' Epistemological Beliefs about Science and Informal Science Reading on Future-Oriented Climate Change Optimism and Awareness of Climate Change Issue

Interestingly, students' epistemological beliefs about science negatively predicted their future-oriented climate change optimism in Denmark ($\beta = -0.087$), the UK ($\beta = -0.078$) and Finland ($\beta = -0.142$) at a significant level of 0.001. This indicated that the more informed students' epistemological beliefs about science it was, the less optimistic on the improvement of climate change in the future they were. Compared to Denmark and the UK, a stronger association was seen between students' epistemological beliefs and future-oriented climate change optimism.

**Table 3** Coefficient paths of SEM in Denmark, UK and Finland

| Paths | Countries | | | | | |
|---|---|---|---|---|---|---|
| | Denmark | | UK | | Finland | |
| | $\beta$ | SE | $\beta$ | SE | $\beta$ | SE |
| Direct effects | | | | | | |
| IFR → FUR | 0.057* | 0.023 | 0.142*** | 0.019 | 0.037 | 0.021 |
| EPI → FUR | −0.087*** | 0.020 | −0.078*** | 0.022 | −0.142*** | 0.024 |
| ISS → FUR | −0.179*** | 0.024 | −0.165*** | 0.022 | −0.062** | 0.022 |
| IFR → ISS | 0.283*** | 0.024 | 0.260*** | 0.020 | 0.141*** | 0.022 |
| EPI → ISS | 0.212*** | 0.023 | 0.266*** | 0.022 | 0.278*** | 0.020 |
| Indirect effects | | | | | | |
| IFR → ISS → FUR | −0.051*** | 0.008 | −0.038*** | 0.006 | −0.020*** | 0.004 |
| EPI → ISS → FUR | −0.038*** | 0.007 | −0.048*** | 0.008 | −0.039*** | 0.007 |
| Model fit indices | | | | | | |
| CFI | 0.957 | | 0.962 | | 0.953 | |
| TFI | 0.950 | | 0.955 | | 0.943 | |
| RMSEA | 0.034 | | 0.024 | | 0.041 | |
| SRMR | 0.034 | | 0.030 | | 0.035 | |

*IFR* informal reading of scientific texts, *EPI* epistemological beliefs about science, *ISS* awareness on climate change issues, *FUR* future-oriented optimism about climate change

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

While for the direct influence of informal science reading on students' future-oriented climate change optimism, only students in Denmark ($\beta=0.057$, $p<0.05$) and the UK ($\beta=0.142$, $p<0.001$) showed such significant positive relationships. This means that the more frequent their informal reading in science, the more optimistic they were regarding the future of climate change. However, Finnish students did not show such a relationship ($\beta=0.037$, $p>0.05$) that informal reading in science was not associated with their future-oriented climate change optimism.

Regardless of their awareness on climate change, both informal reading (Denmark $\beta=0.283$, $p<0.001$; UK $\beta=0.260$, $p<0.001$; Finland $\beta=0.141$, $p<0.001$) and epistemological beliefs (Denmark $\beta=0.212$, $p<0.001$; UK $\beta=0.266$, $p<0.001$; Finland $\beta=0.278$, $p<0.001$) had a direct positive influence on their awareness on the climate change issue for students of all three countries. In Finland, epistemological beliefs appeared to be a slightly stronger predictor than 15-year-old students' informal reading in science.

### Mediating Effects of Awareness on Climate Change Mediates the Relationship Between Their Epistemological Beliefs and Future-Oriented Climate Change Optimism

Across all three countries, students' awareness on climate change exerted negative mediating effects between their informal reading in science and future-oriented optimism about climate change (Denmark $\beta=-0.038$, $p<0.001$; UK $\beta=-0.048$, $p<0.001$; Finland $\beta=-0.039$, $p<0.001$), as well as exerting negative mediating effects between their epistemological beliefs about science and future-oriented optimism in climate change (Denmark $\beta=-0.051$, $p<0.001$; UK $\beta=-0.038$, $p<0.001$; Finland $\beta=-0.020$, $p<0.001$). This means that informal reading of science and epistemological beliefs explained a lower students' future-oriented optimism in climate change as their more awareness on the issue of climate change. However, such mediating effects were considered to be weak as they were below 0.10.

The above findings might be attributed to the reason that students' awareness on climate change exerted a negative direct influence on their future-oriented climate change optimism. This was supported by a negative standardized coefficient in Denmark ($\beta=-0.179$), the UK ($\beta=-0.165$) and Finland ($\beta=-0.062$) at a significant level of 0.001.

### Similarities in SEM Across All Three Countries

In sum, across all three countries, three common trends were identified. Firstly, the more informed 15-year-old students' epistemological beliefs about science it was, their future-oriented optimism in climate change was lower. Secondly, their stronger awareness on the climate change issue predicted their less optimistic view about the future of climate change. Thirdly, their awareness on the climate change issue explained the negative indirect influence of both their epistemological beliefs about science and informal science reading on their optimism about the future of climate change.

## Discussion

### Predictors of Students' Future-Oriented Climate Change Optimism

Drawing on the PISA 2015 dataset, this study contributes to science education literature by identifying mediating relationships among four variables: epistemological beliefs about

science, informal reading in science, awareness on the climate change issue and future-oriented climate optimism. Some previous research studies on PISA datasets focused on how discursive factors influenced environmental awareness (Edsand & Broich, 2020; Xie et al., 2023) instead of specifically future-oriented climate change optimism. Without building a structural equation model, it is difficult to understand the processes by which students develop climate optimism.

As argued by scholars (Solomon & LaRocque, 2019; White & Tytler, 2023), climate change is a pressing emergency, so this paper theorises *future-oriented climate change optimism* that is to be urgently and specifically incorporated into school science curriculum around the globe. It was argued that *future-oriented climate change optimism* comprises *hope* (McAfee et al., 2019) and *anticipation* (Cuzzocrea & Mandich, 2016). Some scholars argued that optimism merely consists of hope or expectation of a positive outcome (Carver & Scheier, 2014). However, as students are scientifically informed, they drew on their developed epistemological beliefs about science, in order to evaluate the socio-scientific issue of climate change (e.g. Dawson, 2015) and anticipate the future of climate change. As supported by the analysis of PISA data, students' epistemological beliefs in science showed a significantly negative relationship with their future-oriented climate change optimism. Importantly, 15-year-old students in the highest EPI countries like Denmark, Finland and the UK had a low optimism in the future of climate change, as the mean score shows that students rated each item between "not improved" and "get worse". This might be attributed to the reason that a more informed understanding of epistemology of science facilitated their forecasting of worsening climate future. Such anticipation about climate future, which might be facilitated by their developed epistemological belief about science, could be a precursor for their action competence for engaging in issues such as climate change. In approximately 8 years after PISA 2015 study, a study taking place in 2023 reported that English students' distress about climate change is related to their self-reported environment protest activity (Finnegan, 2023). In another study taking place in 2022, Finnish university students began to consider their ability to act as climate educators (Yli-Panula et al., 2022).

Although 15-year-old students consistently showed a low future-oriented climate change optimism, it was found that Danish and British students' informal reading positively predicted their future-oriented climate change optimism. One possible account for this is that informal science texts, such as media and newspapers, portrayed a positive message for the future of climate change (Beattie et al., 2017). Despite the important role of hope in climate change in promoting students' environmental engagement (Ojala, 2012a), science education can focus on balancing students' hope and anticipation of the climate future when they are exposed to informal scientific texts, such as television, newspaper and extra-curricular books.

### Mediating Effects of Climate Change Awareness

Another potential contribution is to call for science educators to focus on promoting students' future-oriented optimism while promoting their awareness on climate change issues. Science educators promoted students' environmental awareness (Dori & Tal, 2000; Littledyke, 2008) and environmental activism (Karahan & Roehrig, 2015). The findings indicated that students' optimism in the future of climate change is negatively associated with their climate change awareness. Students' awareness on climate change also plays a negative mediating effect between students' informal reading of science and their optimism in the climate future, as well as that between their epistemological beliefs about science

and their future-oriented climate change optimism. Despite the importance of awareness of climate change, science educators who developed environmental science education curriculum need to make students aware of the issues, at the same time fostering a balance between hope and anticipation. Considering factors and paths in science education, such as informal reading in science and students' epistemological beliefs about science, a balance between hope and anticipation could potentially nurture our young people's action competence in mitigating climate change via raising their awareness as well as anticipation about climate future. The identification of path models has not been articulated in past literature regarding environmental optimism in a PISA study (e.g. Coertjens et al., 2010; Xie et al., 2023).

## Implication to Future-Oriented Climate Science Education: Future Research Directions

As identified in this paper, epistemological beliefs about science and informal reading of scientific texts can be associated with their awareness on climate change and their future-oriented optimism about climate change. Particularly, in the items on epistemological beliefs about the science we analysed, there are three items (EP2, EP5 and EP6) related to the tentative knowledge of science. The negative association might be accounted for by the reason that their tentative view of science elicited their projection of climate getting worse. Young people's climate action competence might be attributed to their stronger belief about the tentative nature of scientific knowledge, as they believe that the climate future can be changed under their power. The relationship between public's understanding of epistemological beliefs about science and actions has been demonstrated in the Covid-19 pandemic (Cheung et al., 2023a; Chan et al., 2023). Therefore, I call for science teachers to develop students' tentative view of science at the same time fostering their belief that climate will improve under collective engagement in the issue of climate change.

It is also argued that science educators need to build a curriculum model that considers future-oriented optimism in climate change. In this curricular model, there should be a balance between *hope* and *anticipation*. An unbalanced articulation of either hope or anticipation in the curriculum would likely bring a negative impact on students' attitudes toward the issue of climate change. Such a curriculum model also considers how to promote students' epistemological beliefs about science and informal reading of scientific texts while at the same time maintaining students' hope and anticipation of the future of climate change.

## Limitations of This Study

This study has a few limitations. Firstly, the operationalization of scales measuring students' informal science reading is self-reported in nature. The rating they endorsed in reporting their informal science reading activities might not match their actual after-school science reading. Future studies can use various qualitative approaches, such as ethnography, to see how students developed optimism in climate change future based on their reading of scientific texts outside the curriculum time. Secondly, the design of PISA is cross-sectional, and this study does not conduct any experimental design. The predicting effects can only be supported by evidence in SEM; hence, future randomized experimental studies were needed to verify the causal effects of students' epistemological beliefs about science and informal reading of science on their awareness of climate change and

future-oriented climate change optimism. Thirdly, PISA 2015 does not have any specific scale for student's engagement in climate change issues; therefore, further research study needs to examine the correlation between their future-oriented optimism in climate change and their engagement in such issues. Fourthly, the present study explores the structural relations of future-oriented climate optimism in three countries with the highest EPI, while the future study can compare such structural relations with countries with the highest and lowest EPI. Fifthly, the structural relations might vary across students with different ESCS. Future research studies can conduct multi-group SEM to explore these structural relations across students with different quantiles of ESCS.

## Declarations

**Ethical Approval** This study involves secondary data analysis of PISA dataset. Hence, ethical approval is not applicable.

**Conflict of Interest** The authors declare no competing interests.



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