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Unpacking Climate Literacy in Science Education: What Explains Students' Willingness to Engage in Climate Action?

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ABSTRACT

Due to the far-reaching and life-threatening consequences of climate change, science education is becoming increasingly important for preparing students to become climate literate citizens. Climate literacy, which encompasses knowledge, skills, and attitudes related to climate change, can provide a strong foundation for informed climate action. While the influence of students' climate change-related knowledge on their engagement in climate action has been the focus of much research and debate, few studies in the field of science education have examined how the combination of cognitive and psycho-social aspects of climate literacy relates to students' climate engagement. The present study addresses this gap by exploring the relative contribution of different aspects of climate literacy (i.e., knowledge, skills, risk perception, and value orientations) to students' willingness to engage in climate action. Using the method of sequential regression analysis, we analyzed data collected from 1309 German and Swedish students. The patterns of the results in both countries are similar: Students' risk perception is found to be the relatively strongest predictor of their willingness to engage in climate action. Value orientations were also identified as strong predictors, while cognitive factors seem to have less explanatory power. Conclusively, our study suggests that science education should consider psycho-social factors alongside teaching of the necessary knowledge, especially if we aim to empower students to go beyond the theoretical discussion of how to combat climate change.

1 | Introduction

The far-reaching and life-threatening consequences of climate change demand immediate and sustained commitment to climate action at both the individual and societal level (IPCC 2022). Understanding the scientific processes underlying climate change can help to grasp the complexity and urgency of the crisis (e.g., Yu et al. 2020) and can serve as an important starting point for climate change-related engagement (e.g., Kolenatý et al. 2022; McNeill and Vaughn 2012). Science education could thus be seen as an important breeding ground for broader social transformation processes and accordingly occupies a prominent position in teaching and learning about climate change (Kranz et al. 2022; Rousell and Cutter-Mackenzie-Knowles 2020).

Many studies that explored students' learning about climate change have focused on promoting students' understanding of the core concepts involved in climate change (e.g., Bhattacharya et al. 2021; Kranz et al. 2022; see also Monroe et al. 2019). Studies with a particular focus on students'

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content knowledge and conceptual understanding have contributed greatly to uncovering and remediating students' misconceptions, for example regarding the ozone layer depletion (Karpudewan et al. 2015), developing learning progressions (e.g., for sea level rise as a consequence of climate change, Breslyn et al. 2016), and designing concept inventories for the core content areas of climate change (e.g., Schubatzky et al. 2023). In addition, studies have examined the relationship between students' knowledge about climate change and their willingness to engage in climate action, although the diffuse mix of results suggests that this question has not yet been conclusively answered (for a positive yet rather weak correlation between knowledge and willingness to act see, for example, Kolenatý et al. 2022; for no significant correlation see, for example, Tolppanen et al. 2022).

Other studies have focused on how psycho-social factors can influence students' engagement with climate change, opening up important avenues to explore students' science learning beyond the traditional focus on science content knowledge. These studies have contributed significantly to understanding the importance of emotions for students' engagement with climate change (e.g., hope; Ojala 2012), reflected on the role of affective-driven approaches for students' learning about climate change (e.g., Bentz 2020), and investigated the influence of more socially and culturally anchored determinants for climate action, such as students' worldviews, norms, beliefs, and value orientations (e.g., Ignell et al. 2019). In recent years, science education scholars have also started to discuss the importance of considering risk and risk perception in science education (Schenk et al. 2019) and climate change education in particular (see, for example, Schreiner et al. 2005; Kagawa and Selby 2012).

Some studies, although rather few in number, have brought together the cognitive (e.g., climate-change related knowledge) and psycho-social aspects (e.g., worldviews) in an integrative manner, underlining the complex interplay of different cognitive and psycho-social factors in the study of students' climate engagement (e.g., Stevenson et al. 2014; Zummo et al. 2021). With a similar integrative note, increasing attention is being drawn to the concept of climate literacy, which aims to create an educational foundation that enables successful participation in social decision-making and developments in dealing with climate change (Azevedo and Marques 2017; U.S. Global Change Research Program 2009, 2024). According to this concept, informed engagement with climate change includes both a person's knowledge and skills related to climate change (i.e., cognitive factors) and a set of attitudes (i.e., psycho-social factors) that help to act upon the knowledge. However, although an increasing number of scholars in science education have started to apply the concept of climate literacy as a theoretical basis for examining students' engagement with climate change, much of the work continues to be predominantly interested in cognitive aspects (e.g., Harker-Schuch et al. 2020; Quarderer et al. 2021). While these studies are of great value—especially as knowledge still seems to be the core business when teaching about climate change (Kranz et al. 2022)—they may overlook how the different aspects of climate literacy (i.e., cognitive *and* psycho-social factors) can jointly contribute to explaining what motivates young people to engage in climate action (for a holistic consideration see, for example, Kolenatý et al. 2022).

This brief synthesis reveals an important gap in the current science education literature: While the effects of students' scientific understanding on their engagement in climate action have been widely and continuously studied, only a few studies have explored how the combination of cognitive and psycho-social aspects of climate literacy is related to students' climate engagement. Accordingly, in this study, we adopt an integrated perspective on climate literacy and define climate engagement, operationalized as students' willingness to act, as the outcome of interest. Specifically, we examine the extent to which both cognitive factors (i.e., students' climate change-related knowledge and data analysis and interpretation skills) and psycho-social factors (i.e., students' risk perception and value orientations) are related to students' willingness to engage in climate action. This more blended perspective on climate literacy aims to provide empirical insights on the interplay between the different aspects of climate literacy, which in turn can inform the design of educational strategies and advance the discussion of how the issue of climate change should be addressed in science education.

2 | Literature Review

2.1 | Climate Literacy and Students' Willingness to Engage in Climate Action

In the light of accelerating climate change, young people are often seen as the bearers of hope for a better future and as those carrying the burden of past decisions (see Baldwin et al. 2022). Against this backdrop, science education can support young people to develop an understanding of climate change and related risks, and to prepare them for informed decision-making in the sense of climate literacy. Climate literacy, embedded in the broader concept of scientific literacy (see Dupigny-Giroux 2010), encompasses an understanding of how the climate system works, how it affects life on Earth, and how human actions affect the climate system (U.S. Global Change Research Program 2009, 2024). It can be further divided into three core aspects: understanding the climate system and processes associated with climate change (*knowledge*), being able to access, analyze, and communicate climate change-related information in a meaningful way (*skills*), and the ability to adopt an informed stance (*attitude*) to ultimately contribute to informed decisions in dealing with and acting upon climate change (Azevedo and Marques 2017; U.S. Global Change Research Program 2009, 2024). Climate literacy can therefore provide a sound basis for well-founded climate action and serves, in the following parts of this paper, as a guiding framework.

Actions, in comparison to mere and often automated behavior, are considered conscious and intentional (Jensen and Schnack 1997). In the context of climate change, two dominant approaches to action have emerged: Mitigation (i.e., measures aimed at reducing greenhouse gases to prevent the further development of climate change) and adaptation (i.e., measures aimed at increasing preparedness for the consequences of climate change) (e.g., IPCC 2022). Adaptation measures can be initiated both at a political (e.g., expansion of dykes in response to a rising sea level) and an individual level (e.g., the installation of air conditioning systems in response to extreme heat) (e.g., Engels et al. 2023). However, as young people are somewhat limited in their direct political and financial power (e.g., voting) and seem to experience difficulties in conceptualizing climate change adaptation (Bofferding and Kloser 2015; Graulich et al. 2021), this paper focuses on actions aimed at mitigating climate change.

Regarding climate change mitigation, two types of engagement can be distinguished: Collective action, which is characterized by acting as part of a larger group in the public sphere, e.g., climate strikes to achieve common goals, and individual action, which refers to decisions that affect actions typically located in the private sphere, such as living on a vegetarian diet (see Wallis et al. 2021). While individual climate action can contribute meaningfully to combating climate change (for a discussion on the role of individual climate action, see, for example, Carrico 2022; see also Pizziol and Tavoni 2024 regarding social tipping points), it remains insufficient without appropriate structural and social change (see Creutzig et al. 2022). To drive such societal change, the need for collective climate action as a form of political participation is becoming increasingly prominent in the educational discourse (e.g., Niebert 2021). However, most young people seem to be convinced that their scope for action lies predominantly in the individual and private sphere: In their mixed-methods study with young adults from Germany, Reuter and Frick (2024) found a strong preference for and habituation towards actions that concern, for example, green consumerism, which underlines "a deep-rooted and widespread adoption of the individualizing logic among young individuals when interpreting or taking action on climate change and climate protection" (p. 10). Similarly, only 9% of climate-engaged respondents from the Youth Climate Action Research Report participated in climate strikes or campaigns; while the three most common climate actions were saving energy (85%), reducing waste (74%), and choosing alternatives to car travel (70%) (InterClimate Network 2023). As young people's climate action still seems to be mainly located in the private sphere, this paper focuses – albeit not without some critical remarks in the discussion– on students' individual climate action.

With regard to students' individual climate action, this paper focuses particularly on students' *willingness* to engage in climate action as the dependent variable of this study (see also chapter 2.3.4). Although there is justified criticism regarding the transferability of intentions to actions, focusing on the degree of willingness to engage in climate action potentially convey a more differentiated picture of students' commitment (i.e., I would almost certainly take the train more often but I would probably not reduce flying) than dichotomizing their engagement (i.e., do you take a certain climate action; yes or no).

2.2 | The Role of Cognitive Factors for Students' Willingness to Engage in Climate Action

2.2.1 | Climate Change-Related Knowledge

Improving learners' conceptual knowledge of climate change (e.g., understanding the basic processes associated with the greenhouse effect) and potential measures to combat climate change (e.g., shifting away from fossil fuel) has long been seen as a central goal of climate change education (e.g., UNESCO 2010). And to this day, knowledge-based approaches that target learners' understanding of the science behind climate change still seem to be the central learning objective: In their comprehensive document analysis, McKenzie (2021) investigated educational activities and developments in 377 submissions to the UNFCCC Secretariat. One of their results indicates that regarding the reported learning dimension, the reference to cognitive aspects far exceeds that of socio-emotional or behavioral learning outcomes. In line with this, numerous reasons have been found in recent years as to why teachers may struggle to focus on more than the scientific processes and conceptual understanding related to climate change. Barriers include, for example, concerns about limited content knowledge and dealing with students' (negative) emotions when addressing climate change (see Beasy et al. 2023), while others might fear dismantling their own climate change-related views and values once the discussion goes beyond the scientific explanation (Rydin et al. 2025; on perceived barriers to professional development in the context of climate change, see Ennes et al. 2021).

Focusing exclusively on formal education settings (K-16), Bhattacharya et al. (2021) reviewed 178 empirical studies on climate literacy and education. In trying to understand the modalities of students' learning about climate change, their analysis revealed that teaching about climate change tends to be closely linked to subject-specific core concepts, which—once again—aims at improving learners' understanding and conceptual knowledge (for similar results see Ardoin et al. 2018; Kranz et al. 2022; Rousell and Cutter-Mackenzie-Knowles 2020). Indeed, it is widely assumed that a rudimentary understanding of the climate system and the role of greenhouse gases is essential for concluding why and how actions need to change. For example, McNeill and Vaughn (2012) discussed in their mixed-methods intervention study with upper secondary students that a better conceptual understanding about climate change and greater knowledge of possible measures to combat climate change are likely to have a positive impact on students' engagement in climate action. Kolenatý et al. (2022) found positive but rather weak correlations between the knowledge of seventh to ninth graders about possible measures ($r = 0.26^{**}$) as well as their effects ($r = 0.18^{*}$) and their willingness to engage in climate action. However, subsequent structural equation modeling revealed no direct link between climate change-related knowledge and students' willingness to act, leading to the conclusion that sufficient knowledge can be viewed as an initial driving force or prerequisite for other factors that motivate engagement in climate action. Tolppanen et al. (2022), on the other hand, found no correlation between university students' knowledge about climate change and their willingness to engage in climate action (see also Kang and Tolppanen 2024 for similar results among upper secondary school students). These inconsistent results suggest that the role of climate change-related knowledge for climate action is not yet entirely understood.

2.2.2 | Data Analysis and Interpretation Skills

In addition to climate change-related knowledge, learners also require a whole range of skills to access, analyze, and communicate climate change-related information: from asking the right questions to developing solid arguments (see U.S. Global Change Research Program 2009, 2024). To sort these skills according to their relevance for climate literacy, Gellermann et al. (2025) conceptually linked the NGSS practices with the climate literacy skills identified in Azevedo and Marques (2017), before validating this selection in an expert rating: In total, 14 experts from the field of climate science, science education, and science teaching ranked the eight theoretically combined skills according to their perceived importance for climate literacy. These experts considered (i) asking questions and defining problems, (ii) analyzing and interpreting data, and (iii) engaging in evidence-based argumentation as most relevant. From this pre-selection, analyzing and interpreting data was chosen for a deeper examination, as much of the climate change-related communication relies on visual representation of climate data. For example, one of the best-known bodies for summarizing and communicating knowledge about climate change and its impacts are the IPCC reports (e.g., 2022) which frequently use bars, graphs, and maps to visualize climate change-related information. Although working with climate data is conceptually considered part of students' climate literacy (Azevedo and Marques 2017; U.S. Global Change Research Program 2009, 2024), we argue that this aspect has been largely underexposed in previous research on climate literacy (for an exception see, for example, Ellwein et al. 2014). Exploring students' abilities to analyze and interpret climate-related data and its potential impact on willingness to act could be a promising and novel perspective for science and climate change education: For example, a study by Herring et al. (2017) showed that interaction with downscaled and visually presented climate data can positively impact an individual's attitudes and concerns about climate change. On the other hand, a study by McMahon et al. (2015) pointed out that misinterpretations such as the overestimation or underestimation of uncertainties presented in a climate graph can occur when skills to read and interpret visualized climate data are lacking. Both studies underline the need to better understand how students' data analysis and interpretation skills affect climate change-related decision-making.

2.3 | The Role of Psycho-Social Factors for Students' Willingness to Engage in Climate Action

In addition to knowledge and skills, a supportive set of attitudes is considered the third aspect of climate literacy (Azevedo and Marques 2017). This attitudinal component is less clearly defined and can refer to various motivational constructs. Two specific constructs, climate change-related risk perception and value orientations, have been argued to be of great interest for students' engagement in climate action, as they reflect how individuals subjectively interpret the threat of climate change (Van der Linden 2015) and how individuals prioritize the urgency of climate change compared to other societal issues and goals (Kahan 2012).

2.3.1 | Climate Change-Related Risk Perception

Beyond improving students' conceptual knowledge of climate change, science education faces the challenge of enabling students to recognize, assess, and address the risks associated with climate change (Stevenson et al. 2017; see also Christensen 2009). Without doubt, climate change is a cause for concern (IPCC 2022), and understanding how young people perceive these climate change-related risks seems important to motivate action (Fang and Yu 2015).

Risk perception describes an individual's subjective judgment of a given risk and is usually conceptualized as a multidimensional construct that includes both cognitive and affective components (Denney 2005; Loewenstein et al. 2001; Slovic 1987): The cognitive dimension typically comprises assessments of the likelihood, severity, and potential consequences of the specific risk. The affective dimension, on the other hand, refers to emotional reactions such as concern and worry (Loewenstein et al. 2001; Slovic et al. 2004). These two dimensions interact in complex ways, shaping how people interpret and respond to threats, including those related to climate change (Van der Linden 2015; Siegrist and Árvai 2020). Risk perception is therefore not simply a rational assessment of facts, but a process that incorporates knowledge, values, emotions, and an evaluation of personal relevance (Loewenstein et al. 2001; Slovic et al. 2004; for the context of climate change see, for example, Van der Linden 2014).

In the past 20 years, much research has been done to investigate the factors that drive risk perception in the context of climate change. For example, research has demonstrated that knowledge of the causes, impacts, and responses to climate change can predict individual risk perception—both among the public (e.g., Shi et al. 2016) and students (e.g., Aksit et al. 2018 among undergraduate students). Similarly, the role of non-cognitive factors in people's risk perception around climate change was examined, with affective responses towards the issue found to be among the strongest predictors (e.g., Van der Linden 2015). Besides the cognitive and affective factors that can influence risk perception, research on climate change-related risk perception highlights the influence of cultural cognition, which suggests that individuals process information about climate threats in a way that is consistent with their cultural values and social identities (see Kahan 2012).

In addition, several studies have provided evidence that risk perception is in turn an important factor influencing (intended) engagement in climate action. For instance, a study by Boyes and Stanisstreet (2012) involving 961 students (grade 6–10) found that greater concern about climate change correlated with willingness to take climate action, even when these actions were believed to be of limited effectiveness. Chhokar et al. (2012) similarly observed a relationship between higher levels of concern and willingness to engage in climate action among 268 grade 12 students in New Delhi. Regarding collective climate action, a study of approximately 4000 young climate strikers from Switzerland found that participants' risk perception (considering their perceived worry, severity, and urgency of climate change) was a significant factor for participation. However, when other factors such as social identity were considered in the full logistic regression model, only worry (but not severity and urgency) continued to be positively associated with participation (Brügger et al. 2020), pointing to the power of emotional resonance in motivating young people's climate engagement.

2.3.2 | Value Orientations

Alongside risk perception, culturally and socially shaped constructs such as values have also received considerable attention with regard to their role for climate action (e.g., Tolppanen and Kang 2021). Values describe individually important principles of life or fundamental and desirable goals that we strive for and that guide our preferences and actions (Schwartz 1992, 2012). With regard to engagement in climate action, four value orientations are of particular interest: altruistic (care for others' well-being), biospheric (care for nature and the living environment), hedonic (care for one's own pleasure), egoistic (care for one's own status, power, and resources) (e.g., De Groot and Steg 2008, 2009; Steg et al. 2014).

The relationship between students' biospheric values and engagement in environmental or climate action seems to have been studied and discussed the most—with fairly consistent results. For example, in one of their studies with 14- to 16-year-old participants from New Zealand, Kelly et al. (2023) found that students' biospheric values were positively correlated with their individual pro-environmental and climate-friendly behavior, such as turning off electrical devices, but also with related interactions, such as discussing environmental issues with parents and peers (for a review on the role of biospheric values for climate action, see Bouman et al. 2021). Climate action, however, goes far beyond protecting the environment and also benefits wider society (e.g., health benefits from the expansion of local public transport; see Roca-Barceló et al. 2024). It is therefore less surprising that a positive correlation was also found between students' climate action and their endorsement of altruistic values, for example among 11-year-old students from Malaysia (Wan Hussain et al. 2021) and among Mongolian undergraduates (Liu et al. 2018). Fewer studies address the relationship between students' climate action and hedonic and egoistic values, and the findings are less conclusive. Liu et al. (2018), for example, indicate a negative influence of egoistic value orientations on Mongolian university students' participation in public activities for the environment, such as donating or participating in protests. Similarly, strong hedonic value orientations might be expected to promote a number of climate-unfriendly decisions or preferences, such as choosing the car over public transport for convenience (see, for example, Line et al. 2010), whereas both egoistic and hedonic value orientations can also support climate action if they are linked, for instance, to financial or health benefits or social prestige (e.g., Griskevicius et al. 2010).

2.4 | Climate Change Education in Germany and Sweden

This study took a cross-national approach and collected data from German and Swedish students. In Germany, a lexical content analysis of the extent of climate change education in formal education requirements concluded that the focus in schools falls primarily on geography lessons and, although not as pronounced, science lessons (Siegmund et al. 2021). A curriculum analysis carried out by Leve et al. (2025) was able to deepen these findings by showing that climate change is only dealt with in fragments within a subject or via the cross-cutting topic of sustainability. Yet, it remains unclear whether and how a link is established between the different subjects to ensure a coherent climate change education. Furthermore, content relating to climate science and society's approach to climate change is rarely mentioned (see also Enke and Budke 2023). A further textbook analysis of science and social science teaching at lower secondary level (Leve et al. submitted) revealed that climate change is mainly present in physics, chemistry, and geography textbooks, with a focus on the causes of climate change and its mitigation. Societal aspects, such as a reference to public discussions, were found to be rather rare.

In Sweden, climate change education is primarily integrated into science, geography, civics, and home and consumer studies in both compulsory and upper secondary education, and is addressed through themes such as ecological systems, energy use, and sustainable development (The Swedish National Agency for Education 2013, 2022). Climate change is often addressed in a fragmented manner within individual subjects, with limited interdisciplinary integration: A study of upper secondary students' written explanations revealed, for example, that their understanding was frequently superficial and lacked coherence, suggesting that the topic is not taught in a comprehensive or integrated way (Holmqvist Olander and Olander 2017). Furthermore, content relating to societal responses to climate change is perceived as limited; instead, the focus is perceived to be on scientific explanations and strategies to mitigate climate change (Borg et al. 2014; Öhman and Öhman 2012).

In summary, the studies outlined above reinforce the impression that a predominantly subject-specific and content knowledge-oriented approach to climate change education seems to prevail in both Germany and Sweden. As relatively affluent and industrialized countries located in Northern Europe, Germany and Sweden face and contribute to the climate crisis differently than less privileged nations, which may, at least to some extent, explain why their focus seems to be more on knowledge about the causes of climate change and its mitigation than on vulnerability and adaptation.

3 | Research Question and Study Aim

To effectively address climate change, scholars in the field of science education are increasingly emphasizing the concept of climate literacy. Climate literacy focuses on three broader aspects: the knowledge students need, the skills they require, and a set of supportive attitudes to make informed decisions with regard to climate change (Azevedo and Marques 2017; U.S. Global Change Research Program 2009, 2024). While each of these aspects is relevant for students' engagement in climate action, existing studies have predominantly focused on the role of students' knowledge. By contrast, only limited evidence exists on the interplay between these aspects. Such an integrated perspective could clarify the aspects' relative contributions regarding students' willingness to engage in climate action. This insight, in turn, would be of great benefit for science teaching, for example when it comes to designing tools and programs for learning about climate change.

To address this gap, we examine the explanatory potential of the different aspects of climate literacy that have been discussed to be of importance for students' engagement in climate action. The research question reads as follows:

> To what extent do the different aspects of climate literacy, namely knowledge, skills, and attitudes (operationalized as risk perception and value orientations) contribute to explaining students' willingness to engage in climate action?

4 | Methods

4.1 | Design and Procedure

This cross-sectional study was conducted within the project *BriCCS—Bringing climate change to school*, in which the same online questionnaire was used for different target groups. The data presented in this paper were collected from 1309 secondary school students in Germany (10th to 13th grade) and Sweden (10th to 12th grade). In a first step, all instruments to be included in the questionnaire were extracted from the literature and professionally translated into German and Swedish. To ensure that the translated instruments were unambiguous and clear, a pilot study was conducted with 441 German and Swedish students from upper secondary school and university. Adjustments that were made to the instruments are described in the relevant sections.

The main collection of data took place in the second half of 2021. For the German data, ethical approval was obtained from the ethics committee at the Leibniz Institute for Science and Mathematics Education and the respective ministries of education in Schleswig-Holstein, Hamburg, and Baden-Württemberg. For the Swedish data, the study was approved by the research ethics committee at Karlstad University.

4.2 | Samples

The German sample consisted of 727 secondary school students ($n = 370$ female and $n = 316$ male[1]) with an average age of 16.57 years (SD = 1.24 years with a range of 14–21 years). Almost all students were attending a Gymnasium or another school type preparing for university entry at the time of the survey, and around three quarter of the students reported living in a rural area or small town with less than 40.000 inhabitants. The Swedish sample comprised 582 students ($n = 322$ female and $n = 251$ male) with an average age of 16.63 years (SD = 1.10 years with a range of 10–24 years). Of these students, all attended a school that prepares for higher education and about two thirds lived in a rather rural area with less than 40.000 inhabitants.[2]

4.3 | Instruments

All instruments and their adapted translations can be found in Supporting Information File S1.

4.3.1 | Background Information

In addition to gender and age, we were interested in students' current commitment to environmental activities, which was measured in a two-stage procedure: Respondents first indicated whether they were involved in any environmental activities (voluntarily or through work/school), and if so, they had to describe in an open-ended response format what type of activities they were involved in. For the present paper, only the information about whether they were involved or not was used.

4.3.2 | Cognitive Factors

To assess the role of cognitive factors, the questionnaire included two instruments, one to measure students' climate change-related knowledge and one for students' data analysis and interpretation skills.

4.3.2.1 | Climate Change-Related Knowledge. To gauge students' knowledge, we used an instrument presented by Libarkin et al. (2018) that focuses on respondents' understanding of basic processes related to climate change. From the original set of 21 items, six items were removed based on the Rasch-analyzed results of the German pilot study to reduce the completion time of the questionnaire. The remaining 15 items included 12 single-choice and three multiple-choice items.

4.3.2.2 | Data Analysis and Interpretation Skills. To assess students' data analysis and interpretation skills, we included five short-response items for middle school (SNAP Natural Hazards, MS-ESS3-2) developed as part of the Stanford NGSS Assessment Project (2023). All five items are designed as single- or multiple-choice items that can be coded as either correct or incorrect, address the context of natural hazards (landslides, earthquakes, and volcanos), and required respondents to analyze and interpret data from bar graphs and maps. As the instrument was embedded in a digital survey tool, students had the opportunity to provide feedback if they experienced technical problems seeing the maps. To improve readability, the fifth item was restructured from a six-column table into six individual sub-questions, which led to an additional answer option "none of the statements is correct" and 10 items in total.

4.3.3 | Psycho-Social Factors

4.3.3.1 | Climate Change-Related Risk Perception. To measure students' perceptions of risk related to climate change, items from two instruments (Leiserowitz 2006; Van der Linden 2015) were adapted and used in our survey. For the majority of items, respondents were asked to rate the assumed likelihood of certain events occurring in the next 50 years due to global warming on a 4-point Likert scale from "not likely" to "very likely" (Leiserowitz 2006). Each event assessment was recorded in two separate items: One item related to respondents' immediate surroundings and the likelihood that these events would affect them; the other item related to global developments and the likelihood that these events would affect people worldwide. Prior to the pilot study, the authors of this paper added six items to capture climate change-related events of high relevance for Northern Europe (i.e., fires, storms, flooding; global and local dimension each). The open-ended comments from the pilot study led to four additional items on climate migration and societal conflicts (global and local each). This type of item eventually comprised 16 questions in the final questionnaire. Five additional items were adopted in a slightly modified form from Van der Linden (2015) and Leiserowitz (2006). These items asked about the extent to which respondents are concerned about global warming, the severity of threats to plants, animals and global society, and the perceived likelihood that the consequences of climate change will affect their own health or have a long-term negative impact on the country in which they live. Overall, risk perception was measured with 21 items.

4.3.3.2 | Value Orientations. To assess students' value orientations, we used an instrument by De Groot and Steg (2008) in a further developed form by Steg et al. (2014), which builds on the work of Schwartz (1992) and Stern et al. (1999). In the instrument, respondents were asked to rank 16 values in order of importance to their own lives, with each value being assigned to one of four value orientations: altruistic value orientation (e.g., equality), biospheric value orientation (e.g., protecting the environment), egoistic value orientation (e.g., wealth), and hedonic value orientation (e.g., pleasure). The 9-point Likert scale for rating ranged from −1 (opposed to my values) to 7 (extremely important), and respondents were prompted to rate no more than two values as extremely important.

4.3.4 | Willingness to Engage in Climate Action

To measure students' willingness to engage in climate action, we used parts of a questionnaire developed and presented by Boyes and Stanisstreet (2012). From the original questionnaire, we only used the subsection "degree of willingness to act," which involves items describing various actions that mainly relate to reducing greenhouse gas emissions and additionally mention the associated personal costs (e.g., time, inconvenience). A total of 11 items were included in our survey that targeted actions directly aimed at reducing greenhouse gas emissions, and four additional items targeted indirect actions, such as learning more about global warming. One item on nuclear energy was not included in the survey. For each action, respondents were asked to rate on a five-point Likert scale how likely they were to take part in these actions. The scale was adapted as a result of the pilot study with an addition to one of the endpoints "I would definitely do it/I already do it." Some items were adapted in terms of language and content to students' everyday lives (e.g., laptops and televisions instead of fridges and washing machines) and to the current state of technology (e.g., smart technology). For ethical reasons, three items that originally asked about voting behavior in political election were modified to more general statements about support for societal change that help to combat climate change.

4.4 | Data Handling and Analysis Procedure

For organizational and data management reasons, the datasets collected in the respective countries were not exchanged or combined but analyzed separately. However, to ensure comparability within the scope of this study, the same questionnaires were used, but translated into the respective national language, and the analysis steps were aligned. In both countries, the data have been processed and analyzed using the statistical software R (R Core Team 2021).

4.4.1 | Data Cleaning and Missing Data

To ensure that parental consent had been obtained from German students, only students who had submitted a signed consent form to the teacher received a unique token in return.[3] By comparing the tokens, we were able to identify students with invalid entries (21 cases in total), which were deleted from the dataset. In Sweden, with the approval of the ethics application, all students had permission to partake in the survey.

With regard to the handling of missing data, all cases in which a quarter or more of the answers for the variables "risk perception," "value orientations," and "willingness to engage in climate action" were missing were deleted. This decision did not apply for the cognitive variables, as missing information and the answer "I don't know" and "I have technical issues" were counted as incorrect answers.[4] This measure resulted in 18 cases being removed from the German dataset ($N = 709$ cases left in total) and 75 cases from the Swedish dataset (507 cases left in total).

4.4.2 | Preparing Data for Analysis

In a first step, the items that required recoding were processed. With regard to the background variables, environmental engagement was dichotomized and screened for invalid combinations (e.g., if the student ticked both "no involvement" and "involvement"), and these combinations were recoded as missing. While gender is not a binary variable, we dichotomized the variable for reasons of data analysis. Two of the 21 items measuring risk perception were rated on a five-point Likert scale. Rescoring of these two items was performed to adjust to the other 19 items, which assess risk perception on a four-point Likert scale. For the cognitive variables, the items measuring respondents' climate knowledge and data analysis and interpretation skills were dichotomized into correct and incorrect answers. Sum scores were calculated for the number of correct answers for each of the cognitive variables. Mean values were calculated for each dimension of risk perception, each dimension of value orientations, and willingness to engage in climate action.

4.4.3 | Steps of Analyses

In a first step, the reliability of all continuous scales was tested in their assumed dimensionality, with results ranging from $\alpha = 0.64$ to 0.84 in the German dataset and $\alpha = 0.74$ to 0.90 in the Swedish dataset (see Supporting Information File S2). Subsequently, the theoretically assumed dimensionality of the variables value orientations (i.e., altruistic, biospheric, egoistic, and hedonic), risk perception (i.e., local/personal and global/societal; called "personal" and "global/societal" risk perception in Van der

Linden 2015), and willingness to engage in climate action (i.e., direct and indirect) was empirically examined applying the method of principal component analyses. Finally, correlations were calculated and the predictive power of the variables was systematically examined using the method of sequential regression analysis.

5 | Results

5.1 | Principal Component Analysis

To test for the assumed (theoretical) dimensionality, principal component analyses (PCA) were performed with the variables: willingness to engage in climate action, risk perception, and value orientations. In both datasets, the PCA revealed a one-component solution for willingness to act, a two-component solution for risk perception, and a two-component solution for value orientations (for scree plots, see Supporting Information File S2). For the latter, joint mean values were created (altruistic/biospheric and hedonic/egoistic). In addition, the PCA in both countries suggested that one item of the risk perception instrument (i.e., "How concerned are you about global warming?") was not perceived by the students as local/personal item, as theoretically assumed, but as a global/societal item. It was therefore considered as part of the global/societal dimension in the further analysis steps.

5.2 | Descriptive Statistics and Correlation Analysis

An overview of the mean values, standard deviations, and correlation between the respective variables is presented in Table 1 for the German dataset and Table 2 for the Swedish dataset.

All predictor variables of this study are significantly correlated with students' willingness to engage in climate action, ranging from $r = -0.35$ to $r = 0.56$ in the German sample and from $r = -0.18$ to $r = 0.62$ in the Swedish sample. In the German dataset, the strongest correlation was found between both dimensions of risk perception ($r = 0.6$). With regard to students' willingness to engage in climate action, risk perception (global/societal) is most strongly correlated ($r = 0.56$) and skills to analyze and interpret data are least ($r = 0.25$). In the Swedish dataset, the strongest correlation was found between students' willingness to engage in climate action and risk perception (global/societal) ($r = 0.62$). Conversely, skills to analyze and interpret data are the least correlated with regard to students' willingness to engage in climate action ($r = 0.10$).

TABLE 1 | Descriptive statistics and correlations in the German dataset.

Variable	Mean	SD	1	2	3	4	5	6
1. Value orientation altruistic/biospheric	5.05	1.07						
2. Value orientation hedonic/egoistic	3.86	1.12	−0.11**					
3. Risk perception (global/societal)	3.25	0.44	0.38***	−0.21***				
4. Risk perception (local/personal)	2.16	0.58	0.29***	−0.25***	0.60***			
5. Climate change knowledge (sum)	5.93	2.47	0.01	−0.07	0.30***	0.19***		
6. Skills to analyze data (sum)	4.91	2.25	0.02	−0.20***	0.20***	0.16***	0.38***	
7. Willingness for climate action	3.35	0.80	0.44***	−0.35***	0.56***	0.43***	0.29***	0.25***

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

TABLE 2 | Descriptive statistics and correlations in the Swedish dataset.

Variable	Mean	SD	1	2	3	4	5	6
1. Value orientation altruistic/biospheric	5.04	1.22						
2. Value orientation hedonic/egoistic	3.86	1.29	0.21***					
3. Risk perception (global/societal)	3.18	0.57	0.48***	−0.18***				
4. Risk perception (local/personal)	2.22	0.64	0.29***	0.01	0.54***			
5. Climate change knowledge (sum)	4.16	2.83	0.16***	−0.22***	0.25***	0.05		
6. Skills to analyze data (sum)	3.54	2.42	0.05	−0.25***	0.17***	0.00	0.49***	
7. Willingness for climate action	3.35	0.90	0.51***	−0.18***	0.62***	0.38***	0.24***	0.10*

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

5.3 | Sequential Regression Analysis

Two sequential regression analyses (each with one of the two datasets) were carried out to examine how the different aspects of climate literacy (i.e., cognitive *and* psycho-social factors) can jointly contribute to explaining what motivates young people to engage in climate action (Table 3 for the German dataset and Table 4 for the Swedish dataset). For a complete presentation of the information, we provide unstandardized coefficients (*b*) with respect to dichotomous variables and, for all other variables, standardized coefficients (β) to evaluate the relative impact of the predictors. Since standardized coefficients are generated from data that have been unified with respect to their unit variance and can thus be compared, a direct comparison of unstandardized coefficients is to be avoided.

Our baseline model (Model 1) investigates the influence of students' background information (i.e., gender, age, and previous engagement in environmental activities) on their willingness to engage in climate action. In both datasets, gender (i.e., self-identification as female) and prior engagement in environmental activities proved to be significant predictors, explaining a total of 12% of the variance among German students ($F(3, 639) = 29.81$, $p < 0.001$, adj. $R^2 = 0.12$) and a total of 8% of the variance among the Swedish students ($F(3, 503) = 16.01$, $p < 0.001$, adj. $R^2 = 0.08$).

Model 2 introduces the cognitive factors, namely students' knowledge about climate change and their data analysis and interpretation skills. In the German and the Swedish dataset, both variables were found to be significant predictors that explain a further 11% of the variance in willingness to engage in climate action among German students ($F(2, 637) = 47.76$, $p < 0.001$, Δ adj. $R^2 = 0.11$) and a further 7% of the variance among Swedish students ($F(2, 501) = 20.33$, $p < 0.001$, Δ adj. $R^2 = 0.07$).

In a third model, both dimensions of risk perception (i.e., global/societal and local/personal) were introduced. Among German and Swedish students, both dimensions of risk perception emerged as significant predictors of their willingness to engage in climate action. In the German dataset, the inclusion of risk perception explained an additional 17% of the variance ($F(2, 635) = 91.46$, $p < 0.001$, Δ adj. $R^2 = 0.17$). With regard to the Swedish dataset, the addition of risk perception explained a further 26% of the variance ($F(2, 499) = 112.67$, $p < 0.001$, Δ adj. $R^2 = 0.26$).

The last model assessed the influence of two different dimensions of value orientations (i.e., altruistic/biospheric and hedonic/egoistic), as suggested by the principal component analyses. In the German dataset, both value orientations are identified as significant predictors that explain an additional 8% of the variance ($F(2, 633) = 46.47$, $p < 0.001$, Δ adj. $R^2 = 0.08$). A similar pattern can be reported from the Swedish dataset, where both value orientations explained a further 6% of the variance ($F(2, 497) = 31.36$, $p < 0.001$, Δ adj. $R^2 = 0.06$).

In total, the final model explains 48% (German dataset) and 48% (Swedish dataset) of students' willingness to engage in climate action, whereas previous involvement (only in the German dataset: $b = 0.14$; $p = 0.02$), climate change-related knowledge (German dataset: $\beta = 0.15$; $p < 0.001$; Swedish dataset: $\beta = 0.10$; $p = 0.01$), data analysis and interpretation skills (only German dataset: $\beta = 0.07$; $p = 0.03$), the global/societal dimension of risk perception (German dataset: $\beta = 0.31$; $p < 0.001$; Swedish dataset: $\beta = 0.36$; $p < 0.001$), the local/personal dimension of risk perception (only Swedish dataset: $\beta = 0.08$; $p = 0.04$), and altruistic/biospheric value orientations ($\beta = 0.25$; $p < 0.001$; Swedish dataset: $\beta = 0.32$; $p < 0.001$) as well as hedonic/egoistic value orientations (German dataset: $\beta = -0.20$; $p < 0.001$; Swedish dataset: $\beta = -0.16$; $p < 0.001$) emerge to be significant predictors.

The variance inflation factor (VIF) was calculated to determine possible multicollinearity. The coefficients of all predictors were below the threshold of 5 (between 1.04 and 1.88 in the German dataset and between 1.04 and 2.04 in the Swedish dataset; see Supporting Information File S2), which indicates that no severe multicollinearity between multiple predictor variables exists (see Vatcheva et al. 2016 for a discussion).

6 | Discussion

The present study aimed to explore different aspects of climate literacy (i.e., knowledge, skills, risk perception, and value orientations) among 10th to 13th graders, and to examine the aspects' relative contributions regarding students' willingness to engage in climate action. To strengthen the validity and overall generalizability of our findings, this study was conducted in two different but comparable countries located in Northern Europe; Germany and Sweden. The results of the two sequential regression analyses show a similar pattern: Among all independent variables, the global dimension of climate change-related risk perception is found to be the relatively strongest predictor of students' willingness to engage in climate action. The local dimension of climate change-related risk perception, on the other hand, could not be identified as a significant predictor in the final model of the German dataset and served as a weak predictor in the final model of the Swedish dataset. Regarding strong predictors, students' value orientations came in second. Here, the results indicate that students who endorse altruistic/biospheric values are more likely to be willing to engage in climate action, while students with strong hedonic/egoistic value orientations likely show the opposite tendency. This result was found in both datasets. Among the cognitive variables, students' climate-change related knowledge and data analysis and interpretation skills were identified as significant predictors in the German dataset, whereas only climate-change related knowledge was found to be a significant predictor in the Swedish dataset. The comparison of the standardized coefficients showed that in terms of students' willingness to engage in climate action cognitive factors seem to be relevant, but less influential. Of the background variables, only previous engagement in environmental activities proved to be predictive in the German dataset; however, the influence appears to be rather marginal.

Overall, our study results emphasize the importance of the psycho-social aspects of climate literacy for explaining students' willingness to engage in climate action. Climate change-related knowledge, on the other hand, proved to be significant in both countries but seems less influential. In the final models, the predictor variables accounted for 48% (Germany) and 48% (Sweden)

TABLE 3 | Results of the sequential regression analysis of the German dataset.

	Background information		Cognitive factors			Risk perception			Value orientation		
	Model 1		Model 2			Model 3			Model 4		
Independent variables	***b***	**SE**	***b***	**SE**	***β***	***b***	**SE**	***β***	***b***	**SE**	***β***
Gender[a]	0.36***	0.06	0.45***	0.06	(0.28***)	0.28***	0.05	(0.18***)	0.10	0.05	(0.06)
Age	0.02	0.02	−0.004	0.02	−0.01	−0.03	0.02	−0.05	−0.03	0.02	−0.05
Engagement[a]	0.49***	0.07	0.39***	0.07	(0.20***)	0.23***	0.06	(0.12***)	0.14*	0.06	(0.07*)
Climate knowledge (sum)			0.09***	0.01	0.27***	0.04***	0.01	0.14***	0.05***	0.01	0.15***
Data analysis skill (sum)			0.05***	0.01	0.14***	0.03**	0.01	0.10**	0.02*	0.01	0.07*
Risk perception (global/societal)						0.7***	0.07	0.39***	0.55***	0.07	0.31***
Risk perception (local/personal)						0.15**	0.05	0.11**	0.10	0.05	0.07
Value orientation altruistic/biospheric									0.18***	0.02	0.25***
Value orientation hedonic/egoistic									−0.14***	0.02	−0.20***
Adj. R^2	0.12 [0.1186]		0.23 [0.2312]			0.40 [0.4012]			0.48 [0.4762]		
(Multiple) R^2	0.12 [0.1228]		0.24 [0.2372]			0.41 [0.4078]			0.48 [0.4836]		
Δ adj. R^2			0.11			0.17			0.08		
F_{change}	29.81***		47.76***			91.46***			46.47***		

Note: Dependent variable is willingness to engage in climate action. Only complete cases ($N = 643$).
[a]These are dichotomous variables; for all entries.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

TABLE 4 | Results of the sequential regression analysis of the Swedish dataset.

	Background information		Cognitive factors			Risk perception			Value orientation		
	Model 1		Model 2			Model 3			Model 4		
Independent variables	***b***	**SE**	***b***	**SE**	***β***	***b***	**SE**	***β***	***b***	**SE**	***β***
Gender[a]	0.51***	0.08	0.52***	0.07	(0.59***)	0.20**	0.07	(0.23**)	0.08	0.06	(0.09)
Age	0.07	0.04	0.03	0.04	0.03	0.02	0.03	0.02	0.01	0.03	0.01
Engagement[a]	0.19***	0.10	0.25**	0.10	(0.28**)	0.18*	0.08	(0.20*)	0.07	0.08	(0.07)
Climate knowledge (sum)			0.09***	0.01	0.27***	0.05***	0.01	0.15***	0.03*	0.01	0.10*
Data analysis skill (sum)			−0.01	0.02	−0.02	−0.02	0.01	−0.05	−0.02	0.01	−0.07
Risk perception (global/societal)						0.81***	0.07	0.52***	0.58***	0.07	0.37***
Risk perception (local/personal)						0.10	0.06	0.07	0.12*	0.06	0.08*
Value orientation altruistic/biospheric									0.23***	0.03	0.32***
Value orientation hedonic/egoistic									−0.11***	0.03	−0.16***
Adj. R^2	0.08 [0.0817]		0.15 [0.1473]			0.41 [0.4102]			0.47 [0.4742]		
(Multiple) R^2	0.09 [0.0872]		0.16 [0.1557]			0.42 [0.4184]			0.48 [0.4835]		
Δ adj. R^2			0.07			0.26			0.06		
F_{change}	16.01***		20.33***			112.67***			31.36***		

Note: Dependent variable is willingness to engage in climate action. Only complete cases ($N = 507$).
[a]These are dichotomous variables; for all entries.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

of the total variance in students' willingness to engage in climate action.

6.1 | Cognitive Factors

6.1.1 | Climate Change-Related Knowledge Is a Weak to Medium Predictor for Students' Willingness to Engage in Climate Action in Both Datasets

The role of climate change-related knowledge for climate action has already been vividly discussed in science education and beyond, and the overall picture shows quite mixed results (e.g., Busch et al. 2019; Di Giusto et al. 2018). Our study contributes to this picture by providing evidence that climate change-related knowledge was a significant predictor for students' willingness to engage in climate action in both countries, even when controlling for age, gender, previous engagement, risk perception, and value orientations. Comparing the standardized coefficients showed furthermore that knowledge had a moderate contribution to explaining students' willingness for climate engagement.

In purely descriptive terms, around 40% of the items measuring climate knowledge in Germany ($M = 5.93$) and around 28% of the items in Sweden ($M = 4.16$) were answered correctly by students. This result seems somewhat sobering from a science education perspective, but it must be acknowledged that the items were originally developed with two different target groups, namely advanced high school students and university students. Only later were the two studies merged for measuring climate change understanding among the wider public (Libarkin et al. 2018). The removal of five items after the pilot study, including the two easiest items according to Libarkin et al. (2018), may have made the instrument more challenging for students in grades 10–13.

In this study, we primarily focused on students' understanding of the scientific processes surrounding the climate system and the causes of climate change (e.g., radiation and greenhouse gases). While some studies have already shown that knowledge about the causes of climate change is associated with young people's willingness to engage in climate action (e.g., Tasquier and Pongiglione 2017), other studies suggest that different types of knowledge relate to different types of climate action: In a study by Thaller et al. (2020) conducted with the Austrian public, for example, basic knowledge about the climate system and the causes of climate change played a significant—albeit rather weak—role for participation in climate action of a social nature, such as talking to others about climate change or being active in a local group. Yet, this type of knowledge was unrelated to participation in individual climate actions, such as reducing air travel and meat consumption (referred to as conservation behavior) or climate citizenship (e.g., signing a petition or using one's political voice). Kolenatý et al. (2022) found in a study with 12- to 17-year-old students that only knowledge about actions contributing to climate change and the effectiveness of countermeasures, but not the conceptual understanding of climate change and possible impacts (referred to as system knowledge), correlated significantly with students' willingness to act. However, subsequent structural equation modeling suggested a significant but indirect link between system knowledge and students' willingness to act (via self-efficacy). Conclusively, while knowledge of the scientific processes surrounding climate change appears to be important for understanding why we need to act in the first place, it can also positively influence other types of knowledge and other factors that ultimately lead to climate action (e.g., Frick et al. 2004; Stevenson et al. 2018).

6.1.2 | Data Analysis and Interpretation Skills Are a Weak Predictor for Students' Willingness to Engage in Climate Action in the German Dataset

An important aspect of climate literacy is the ability to evaluate, interpret, and share climate change-related information (Azevedo and Marques 2017; U.S. Global Change Research Program 2009, 2024). Although much of the climate change-related information is presented through visualizations typical for science (e.g., charts, bars, and scales), it remains unclear how these visualizations can support decision-making (see Moser 2010). With this in mind, a first attempt was made to measure students' data analysis and interpretation skills. In the final model of the sequential regression analyses of the German dataset, these skills were identified as a significant predictor for students' willingness to engage in climate action; yet, its influence seems to be rather marginal.

From a descriptive point of view, about half of the items were answered correctly in the German dataset ($M = 4.91$) and about a third of the items in the Swedish dataset ($M = 3.54$), even though the instrument was originally developed for middle school students. However, it should be noted that this instrument was placed last in the questionnaire, which could have led to test fatigue or missing data, which in turn were coded as incorrect responses. Another, less technical explanation could be that students might found it difficult to meaningfully connect the items on data analysis and interpretation with their own experiences and emotions: For example, in a study with university students, Cooper et al. (2020) demonstrated that when students collected the analyzed data themselves, they reported a significantly stronger emotional connection to their work. Similar mechanisms might also be possible in relation to students' engagement in climate action, meaning that if students had the opportunity to collect and analyze their own data, different results could be expected. A particularly successful example of combining data analysis and interpretation with students' lived realities can be found in the study by Calabrese Barton and Tan (2010), in which students aged 10 to 14 conducted experiments and collected data to investigate the effects of urban heat islands (a phenomenon that is discussed in connection with climate change; see IPCC 2022). By processing their findings in self-produced documentaries, the students were not only able to contextualize and personalize their science learning, but also to explore how data can be used for broader societal relevance.

With regard to science education, students' difficulties in analyzing and interpreting data can be considered a cause for concern (e.g., Pols et al. 2021). Working with climate change-related data in class could offer a promising starting point for integrating and practicing these skills: Gold et al. (2015), for example, provide a three-module curriculum for upper secondary school that includes working with authentic Arctic climate data. Based on the results of the present study, an interesting next step would be to understand how such inquiry- and data-driven learning interventions affect the development of students' willingness to engage in climate action.

6.2 | Psycho-Social Factors

6.2.1 | The Global/Societal Dimension of Climate Change-Related Risk Perception Is the Relatively Strongest Predictor for Students' Willingness to Engage in Climate Action in Both Datasets

A key finding of our study was that *global/societal* risk perception was the strongest relative predictor of students' willingness to engage in climate action in both datasets, while *local/personal* risk perception was, in the final model, less (Swedish dataset) or even not (German dataset) predictive. However, this result warrants caution: Looking at the way in which risk perception was assessed, most items (16 out of 21 items; some from the original instruments and some developed as part of the pilot phase) asked about the perceived likelihood that certain climate change-related consequences, such as flooding or a reduction in living standards, will occur in the next 50 years due to global warming, either for themselves or for where they live (i.e., local/personal risk perception) or worldwide (i.e., global/societal risk perception). Thus, this instrument may also have implicitly measured students' knowledge about the impacts of climate change and their geographical distribution.

Indeed, research has shown that knowledge about the negative consequences of climate change (but also about the causes of climate change and ways to response to it) can influence an individual's climate change risk perception (e.g., Shi et al. 2016; Van der Linden 2015; for the influence on concern see Milfont 2012). This emphasizes, as outlined in the theoretical background, that risk perception cannot be viewed as a purely affective or intuitive construct, but that the cognitive and non-cognitive components of risk perception are closely intertwined (see also Loewenstein et al. 2001; Slovic et al. 2004). From this angle, the predictive power of *global/societal* risk perception could also indicate that students are (simply) more aware of the global impacts of climate change than the local ones. Finally, another conclusion from our findings might be the need to promote students' awareness of the local consequences of climate change more purposefully, especially as focusing on the global consequences may reinforce the perception that climate change is only taking place "elsewhere": As O'Neill and Nicholson-Cole (2009) have noted, climate communication strategies that rely on global or distant images (e.g., polar bears on melting ice sheets) can unintentionally reinforce the perception that climate change is a faraway issue, disconnected from an individuals' immediate surroundings. This is consistent with study findings emphasizing the importance of local framing (i.e., making climate change personally relevant by highlighting local, community-level impacts; Scannell and Gifford 2013; Spence et al. 2012). Moreover, given that our respondents live in Germany and Sweden, countries that could be considered less exposed to certain climate impacts compared to many other regions, the findings may also reflect their limited personal experiences of climate-related consequences. Our findings, in light of these considerations, may therefore not only reflect a current gap in students' knowledge about local impacts of climate change, but also underscore the need for enhanced educational strategies that explicitly present climate change as locally relevant and urgent.

A closer look at students' response behavior when measuring risk perception also revealed that one particular item (i.e., "How concerned are you about global warming?") explained almost a third of the variance in students' willingness to engage in climate action, in both countries (for results of the analyses of variance, see Supporting Information File S2). This was the same item that had been recoded from the local/personal dimension to the global/societal dimension following the principal component analyses (see chapter 5.1). Maintaining the theoretical allocation would thus have given more weight to the local/personal dimension of risk perception, which in turn could have led to a more balanced picture between the two dimensions and their influence on students' willingness to engage in climate action.

In conclusion, we explicitly refrain from highlighting the promotion of global/societal risk perception (or local/personal risk perception) and instead call for further, preferably qualitative, in-depth studies on students' risk perception to clarify the role of both dimensions with regard to climate action.

6.2.2 | Value Orientations Are Strong Predictors for Students' Willingness to Engage in Climate Action

Another psycho-social factor that has received particular attention in relation to students' climate engagement is value orientations (e.g., Kang and Tolppanen 2024). The results of the present study underscore familiar patterns, namely that different value orientations have different effects on students' willingness to engage in climate action: Altruistic and biospheric value orientations were strongly expressed in both samples ($M = 5.05$ for the German sample; $M = 5.04$ for the Swedish sample) and served as strong predictors for students' willingness to act. Conversely, egocentric and hedonic values were much less pronounced in both student samples ($M = 3.86$ in both samples) and served as negative predictors for students' willingness to engage in climate action.

As discussed in Kang and Tolppanen (2024), science subjects may be a promising avenue to promote biospheric value orientations in the course of school education, since subjects such as biology can introduce students to the wonders of (non-human) life and provide them with direct experiences of nature. Specific instructional approaches, such as the use of socioscientific issues, can also create scope for students to explore their own value orientations and moral understanding in science lessons (Zeidler 2014). Our results underscore the importance of such value-oriented approaches in science education that may help to bridge the gap between discussing possible climate actions and actual engagement.

7 | Limitations

Although this study opens up new avenues for exploring the role of risk perception in science and climate change education, it is not without notable limitations:

While the youth-led climate movement "Fridays For Future" has strongly influenced the discourse on climate change in recent years (see Fisher 2019), our study—like most studies in education (Kranz et al. 2022)—focused on students' individual climate actions to mitigate climate change. We deliberately chose this focus, as it seems that the vast majority of students are still not involved in collective action (e.g., InterClimate Network 2023), but would like to point out that individualizing the issue of climate change simplifies the problem and also obscures the need to transform larger socio-political structures (see Shove 2010). Furthermore, opportunities to take climate actions are limited by accessibility, privilege, and available resources, which means that not everyone has the same opportunities to get involved (e.g., Gibson-Wood and Wakefield 2013; Kessler 2022). Against this background, we must critically acknowledge that this study serves the prevailing tendency to place excessive responsibility on individuals and possibly contributes to reproducing class-specific prejudices and attributions by linking willingness to engage in climate action with class-specific capital (see Weselek 2024). Consequently, we refrained from including information on students' socioeconomic background. We encourage fellow researchers, however, to understand students' climate engagement in the many roles and contexts they occupy in society to strive for and promote a more equitable and meaningful approach to tackling climate change (see Pearson and Schuldt 2018).

Second, the items that measured students' data analysis and interpretation skills referred to natural hazards. Although natural hazards such as heavy rainfall will occur more frequently due to ongoing climate change, the reference to climate change may have been too implicit for participants. Future research should consider developing items to measure data analysis and interpretation skills with actual illustrations, for example, from the IPCC (2021), to increase contextual embedding and authenticity. In addition, there is a wide range of skills that can be considered important for accessing and negotiating information related to climate change. As the chosen study design focused on the use of closed-ended items, we deliberately selected the skill of data analysis and interpretation (e.g., compared to evidence-based reasoning) as one of the skills that was considered particularly relevant (see Gellermann et al. 2025). However, future studies should address the diversity of skills related to climate literacy and devote them the attention they deserve, as they offer a promising and partly novel perspective on learning about climate change.

The third limitation concerns the construct of risk perception. With regard to its operationalization, the different views on what exactly is meant by risk perception, as well as the overlaps and blurring with constructs such as concern, fear, worry, and anxiety (to name but a few) pose major challenges for research (see, for example, Wolff et al. 2019 for the study of perceived risk in the tourism sector). In this study, we contributed to this fuzziness to some extent because, while we measured risk perception, we also saw that the item asking about students' level of concern about global warming explained the most variance in students' willingness to act. Furthermore, we considered the relationship between risk perception and willingness to engage in climate action as linear; yet, this assumption requires further critical examination.

Finally, residual diagnostics indicated that the distribution of residuals was uneven and not completely random in both datasets, suggesting a systematic effect at the high and low ends (see Supporting Information File S2). Since the deviations in the residuals mainly affected certain value ranges (and not the overall structure of the relationship), we classified the issue as minor and decided to continue with the choice of method and interpretation of data without further adjustments. Overall, it should also be noted that linear regression estimates are considered relatively robust to moderate violations of model assumption. Similarly, the MCAR tests in both datasets did not yield definitive conclusions, so caution is warranted when interpreting the results of the sequential regression analyses.

8 | Implications for Science Education

Science education holds a prominent role in both teaching and learning the science of climate change and facilitating successful participation in societal decision-making on climate change. Although most climate change instruction still centers climate change-related knowledge (Kranz et al. 2022; Rousell and Cutter-Mackenzie-Knowles 2020), our findings support the argument that this focus may be insufficient if the ultimate goal is to empower students to take action on climate change. In addition to equipping students with the necessary knowledge to make informed decisions regarding climate change (or any other science-related issue of societal concern), science education also needs to foster critical awareness and agency, laying the foundation for active citizenship in the pursuit of social transformation (see Sjöström 2024). Enabling this kind of science learning could begin with recognizing and addressing the various feelings (e.g., perceptions of risks) and underlying values related to climate change. Correspondingly, it appears valuable that assessment policies move beyond factual recall and towards evaluating students' ability to apply knowledge, as well as their ability to contribute to addressing global challenges, as reflected in the latest PISA Science Framework (OECD 2023).

Today's students will feel the effects of climate change more acutely than any generation before (IPCC 2022), and it seems more important than ever that young people are educated about the associated risks. Reflecting on the risks of climate change in science lessons could, as our findings suggest, help students to consider engaging in climate action and potentially also contribute to a more nuanced understanding of the urgency of the issue and the vulnerability of regions and people. This, in turn, could help to establish the increasingly demanded critical perspective in climate change education (e.g., Svarstad et al. 2023), as it provides an opportunity to center the prevailing injustices associated with climate change.

Although we consider the inclusion of more equity-oriented concepts in climate change education to be essential—not least in light of our findings—several studies have already shown that science teachers experience difficulties integrating socio-political and ethical aspects into their science teaching (e.g., Garrecht et al. 2023). One approach could be to focus more strongly on the possibilities of practicing interdisciplinary teaching concepts and collaboration between teachers of different subjects (e.g., Kate et al. 2019). To support science teachers in implementing this form of teaching, additional support and resources appear to be needed, along with professional development opportunities (see, for example, Wise 2010). From a policy perspective, curriculum frameworks could clearly mandate cross-curricular treatment of the issue of climate change and allocate time and resources for teachers to plan and implement interdisciplinary work.

While we have so far focused on the opportunities that arise from addressing students' climate change-related risk perceptions, we would also like to draw attention to the responsibilities and potential harms in this regard. First, focusing on risk may also help to legitimize the continuation of current practices, thereby accepting the underlying harmful structural conditions that can reproduce existing injustices rather than focusing on transforming the systems that have fueled and are fueling climate change (Osborne and Carlson 2023). Second, while our results show that risk perception can help explain students' commitment to climate action, there is also evidence that an exaggerated perception of risk can have the opposite effect: a higher perception of risk was found to be associated with stronger negative emotions such as anxiety (Reese et al. 2023), whereas anxiety can affect individuals' willingness to act (e.g., Stanley et al. 2021 for a negative association between anxiety and engagement in collective climate action). Risk perception therefore appears to be potentially both a driving force and an obstacle to climate action. The key question that arises from this, then, is how we can promote risk perception responsibly in science education in such a way that it motivates rather than hinders students' engagement with climate change. Recent studies suggest that balancing risk perception and agency-oriented constructs such as hope (e.g., Ojala 2012) could be a promising approach to motivating students to take climate action (e.g., Stevenson and Peterson 2016). For science educators, this could involve linking global climate processes to students' local environments, for example through place-based activities such as analyses of local adaptation strategies (for an example, see Haglund et al. 2025). This could help providing a more nuanced picture of our climate-altered world, considering the risks as well as the hope and agency for coping with past and present impacts.

Conclusively, we argue that science education must go beyond the prevailing focus on knowledge to ensure that students not only understand the scientific background of climate change but also develop the motivation to engage with the issue. By addressing both the cognitive and psycho-social components of climate literacy, science teachers might help students develop a broader and more meaningful perspective on climate change and support them in going beyond the theoretical discussion of how to combat climate change.

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Ethics Statement

Studies reported in this paper were approved by the Ethics Committee at IPN Kiel (reference number: 2020_GA39) as well as the respective ministries of education for the data collection in Germany and by the Research Ethics Committee at Karlstad University (reference number: HS 2020/786) for the collection of data in Sweden.

Data Availability Statement

Raw data of the present study are available upon reasonable request. For the German raw data, please refer to the corresponding author garrecht@leibniz-ipn.de. For the Swedish raw data, please refer to nina.christenson@kau.se.

Endnotes

[1] While gender is not a binary variable, we dichotomized the variable for reasons of data analysis, which resulted in missing data in nine (German dataset) and nine (Swedish dataset) cases (for a critical discussion, see Lindqvist et al. 2021).

[2] For further information regarding the cross-national approach, the choice of countries, the sampling procedure and post hoc power analyses, please see Supporting Information File S2. For relevant excerpts from the R-script, please see Supporting Information File S3.

[3] All tokens were provided and there was no record of which token was assigned to which student.

[4] None of the participating teachers overseeing the data collection reported back any technical problems, so it was assumed that students may have ticked the box 'I have technical issues' as there was no 'I don't know' option in the first four items, and also for the last item as it may have been less exposing.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **File S1:** tea70045-sup-0001-Supinfo-S1.docx **File S2:** tea70045-sup-0002-Supinfo-S2.docx **File S3:** tea70045-sup-0003-Supinfo-S3.docx