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Development and validation of the Climate Change Literacy Questionnaire (CCLQ) for children aged 10 to 11 in Denmark

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ABSTRACT

This study developed and validated a novel 30-item Climate Change Literacy Questionnaire (CCLQ) for children aged 10 to 11 in a Danish context. The CCLQ operationalizes climate change literacy (CCL) as a multidimensional construct encompassing four domains: *self-perceived knowledge* of climate change causes, consequences, mitigation and adaptation; climate-relevant *behavior* in everyday contexts; *motivation* related to climate change learning and action; and *systemic and collective orientation* toward the social, collective and cross-contextual dimensions of climate change. Two independent samples of 4th-grade pupils ($N=1691$) were recruited across two phases: a development phase involving item generation, focus group interviews, pretesting, expert assessments, and exploratory factor analysis; and a validation phase including large-scale testing, confirmatory factor analysis (CFA), internal reliability (Cronbach's α , McDonald's Ω), test-retest reliability (intraclass correlation coefficient, ICC), convergent validity (regression analysis), and measurement invariance. Results supported a bifactor model with a global CCL factor, strong internal reliability ($\alpha=0.905$, $\Omega=0.903$), high test-retest reliability (ICC = 0.901), consistent model fit across gender and SES groups, and convergent validity with sustainable food literacy. The CCLQ should be interpreted as an age-appropriate measure of these four domains of CCL in children aged 10 to 11, rather than an exhaustive measure of all climate change education outcomes. The CCLQ may support research and evaluation of climate change education initiatives in Danish primary school settings and provide a basis for future translation, cultural adaptation and validation in other languages and educational contexts.

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1. Introduction

The World Health Organization (WHO) has declared climate change the greatest challenge of the twenty-first century (Bayar 2025). In the past decade, several regions have experienced extreme weather events such as unprecedented temperatures, storms, floods, and wildfires, causing adverse impacts to public health, supply chains, infrastructure, and economies (Intergovernmental Panel on Climate Change 2019; Rousi et al. 2022). These adverse impacts will continue to intensify if collective action to reduce global greenhouse gas emissions is not rapidly accelerated (Calvin et al. 2023; Steffen et al. 2015). Current trajectories in climate change thus indicate that children of today, regardless of their residence, face a future in which they will need to navigate the increasingly complex challenge of climate change. However, a growing gap persists between what the scientific community knows about climate change and how institutions, societies and individuals act (Knutti 2019; Veijonaho et al. 2024). This underlines a need to enhance current and future generations' motivation for and ability to engage in both individual and societal action to mitigate and adapt to climate change (Horry et al. 2023; Otto et al. 2019). Specifically, there is a need for initiatives, policies and programs targeting children's competences related to climate change in both formal and informal settings.

Evidence suggests that, due to a lack of direct control over the environment in which they live, as well as their anatomic, cognitive, immunologic and psychologic state, children are particularly vulnerable to the impacts of climate change (Stanberry, Thomson, and James 2018). Current strategies to mitigate climate change often emphasize green technologies such as electric vehicles and solar panels, while the potential of educational initiatives and policies are more rarely used in both the public and political sphere. However, studies have stressed the importance of education as a key climate change mitigation strategy (Bedford 2016; Busch, Henderson, and Stevenson 2019; Cordero, Centeno, and Todd 2020; Park, Choe, and Kim 2020), and highlighted education as the strongest predictor of public awareness of climate change (Johnston 2020). Young people have actively called for more holistic approaches to climate change education, which fosters the necessary knowledge, skills, values, attitudes, and behaviors needed to understand and act upon climate change (Anderson 2024; Horry et al. 2023). A recent systematic review identified knowledge, behavior, actions, experiences and attitudes as the most frequently addressed topics in climate change education in primary and lower secondary education (Nepraš, Strejčková, and Kroufek 2022), and the educational setting has been emphasized as an opportune first lever for promoting the literacy of children and adolescents, including in relation to climate change (Anderson 2024; Leal Filho and Hemstock 2019; Otto et al. 2019). Studies further suggests that sustainable habits during childhood often transfer into adulthood, and that a trickle-down effect occurs between generations, particularly from children to their parent(s) (Anderson 2024). Moreover, young people experience a greater sense of hope about climate change when equipped with tools that they can personally use to address the issue (Ojala 2013; Ratinen and Uusiautti 2020). Children thus constitute an important target group for climate change action, as they will arguably experience the longest-lasting consequences of climate change and be more prone to adapting their habitual patterns and worldviews at this age

(Harker-Schuch 2019). Despite this, a recent report by the UNESCO *Monitoring and Evaluating Climate Communication and Education Project* highlights that action must be accelerated in ensuring that climate change and sustainability are integrated in the curriculum of primary schools (Benavot and McKenzie 2026). Likewise, a systematic review identified ineffectual didactic approaches to climate change education when attempting to influence student's attitudes and behaviors (Rousell and Cutter-Mackenzie-Knowles 2020). As educational programs and interventions targeting this age group become more prevalent, there is a need for valid and reliable monitoring and evaluation tools to identify their effects on equipping children with the tools they need to address climate change.

1.1. Defining climate change literacy

The concept of climate change literacy (CCL) has been proposed as a framework for the competences needed to understand and make informed decisions about climate change (Pan et al. 2023). Johnston (2020) briefly defines CCL as 'competence or knowledge in the area of climate change, its impacts and its solutions' (Johnston 2020) (p. 200). However, due to the novelty of the concept, research consensus on its conceptual meaning, scope and content is yet to be developed. The use of the term in the existing literature varies according to aim, setting and age-group, and encompasses both narrow and broader aspects of CCL. Additionally, aspects of CCL are often referenced in similar yet differing concepts such as climate literacy, climate science literacy, climate capability, climate change competence or climate change attitudes (Azevedo and Marques 2017; Christensen and Knezek 2015; Dupigny-Giroux 2008; Horry et al. 2023; Kolenatý, Kroufek, and Činčera 2022; Miléř and Sládek 2011; Taurinen et al. 2025). A common feature of these concepts is the intersection between climate change science, effects and environmental education strategies with a goal to promote, stimulate, and cultivate pro-environmental knowledge, attitudes, values, and behaviors (Azevedo and Marques 2017; Johnston 2020; Kolenatý, Kroufek, and Činčera 2022). For example, recent frameworks such as the U.S. Global Change Research Program Climate Literacy Guide and the Transformative Skills Guide emphasize the importance of understanding climate systems and human impacts, evaluating credible information, communicating effectively, making informed decisions and developing action-oriented capacities for climate change adaptation and mitigation (Bodor et al. 2025; USGCRP 2024), while the Climate Change Competence (C3) framework proposes the dimensions of knowledge, skills and attitudes as the most integral set of competences to navigate climate change (Fuertes et al. 2020).

Some researchers refer to CCL and climate literacy interchangeably (Azevedo and Marques 2017; Leve, Michel, and Harms 2023; Suhaimi and Mahmud 2022). In this study, we regard climate literacy and CCL as closely related but not identical constructs. Climate literacy is commonly used as a broad construct referring to knowledge of the climate system and the ability to access, evaluate, communicate and reason about climate-related information, including climate science specifically (Azevedo and Marques 2017; Martin et al. 2025). CCL as a concept narrows and specifies these broader competences in relation to anthropogenic climate change as a socio-scientific and educational issue, including knowledge and competencies related to causes,

consequences, mitigation and adaptation responses (Johnston 2020; Stevenson, Nicholls, and Whitehouse 2017). Johnston (2020) operationalizes their definition of CCL as a combination of 'competencies that can include (1) knowledge of climate system science, (2) understanding of the impacts and threats of climate change, and (3) motivation to make informed decisions to implement mitigative and adaptive solutions to the climate crisis' (Johnston 2020) (p. 202). Skills in systems thinking and communication are further proposed as potential fourth and fifth domains (Johnston 2020), whilst others have highlighted the importance of attitudes, beliefs, self-efficacy, and values as well as personal concern and climate-friendly behaviors (Kuthe et al. 2020). This more targeted focus is particularly relevant in educational and intervention research, where the aim is often not only to assess a general understanding of the climate system, but also children's understanding of human-induced climate change and their capacity to make sense of climate-relevant actions and solutions.

However, existing definitions of CCL and related constructs cannot be transferred directly to children aged 10 to 11 without considering developmental appropriateness, item comprehensibility and the educational contexts in which children encounter climate change. Children in late primary education may be able to engage with concrete cause-effect relations, everyday examples of mitigation and adaptation, and social dimensions of climate change, but they should not be expected to demonstrate abstract climate science knowledge, policy reasoning, economic understanding or advanced systems thinking often associated with older adolescents or adults. Recent work on climate change competence in pre-teens illustrates this point by adapting broader competence dimensions to children's cognitive development, language level, curriculum context and degree of control over the actions addressed in the items (Ortega-Quevedo et al. 2024). Questionnaire-based assessment in this age group also requires careful attention to item concreteness, response burden, response formats and pretesting, as children's responses may be influenced by comprehension, scale interpretation and contextual cues (Borgers, Sikkels, and Hox 2004; Mellor and Moore 2014; Rebok et al. 2001). This supports the need for an age-appropriate operationalization of CCL that captures relevant dimensions of CCL, rather than a direct adaptation of instruments developed for older populations.

Drawing on these perspectives as well as prevailing behavior change models related to climate change such as the Climate Change Behavior Model (Stevenson, Nils Peterson, and Bondell 2018), we approached CCL among children aged 10 to 11 as a multidimensional construct, defined as *the necessary knowledge, understanding, attitudes, motivation, behaviors and skills needed to engage critically and action-oriented in climate change adaptation and mitigation efforts*. This definition is consistent with existing literature emphasizing that effective climate change education in this age group should extend beyond factual knowledge alone and include participatory, interdisciplinary, affective, and action-oriented dimensions (Fuentes et al. 2020; Monroe et al. 2019; Rousell and Cutter-Mackenzie-Knowles 2020; Stevenson, Nicholls, and Whitehouse 2017). For the purpose of this study, these perspectives provided the conceptual starting point for developing an age-appropriate and context-specific operationalization of CCL across the 4 domains: Self-perceived knowledge, Behavior, Motivation, and Systemic and collective orientation.

Self-perceived knowledge was defined as children's perceived knowledge, understanding and confidence in relation to the complex interplay between climate change causes, consequences, and actions which enable effective mitigation and adaptation. In contrast to the concept of climate literacy, our conceptualization of CCL emphasizes not only science-oriented knowledge of causes and consequences of climate change but also adaptation and mitigation efforts. The domain was informed by the environmental knowledge framework applied to climate change education by Bofferding and Kloser (2015), which distinguishes between system knowledge (of climate change causes, mechanisms and consequences), action knowledge (of possible mitigation and adaptation responses) and effectiveness knowledge (of the relative impact of different actions) (Bofferding and Kloser 2015; Frick, Kaiser, and Wilson 2004). This distinction captures that CCL requires more than knowing that climate change occurs; it also involves understanding what can be done and which responses are likely to matter most. We operationalized these aspects as self-perceived rather than objective knowledge as sustainable behavior is not only influenced by what children objectively know, but also by whether they feel sufficiently informed and capable of applying that knowledge. Self-perceived knowledge thus captures children's perceived understanding and confidence in relation to climate change action, and should thus be interpreted as perceived understanding, confidence or familiarity, and not as an indicator of factual climate science knowledge.

Behavior was defined as the degree to which children report engaging in concrete, every day and age-appropriate climate-relevant behaviors, relevant to a Danish context and at an individual level. Frequency of behavior has been shown to reflect sustained action across time and can thus be considered focal in determining behavior (Fleeson 2004). The ability to engage in climate change action is further viewed as a key determinant, particularly for younger people, as it enhances a sense of personal engagement in climate action (Devine-Wright, Devine-Wright, and Fleming 2004; Meinhold and Malkus 2005). The domain was not intended to measure the objective climate impact of children's actions or their full independent control over household consumption or family-level decisions. Rather, items reflect the contextual indicators of children's emerging climate-relevant behavior, acknowledging that everyday behaviors may be shaped by motivation, habits, family practices and contextual constraints (Ajzen 1991; Kaiser and Fuhrer 2003; Kollmuss and Agyeman 2002).

Motivation was defined as an affective or value-based state indicating a positive attitude towards actions alleviating climate change, such as the perceived importance of not polluting the environment. This includes a sense of motivation for implementing solutions for mitigation and adaptation (Johnston 2020). This definition is grounded in the Self-Determination Theory, which conceptualizes motivation not only in terms of its strength, but also in terms of its quality or regulatory basis, ranging from more controlled to more autonomous forms of motivation. From this perspective, children's motivation to engage with climate-relevant behaviors may reflect different degrees of internalization, from acting because of external expectations to acting because the behavior is personally valued or experienced as meaningful (Ryan and Deci 2000). Previous studies have noted the importance of climate change attitudes in influencing willingness to engage in climate change action (Bofferding and Kloser 2015; Ojala 2012), as well as personal beliefs, friends and family on climate change concern among

adolescents (Stevenson, Peterson, and Bondell 2019). Personal values and willingness to act in favor of climate change action have been further linked to sustainable behaviors (Boyes, Skamp, and Stanisstreet 2009; Dijkstra and Goedhart 2012), and climate change concern has been identified as a predictor of positive climate change behavior (Hornsey et al. 2016). This is consistent with the environmental behavior literature, where knowledge is generally considered important but not sufficient for behavior change. Items in this domain thus capture the motivational, psychological, and contextual factors that shape behavior such as attitudes, perceived competence, self-efficacy, perceived behavioral control, and beliefs about whether one's actions are effective (Ajzen 1991; Frick, Kaiser, and Wilson 2004; Kaiser and Fuhrer 2003; Kollmuss and Agyeman 2002).

Finally, *Systemic and collective orientation* was defined as children's age-appropriate awareness that climate change extends beyond individual behavior and involves collective, social and cross-contextual dimensions. The term *orientation* was used to avoid implying that the domain assessed advanced systems thinking or a full understanding of complex socio-ecological systems. The items thus capture children's emerging sense that climate change may affect people's health and lives, that actions in one country may have consequences elsewhere, and that children may contribute to climate-related solutions. This interpretation is consistent with climate change education literature emphasizing perceived responsibility, locus of control and other-regarding orientations as relevant for pro-environmental engagement (Kollmuss and Agyeman 2002; Monroe et al. 2019; Nepraš, Strejčková, and Kroufek 2022; Rousell and Cutter-Mackenzie-Knowles 2020), and that children in this age range are generally able to engage with climate change as a complex socio-scientific issue (Sjöblom et al. 2022).

Given the limited literature on CCL in children below adolescence, these 4 domains provide a conceptual starting point for developing an age-appropriate and context-specific operationalization of CCL among children aged 10 to 11, rather than a universal construct encompassing all possible outcomes related to climate change education across age groups and contexts.

1.2. Measuring climate change literacy in children aged 10 to 11

This conceptual starting point raises an important measurement challenge: How can CCL be assessed in a way that is both theoretically meaningful, psychometrically robust and developmentally appropriate for children aged 10 to 11? Research indicates that children develop perceptions, concerns and misconceptions about climate change before adolescence, and that climate change education can support more accurate understanding when it is developmentally appropriate and connected to children's everyday experiences (Lee et al. 2020; Monroe et al. 2019; Rousell and Cutter-Mackenzie-Knowles 2020; Sjöblom et al. 2022). At this age, children are typically in late primary education and increasingly encounter climate change through school, media, family practices, and public debate. At the same time, their conceptual understanding, emotional responses, perceived agency, and understandings of possible climate-related actions are still developing. Children aged 10 to 11 should not be expected to understand the full scientific, economic and political complexity of

climate change in the same way as older students or adults. However, this does not imply that climate change is irrelevant or inappropriate in late primary education. Rather, it underscores the need for age-appropriate measures that can assess dimensions of CCL that are meaningful to this age group and relevant to climate change education and evaluation.

In the existing literature, measures of CCL have tended to focus on singular, or a narrow range of dimensions related to CCL as well as adolescent or adult populations. For instance, the 41-item Climate Change Knowledge Scale, validated in a Swiss adult population (18 years and above), focuses mainly on climate-related knowledge with some but few attitudinal variables (Tobler, Visschers, and Siegrist 2012). More recent instruments include the 24-item Climate Capability Scale, validated in adults and adolescents aged 12 to 15 years in the UK, which encompasses a broader range of dimensions related to knowledge and attitudes, individual behaviors, and governance (Horry et al. 2023). The Climate Change Attitude Survey, validated for U.S. middle school students (grade 5 through 8), comprises 15 items related only to affective responses to climate change. Although this instrument also includes attitudes and motivation towards climate change, the authors encourage other researchers to utilize their questionnaire as a foundation for the development of a broader CCL instrument, which also encompasses dimensions related to knowledge and behaviors (Christensen and Knezek 2015). A recent validation study conducted in a Spanish setting provides evidence that climate change competencies, including knowledge, skills and attitudes, can be meaningfully assessed through questionnaire methods among children aged 10 to 12 when constructs and items are developmentally appropriate (Ortega-Quevedo et al. 2024). Collectively, these instruments provide important foundations for measuring climate-related knowledge, attitudes, capability and behavior. However, despite the importance of assessing the impacts of CCE in primary school, very few studies have dealt with the urgent issue of developing and validating a CCL assessment tool for children in late primary education, and, to our knowledge, none in a Danish context.

The scarcity of validated CCL instruments for younger children may also reflect broader uncertainty about how climate change education should be introduced and assessed in late primary education. In Denmark, climate change education is increasingly addressed through school-based and practice-oriented initiatives. Examples include *Den Grønne Rygrad*, which supports practice-based climate and sustainability education in Danish compulsory schools, *Grøn Skole*, which supports schools' work with environmental and sustainability education, and *Haver til Maver*, a school garden programme that engages children in hands-on activities related to food, nature and sustainability (*Den Grønne Rygrad*, 2024n.d.; *Grøn Skole*, 2024n.d.; *Haver til Maver*, 2024n.d.). The implementation of such initiatives creates a methodological need for validated instruments that can assess whether, how and for whom these activities affect children's CCL. Such measures are vital for both researchers, practitioners and policymakers to track changes over time; explore demographic and cultural associations with CCL; measure relationships between CCL and other relevant outcomes; understand the social drivers of climate change; evaluate the effectiveness of activities and interventions aiming to improve climate change mitigation and adaptation efforts in schools and other settings; and to guide evidence-based policy development in this area.

1.3. Study objectives

The aim of this study was to develop, test and validate an age-appropriate questionnaire to measure CCL in children aged 10 to 11 in a Danish context, operationalized across the 4 domains: Self-perceived knowledge, Behavior, Motivation, and Systemic and collective orientation. The study examined whether this 4-domain structure was supported by evidence from item development, pretesting, expert assessment and psychometric validation, with the overall aim of providing an instrument for research and evaluation of climate change education initiatives in Danish primary school settings.

2. Methods

2.1. Procedure

The questionnaire was developed and validated in two phases ([Figure 1](#)) inspired by recent best practices for developing and validating scales for health, social, and behavioral research (Boateng et al. [2018](#)). The first phase involved specifying a conceptual definition, item development, pretesting, initial factor structure analysis, focus group cognitive interviews, and expert assessments. The second phase involved investigation of the questionnaire's psychometric properties in a larger, independent validation sample. The study constitutes a sub-study of the FoodACT research study, which aims to evaluate a school garden program on pupils' food literacy, CCL, physical activity, and school motivation (Stage et al. [2025](#)).

2.2. Phase I: development

2.2.1. Initial item and scale development

The development of items was inspired by the UNESCO framework for literacy, in which literacy is defined as 'a means of identification, understanding, interpretation, creation, and communication in an increasingly digital, text-mediated, information-rich and fast-changing world' (UNESCO [2025](#)) (para. 2). Building upon this broad understanding of literacy, and the conceptualization of CCL outlined in the Introduction, a literature search was conducted to identify existing questionnaires that aligned with our conceptual definition. Authors were contacted where necessary to obtain questionnaires, which allowed us to identify items insufficiently covered in the existing literature and generate new items where relevant. A first draft of 26 items was guided by our conceptualization and inspired by the most relevant existing instruments such as the Climate Change Capability Scale (Horry et al. [2023](#)), and the Climate Change Attitude Survey (Christensen and Knezek [2015](#)). However, there was a need to adapt items at a linguistic, contextual and topical level to ensure relevance and comprehensibility for Danish children aged 10 to 11. The initial draft included the provisional dimensions of Self-perceived knowledge, Motivation and Behavior as these were heavily represented in the existing literature as closely connected in the quest for concrete climate change action (Azevedo and Marques [2017](#); Johnston [2020](#)). A separate domain concerning systemic and collective aspects of climate change was not specified at this stage, but the item pool included some items

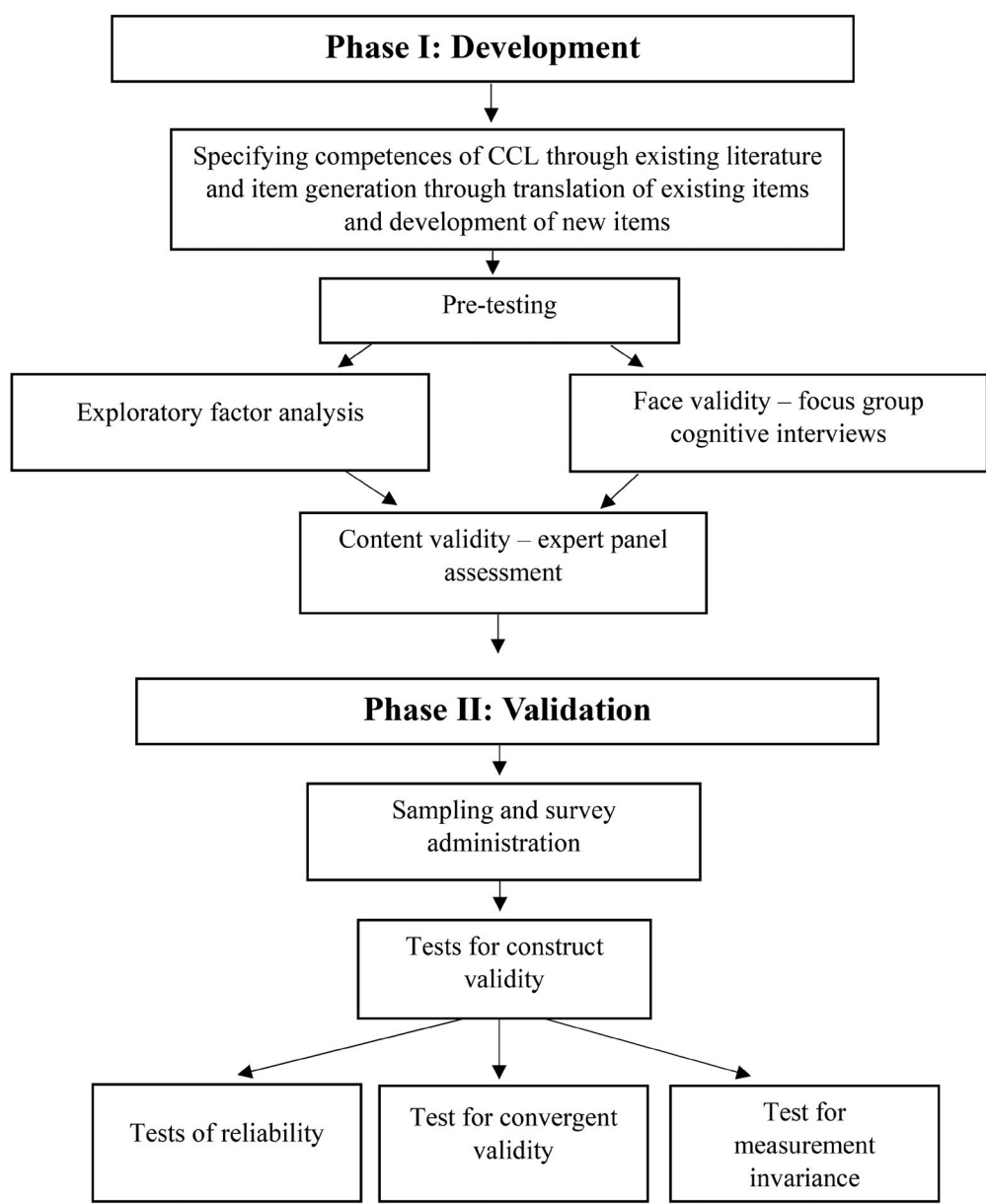


Figure 1. Overview of study phases and subcomponents.

addressing broader social, interpersonal and cross-contextual aspects of climate change. Emphasis was placed on the need for the questionnaire to address the complex linkages between climate change and individual and societal actions (Calvin et al. 2023) whilst remaining age-appropriate, concrete and relevant to children's everyday contexts. Items represented fallible and contextually situated indicators of the broader latent domain, rather than exhaustive or universal representations of e.g. all climate change knowledge children should possess. Items were subsequently allocated to either the Self-perceived knowledge domain (9 items), Motivation domain (9 items) or Behavior domain (8 items).

The Self-perceived knowledge items were formulated to reflect a broad and age-appropriate understanding of climate change guided by Bofferding and Kloser (2015) distinction between system, action and effectiveness knowledge. For children aged 10 to 11, such knowledge should include not only basic mechanisms of anthropogenic climate change but also concrete and age-appropriate examples of consequences, mitigation, and adaptation-related practices because these examples help children connect abstract climate processes to everyday practices in a Danish context (Bofferding and Kloser 2015; Monroe et al. 2019; Ortega-Quevedo et al. 2024). At a thematic level, a few items captured more abstract reasoning on the drivers of climate change, whereas the majority was based on concrete knowledge that our target group was likely to encounter in school, family and media, such as isolated drivers of climate change (e.g. air pollution), contrary to older students where the domain could reasonably be operationalized through more abstract and systemic content, including uncertainty, governance, climate justice and comparative assessments of mitigation effectiveness. In the initial draft, items assessed the degree to which a statement could be considered 'correct,' utilizing the response categories: to a very low degree (1), to a low degree (2), to a high degree (3), to a very high degree (4). The domain should thus be interpreted as children's perceived correctness of climate-related statements rather than as objective factual knowledge.

Items in the Motivation domain were formulated to capture developmentally relevant attitudes, values and motivational orientation toward climate change. Abstract political commitment or detailed reasoning about climate policy was not considered age-appropriate, whereas evaluative orientation toward climate action, including perceived importance, concern and willingness to contribute to everyday contexts was emphasized. This aligns with climate change education literature emphasizing affective, participatory and action-oriented dimensions of learning, and with environmental behavior research showing that motivation, attitudes, perceived responsibility and perceived behavioral control are relevant for pro-environmental engagement (Ajzen 1991; Fleeson 2004; Kollmuss and Agyeman 2002; Monroe et al. 2019; Rousell and Cutter-Mackenzie-Knowles 2020). The items used a 4-point agreement response scale ranging from strongly disagree (1), somewhat disagree (2), somewhat agree (3), and strongly agree (4).

Items in the Behavior domain were formulated to assess children's self-reported engagement in concrete, daily and age-appropriate climate-relevant behaviors within a Danish context. Item content was selected to reflect practices that children aged 10 to 11 could reasonably recognize, participate in or influence within Danish school and family contexts, including consumption, food, waste, transport and family practices. The aim was not to assess children's independent control over high-impact mitigation choices, household consumption patterns or civic and political action, which were considered less proximal and less aligned with the typical decision-making autonomy of this age group. This choice is consistent with climate change education literature emphasizing personal relevance, action-oriented learning and children's participation in responses to climate change, while also acknowledging that children's behavior is shaped by habits, family routines and contextual constraints (Kaiser and Fuhrer 2003; Kollmuss and Agyeman 2002; Monroe et al. 2019; Nepraš, Strejčková, and Kroufek 2022). Items utilized a frequency response scale of never (1), rarely (2), often (3), and always (4).

Although motivation and behavior are closely related, they were treated as separate domains during item development as they represent different aspects of CCL. Motivation captures children's motivational orientation and perceived importance toward climate change learning and action, whereas Behavior captures self-reported engagement in concrete everyday behaviors. This distinction is consistent with research showing that behavior is shaped by, but not reducible to, motivation, attitudes, perceived behavioral control, habits and contextual conditions (Ajzen 1991; Fleeson 2004; Kollmuss and Agyeman 2002).

Across domains, short 4-point response scales with verbally labeled response options were used to reduce cognitive burden while preserving meaningful response graduation for 10 to 11-year-old children. This choice was informed by methodological research indicating that response quality in children is affected by the number of response options, and the clarity of response labels, and that verbally labelled response options are preferable because children may have limited understanding of purely numerical response formats (Borgers, Sikkel, and Hox 2004; Coombes et al. 2021; Mellor and Moore 2014). No central 'Don't know' category was included as opinions on the methodological advantages or disadvantages of an odd number of categories for symmetrical scales are divided (Fayers and Machin 2007), and we therefore preferred pupils to be encouraged to form an opinion on the question. Item selection was guided by a content-validity rationale: each item had to reflect a theoretically relevant aspect of the target domain, be concrete and comprehensible for children aged 10 to 11, be relevant to Danish primary school and everyday contexts, and be answerable without requiring advanced scientific, political or economic reasoning. The items were thus not intended to represent the full complexity of CCL, but to function as age-appropriate indicators that collectively operationalize aspects of CCL relevant to children aged 10 to 11 in a Danish context. An overview of items, domain allocation and intended indicator rationale is provided in [Supplementary Material A](#).

2.2.2. Pretesting and face validity

The first draft questionnaire was discussed amongst the authors followed by an informal preliminary target group evaluation in a convenience sample of 7 children of colleagues and family. Minor alterations were made to the wording of selected items to increase comprehensibility and acceptability. The questionnaire was subsequently piloted in the spring of 2023, which involved pretesting, focus group cognitive interviews, initial factor structure analysis and expert assessments. The aim was to assess whether the target group found the questionnaire acceptable, comprehensible, relevant, and unambiguous prior to administering it at large scale (Boateng et al. 2018).

2.2.2.1. Participants. A development sample of 168 4th grade pupils (aged 9 to 11) from two schools in Frederiksberg, Denmark was recruited for phase I ([Figure 2](#)). Written informed consent was obtained from the legal guardians of 135 out of 168 pupils (80.4%). At the time of pretesting, 130 of the 135 pupils completed the questionnaire (96.3%).

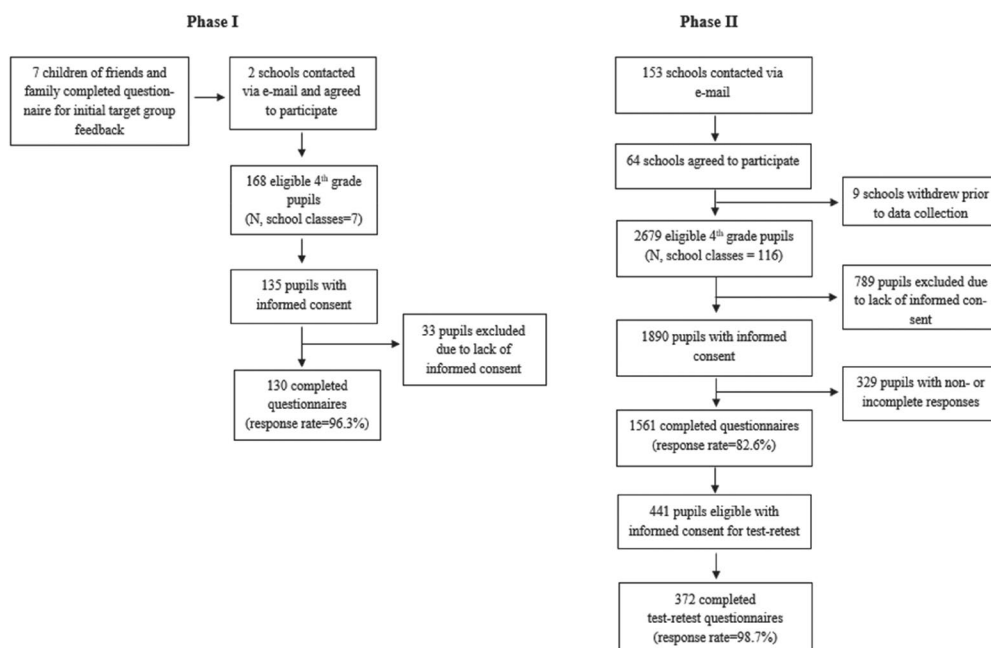


Figure 2. Flowchart of participant recruitment and response rates for phase I and II.

2.2.2.2. Pretesting. Pupils completed the questionnaire ([Supplementary Material A](#)) during a regular school session in the presence of a teacher and two researchers. The questionnaire was completed individually on laptops in the electronic questionnaire program SurveyXact (Rambøll Management, Consulting version 6.10, Copenhagen, Denmark). An instructional video (duration of 40 seconds) was provided at the beginning of the questionnaire to clarify the procedure. Pupils were instructed that it was not a test, and that there were no wrong answers. The researchers observed which questions, response options, and/or issues related to the electronic format prompted pupils to raise their hands for assistance.

2.2.2.3. Focus group cognitive interviews. Focus group cognitive interviews were conducted to enhance face validity, i.e. that items reflect the intended domain of study and are meaningful to the target group. A total of 7 focus groups of approx. 45 minutes were facilitated immediately after the pretest with subsamples of 5 to 6 pupils from each school class. The aim was to explore the pupils' comprehension of and attitude towards items, format, and response categories (Boateng et al. 2018). To ensure full coverage of the target population, a teacher purposefully selected participants, including boys and girls with varying academic abilities. An interview guide was used to facilitate the discussion of targeted items as well as more general questions, whilst non-verbal communication, key opinions and interactions were observed. Potential modifications were proposed to single words, phrases, and whole sentences to explore whether these increased the clarity of items. The interview guide and condensed field notes are enclosed in [Supplementary Material B](#).

2.2.2.4. Exploratory factor analysis. Exploratory Factor Analysis (EFA) was conducted on data from the pretest to statistically examine the initial underlying factor structure. Although our conceptual definition initially hypothesized 3 main domains of CCL, the EFA allowed for examining unexpected structures that could explain a pattern of correlations between the proposed items (Fayers and Machin 2007). The suitability of data for factor analysis was assessed using the Kaiser-Meyer-Olkin (KMO) test of sampling adequacy (value greater than 0.6) and Bartlett's test of sphericity (p-value above 0.05). The number of factors was determined through a combination of retaining factors with Eigenvalues greater than 1 and a Scree Plot. Principal Axis Factoring was used as extraction method with Promax Rotation (Costello and Osborne 2019). Items that did not load uniquely on any factor and items with cross-loadings > 0.25 were removed through iterations. Items with factor loadings of 0.40 and above were retained, whereas items with loadings below this threshold were considered for removal or re-examination (Boateng et al. 2018). As there is limited existing evidence on instruments measuring CCL in children aged 10 to 11, and since a sample of 200 to 300 participants is usually recommended for factor analysis (Boateng et al. 2018), the proposed internal structure was critically reviewed based on coherence with our conceptual definition and results from focus group assessments. Analyses were performed in IBM SPSS Statistics (version 29.0.1.0; IBM Corp). Adjustments based on this step and focus group interviews were made simultaneously, which resulted in a second draft questionnaire of 29 items ([Supplementary Material A](#)).

2.2.3. Expert assessments

To enhance the content validity, i.e. the extent to which items are sensible and reflect the intended domain of the study, an expert panel was recruited to critically assess content relevance, representativeness, and technical quality (Boateng et al. 2018; Fayers and Machin 2007). 6 experts from varying disciplines, including climate change and sustainability education, health promotion, and psychometrics in relation to children were invited. Experts were asked to review the theoretical foundation of each domain, as well as the appropriateness, interpretability, applied and contextual relevance of items in the second draft questionnaire. If deemed necessary, reviewers could propose new items. Comments and suggestions were summarized into a single draft for comparison of feedback. Proposed modifications were either accepted, rejected, or adapted based on the highest possible degree of coherence with other reviewer comments. Based on this, a final draft questionnaire of 32 items was constructed for further validation in phase II ([Supplementary Material A](#)).

2.3. Phase II: validation

2.3.1. Participants

An independent validation sample of primarily 4th grade pupils and 2 school classes of 3rd grade pupils (aged 8 to 13) from the regions of Zealand, Greater Copenhagen, and Southern Denmark was recruited in the fall of 2023 to determine and confirm the acceptability, validity, sensitivity, responsiveness, reliability, and general applicability of the final draft questionnaire in a large representative sample (Fayers and Machin

2007). For detailed information on power analysis and sample size calculations, please refer to the FoodACT study protocol (Stage et al. 2025). A total of 153 public schools were contacted by e-mail and 56 schools agreed to participate (116 school classes). The recruitment strived to ensure gender parity, socioeconomic and geographic representativity. Prior to data collection, informed consent was obtained from the legal guardians of 1890 out of 2679 pupils (70.5%). A total of 1561 pupils completed the questionnaire (82.6%). A subsample of 15 schools (29 school classes, 441 pupils) from the total sample were invited for a retest approx. one week after the first test. A total of 372 pupils completed the retest (84.4%). Figure 2 depicts the sampling of participants and response rates in phase I and II. School classes were offered a voucher (value of 1500 DKK) for their participation.

2.3.2. Procedure

The final draft questionnaire was administered electronically in SurveyXact (Rambøll Management, Consulting version 6.10, Copenhagen, Denmark) along with 2 other study measures used for a different study (food literacy and school motivation) during a single school session in the spring of 2024. The full questionnaire took an average of 22 minutes to complete with the CCLQ placed between the food literacy and school motivation questionnaires. The procedure was similar to the pretest; however, no researchers were present during administration of the questionnaire, leaving the teachers at the participating schools responsible for overseeing the completion.

2.3.3. Other measures: sustainable food literacy

To test for convergent validity, pupils were administered a subscale of the Food Literacy Questionnaire for Schoolchildren (FLQ-sc) measuring sustainable food literacy (Stjernqvist et al. 2021), which we expected to be correlated with CCL. The FLQ-sc consists of 37 items across 5 subscales derived from Benn's (2014) model of food literacy. The FLQ-sc sustainable food literacy subscale consists of 6 items related to sustainable food production, consumption, waste, and animal welfare. Items followed a Likert-scale reflecting opinion from 1 (strongly disagree) to 4 (strongly agree), with a score of 4 indicating the highest possible score. A total subscale score was calculated by the mean score of items with each item weighing equally.

2.3.4. Background variables

Information on the age and gender of pupils as well as parental socioeconomic status (SES) was obtained by self-reports from parents at the time of informed consent. Age was measured by the item: 'What is the birthdate and -year of your child?' and constructed as a continuous variable indicating age in years at baseline (1 March 2024). Gender was measured by the item 'What is the gender of your child?' with the response categories 'Girl', 'Boy' or 'Other.' SES was coded using the Danish Occupational Social Class measurement, which categorizes SES based on the highest ranking parental occupational status from 1 (highest) to 6 (lowest) (Christensen et al. 2014).

2.4. Data analysis

2.4.1. Scale descriptives

CCL subscale scores were calculated as the mean of items with all items weighing equally. 2 items were negatively worded and reversed prior to combining with remaining items into scale scores. All scales were standardized to a range from 1 to 4, with 4 indicating the highest possible score. A total scale score was estimated by calculating the mean score of the 4 subscale items with each subscale weighing equally. As all scales were additive, item-level missing data would impact validity and reliability analyses. Analyses utilizing a total scale score thus excluded pupils that had not answered all items within all scales ($N=21$). Mean scores, skewness, and kurtosis were calculated for subscales and the total scale in the phase II sample.

2.4.2. Construct validity: investigation of internal structure

Confirmatory factor analysis (CFA) was conducted in 3 different models to assess the fit of the factor structure identified through phase I (Boateng et al. 2018). The fit of a confirmatory bifactor (4-factor) model with an underlying global factor (Model 2 in Figure 3) was compared with 2 alternative models, i.e. a unidimensional (1-factor) model (Model 1 in Figure 3) and a bifactor model with no underlying global factor (Model 3 in Figure 3). The aim was to evaluate whether the 2 alternative models significantly improved the fit of the preferred Model 2. The models were fitted in 2 rounds to ensure that model fit indices improved upon removal of items that showed either poor loadings on the primary factor or cross-loadings with other factors. Model fit indices used to compare the 3 models were chi-square statistics (χ^2), comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA) and standardized root mean square residual (SRMR), with the following cut-off criteria for an acceptable model fit: $\chi^2/df < 5.00$, $CFI \geq 0.95$, $TLI \geq 0.95$, $RMSEA \leq 0.06$, and $SRMR \leq 0.08$ (Boateng et al. 2018; Hu and Bentler 1999). Standardized factor loadings ≥ 0.50 indicated a meaningful relationship between the item and its corresponding factor, whereas loadings between

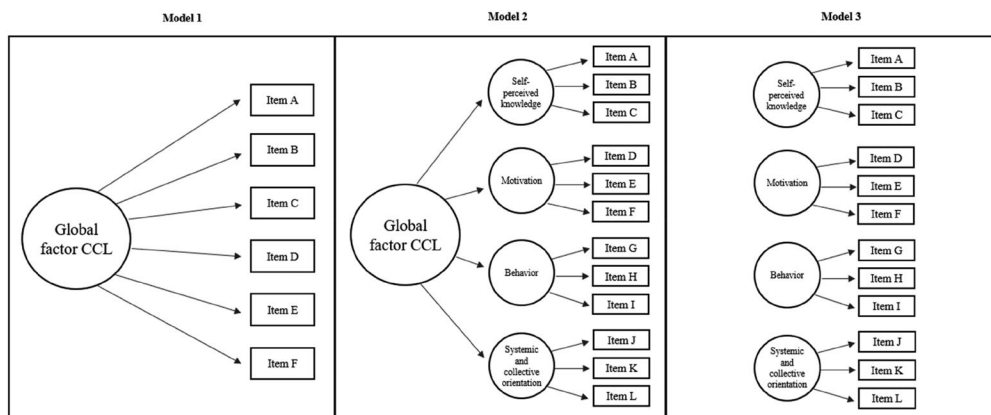


Figure 3. Comparison of 3 models for confirmatory factor analysis. Model 1 illustrates a unidimensional model, Model 2 illustrates a confirmatory bifactor model with an underlying global factor, and Model 3 illustrates a bifactor model without an underlying global factor.

0.30 and 0.49 were compared to other internal validity measures before any decisions on removal. Items with very poor loadings (≤ 0.30) were excluded (Boateng et al. 2018; Hu and Bentler 1999). The 3 models were fitted in 2 sequences; the first round fitted all 3 models using the 32 original items, whereas the second round fitted the models after removal of 2 items with poor loadings on their primary factor. Analyses were performed using the R package, Lavaan (Rosseel 2012), accounting for the ordinal nature of data and utilizing Maximum Likelihood to estimate the parameters.

Pearson's R correlation analysis was conducted to assess the relationship between the subscales. Correlation coefficients <0.1 were considered trivial, 0.10 – 0.29 small, 0.30 – 0.69 moderate, and ≥ 0.70 high (Boateng et al. 2018). We expected the subscales to be conceptually related, i.e. reflecting different aspects of the overarching construct of CCL, and therefore to exhibit moderate correlations. Positive correlations (i.e. high scores on one subscale associated with high scores on another) and moderate strength correlations (i.e. scales are related but distinct) were considered evidence of construct validity. Conversely, low or no correlations between subscales would suggest limited construct validity. P-values <0.01 were considered significant. Analyses were conducted in SPSS Statistics 23 (IBM Corp, Armonk, NY, USA).

2.4.3. Reliability tests

Reliability tests were conducted to determine the degree of reproducibility and consistency in the questionnaire (Boateng et al. 2018). The internal consistency of each subscale was investigated by estimating Cronbach's α and McDonald's Ω coefficients. A threshold of 0.70 and above indicated acceptable reliability, however coefficients between 0.80 and 0.95 were preferred for psychometric quality (Fayers and Machin 2007). Test-retest reliability was assessed using intraclass correlation coefficient (ICC) in a 2-way mixed model with absolute agreement type. A high level of agreement between the repeated measurements would indicate a high reliability ($ICC \geq 0.75$), whereas a high degree of random variability ($ICC \leq 0.75$) would indicate the opposite (Boateng et al. 2018). Analyses were conducted in SPSS Statistics 23 (IBM Corp, Armonk, NY, USA).

2.4.4. Convergent validity: investigation of the associations with other variables

Convergent validity was assessed as the extent to which the total CCL score and subscale scores were positively associated with the FLQ-sc sustainable food literacy subscale score (Fayers and Machin 2007). We performed 5 linear mixed models adjusted for gender, age and clustering in school classes to assess the relationship between the FLQ-sc subscale as the dependent variable and the 5 CCL scales as independent variables. Analyses were conducted on data from all participants in phase II with complete responses on the scales that were compared. P-values <0.05 were considered significant. Analyses were conducted in SPSS Statistics 23 (IBM Corp, Armonk, NY, USA).

2.4.5. Measurement invariance

Measurement invariance was investigated to determine the extent to which the underlying factor structure was consistent across gender and SES (Boateng et al. 2018). CFA was performed sequentially at 3 levels - configural, metric, and scalar - using the

R package, Lavaan (Rosseel 2012). For this purpose, SES was categorized into low (group 5 and 6), middle (group 4 and 3) and high (group 2 and 1). The configural model examined whether the hypothesized factor structure was similar across the investigated groups. The metric model checked whether the factor loadings were consistent across gender and SES. The scalar model examined whether the item intercepts were similar across gender and SES groups. An adequate configural invariance indicated a similar factor structure across groups, whereas adequate metric invariance indicated similar factor loadings across groups, and adequate scalar invariance indicated that groups start from the same baseline when completing the questionnaire (Boateng et al. 2018). Stability in the model fit between the 3 levels of invariance indicated that their respective invariance assumption (configural, metric, or scalar) hold, and that any observed differences in scores reflect true differences in the construct and not measurement bias. The following cut-off criteria were used: $\chi^2/df < 5.00$, CFI ≥ 0.95 , TLI ≥ 0.95 , RMSEA ≤ 0.06 , and SRMR ≤ 0.08 (Boateng et al. 2018; Hu and Bentler 1999).

2.5. Ethical considerations

The study adhered to the European General Data Protection Regulation. The study was exempted of an ethics approval by the Regional Committee on Research Ethics as it did not include any biomedical samples or risks to participants (Reference no. H-23010743) (Israel and Hay 2006). Pupils were informed that their participation was voluntary and anonymized, and of the option to withdraw at any time upon request. The study was preregistered as part of the FoodACT research study at ClinicalTrials.gov (Reference no. NCT05839080).

3. Results

3.1. Socio-demographic characteristics

A total of 130 pupils completed the full questionnaire in phase I (no incomplete responses), 1561 in phase II (22 incomplete responses) and 372 in retesting (5 incomplete responses). As depicted in Table 1, participants in phase II were evenly distributed

Table 1. Socio-demographic characteristics of participants in phase I, II and retesting.

Characteristic	Phase I (N=130)	Phase II (N=1561)	Retesting (N=372)
		N (%)	
Gender			
Girl	77 (59.2)	802 (51.4)	210 (56.5)
Boy	53 (40.8)	758 (48.6)	162 (43.5)
Other	0 (0.0)	1 (0.1)	0 (0.0)
Age (Mean, SD)	10.89 (0.30)	10.26 (0.51)	10.30 (0.47)
SES			
Social class I	–	756 (48.4)	147 (39.5)
Social class II	–	390 (25.0)	99 (26.6)
Social class III	–	156 (10.0)	52 (14.0)
Social class IV	–	170 (10.9)	54 (14.5)
Social class V	–	43 (2.8)	10 (2.7)
Social class VI	–	34 (2.2)	10 (2.7)

Note. Missing data on SES in phase II, N=12 (0.8).

on gender (51.4% girls), whereas a slight skewness towards girls was evident in phase I and retesting, potentially due to the smaller sample sizes (phase I = 59.2%, retesting = 56.5%). The mean age of participants was 10.89 years (SD = 0.30) in phase I, 10.25 years (SD = 0.51) in phase II and 10.30 years (SD = 0.47) in retesting. Most pupils in phase II and retesting were in the highest SES group (phase II = 48.4%, retesting = 39.5%), whereas no information on SES was gathered for phase I due to its preliminary scale.

3.2. Phase I: development

3.2.1. Face validation: focus group cognitive interviews

The focus groups revealed some confusion around terms and words in some items belonging to the Self-perceived knowledge and Motivation domains. Item 1 ('Our planet has unlimited resources') was excluded as pupils did not understand the general intention of the item. Item 8 ('Only humans cause climate change') was excluded as pupils found the nature of the question ambiguous. Item 18 ('It is important to me to learn about the environment and climate change') and item 25 ('I want to take care of the nature and its resources') were considered too similar and revised for improved discrimination. Item 4 ('Air pollution is a problem in Denmark') was removed as pupils only found it relevant in the context of other countries. Lastly, item 19 ('I feel concerned about climate change') was removed due to ethical considerations that an emotional state of concern could be prompted in the pupils when considering the question. In general, pupils expressed positive experiences with the online format of the questionnaire, as well as the use of scaled response options. Some pupils requested a middle category of 'Don't know,' however, as described in the Methods section, we found an even number of categories preferable so that pupils were encouraged to form an opinion on the question.

3.2.2. Exploratory factor analysis

The final EFA revealed a 3-factor model with a total of 17 items with factor loadings above 0.40 ([Supplementary Material C](#)). Most items that had initially been assigned to either the Motivation or Behavior domain loaded on the same factor. However, because Motivation and Behavior had been defined as different dimensions of CCL, it was not considered conceptually meaningful at this stage to combine them into one single domain.

Results further indicated a distinct cluster of items that did not fit meaningfully within the initial 3 domains. The content of these items reflected systemic, interpersonal and collective aspects of climate change, capturing an awareness that climate change is an issue beyond individual knowledge, motivation and behavior. This aligned with research indicating that pro-environmental engagement is shaped not only by knowledge, values and perceived responsibility, but also other-regarding orientations such as empathy and concern for others (Kollmuss and Agyeman 2002). Based on the empirical and conceptual agreement, the cluster was labelled *Systemic and collective orientation* and included as a provisional fourth domain in the second draft of the questionnaire for further validation. A 4-point agreement response scale was used ranging from completely disagree (1), somewhat disagree (2), somewhat agree (3), and completely agree (4).

The collective revisions from the EFA results and focus groups resulted in 9 items eliminated and 12 new items introduced, as well as some general modifications to wordings of items. The second draft questionnaire distributed for expert assessments thus consisted of 4 domains: Self-perceived Knowledge (7 items), Motivation (6 items), Behavior (9 items), and Systemic and collective orientation (7 items) ([Supplementary Material A](#)).

3.2.3. Content validation: expert assessments

Expert assessments yielded some debate on the conceptual differentiation between climate change, environment, nature, and sustainability. As climate change is inherently linked to issues such as environmental change, biodiversity, and sustainable consumption, we retained items that were relevant for climate change whilst being directly or indirectly related to a variety of these challenges, e.g. item 10 ('I turn off the water tap while brushing my teeth'). Other proposals included replacing 'I eat more vegetarian' in item 11 with 'I eat more fruits/vegetables', as the former could be interpreted too categorically by the target group. To capture the choice of excluding meat from the diet in consideration of the climate, the item was instead revised to 'I eat less meat.' An increased use of examples when mentioning terms or settings was further suggested to connect the item with a concrete everyday context, e.g. in item 7, 21 and 25. It was proposed to modify item 22 ('I like to talk to my family or friends about climate change') as some children may avoid the subject due to worry or anxiety, and 'I like to' was thus replaced with 'I think it is important to'.

Several revisions concerned the alignment between item wording and the intended interpretation of the domain. In the Self-perceived knowledge domain, experts noted that asking children to indicate the extent to which statements were 'correct' could be interpreted as an objective knowledge test, although it was designed as a self-report measure. To strengthen the alignment between item wording and interpretation as self-perceived knowledge rather than factual knowledge, response categories were revised to a 4-point difficulty scale assessing children's perceived ease or difficulty in explaining, mentioning or giving examples of climate-related topics. In the Behavior domain, the stem 'for the sake of the climate' was added to distinguish climate-relevant behavioral orientation from behavior frequency alone, as the same behavior may be performed for several reasons, and the frequency scale was altered to include less extreme end-scale categories.

Finally, experts supported the relevance of the newly introduced Systemic and collective orientation domain for both the Danish educational context and the target group as well as the conceptual distinction from Self-perceived knowledge, Motivation and Behavior. However, minor refinements of item wordings and new items were introduced to ensure that the domain captured children's age-appropriate orientation toward social, collective and cross-contextual aspects of climate change, rather than implying advanced systems thinking.

In total, 7 new items were introduced while 4 were excluded across the 4 domains. Minor changes to the wordings of selected items and response categories were further accepted to improve clarity and comprehension. Together with revisions informed by the EFA and focus groups, these changes resulted in a 32-item final draft questionnaire

across 4 domains: Self-perceived knowledge (10 items), Motivation (7 items), Behavior (9 items), and Systemic and collective orientation (6 items) for phase II testing and retesting in an independent validation sample ([Supplementary Material A](#)).

3.3. Phase II: validation

3.3.1. Item reduction and investigation of internal structure

The initial CFA indicated that a bifactor model with an underlying global factor was the most appropriate structure for assessing CCL among children aged 10 to 11. Out of the 32 factor loadings, 30 met satisfactory criteria, ranging from 0.44 to 0.79. However, 2 items were removed due to inadequate loadings: the loading for item 12 ('I am tired of hearing about climate change') fell between 0.30 and 0.40, and the loading for item 29 ('I believe that technology alone can stop climate change, for example electric cars and wind turbines') was negative, presumably due to respondents misunderstanding its negative wording. The reduced 30-item questionnaire showed an acceptable fit for our preferred Model 2 (bifactor model with a global factor, CFI = 0.983, TLI = 0.981, SRMR = 0.055, RMSEA = 0.048 (0.046;0.051) with fit indices exceeding the established cut-off criteria and which were distinctly better than Model 1 (unidimensional model, CFI = 0.918, TLI = 0.912, SRMR = 0.101, RMSEA = 0.105 (0.103;0.107)). [Table 2](#) presents fit indices from CFAs across the 3 models on both the 32-item and 30-item questionnaires. Standardized factor loadings for Model 2 are depicted in [Figure 4](#). First-order standardized factor loadings for the 4 subscales – Self-perceived knowledge (0.58), Motivation (0.90), Behavior (0.82), and Systemic and collective orientation (0.98) – exceeded acceptable thresholds and were statistically significant. Within each subscale, factor loading ranges were as follows: Self-perceived knowledge (0.51–0.78), Motivation (0.68–0.80), Behavior (0.44–0.67), and Systemic and collective orientation (0.60–0.78). Although 4 items within the Behavior subscale fell slightly below the preferred threshold of 0.50, none were below 0.30. Model 3 (bifactor model without an underlying global factor) did not yield a meaningful improvement in fit indices compared to Model 2, and Model 2 was thus retained as the final model for subsequent analyses.

The factor inter-correlation matrix showed positive, moderate correlations between all scales ([Table 3](#)). The strongest association was observed between the Systemic and collective orientation and Motivation domain, approaching the threshold between moderate and strong, whilst the weakest correlation occurred between the Behavior and Self-perceived knowledge domain. These patterns indicate that although the subscales are related, they capture distinct aspects of CCL.

Table 2. Indices for the fit of different models based on confirmatory factor analysis.

Items	Model	χ^2	df	CFI	TLI	SRMR	RMSEA (95% CI)
32	1	7900	464	0.915	0.909	0.098	0.101 (0.099;0.103)
	2	2150	460	0.981	0.979	0.056	0.049 (0.046;0.051)
	3	2031	458	0.982	0.980	0.054	0.047 (0.045;0.049)
30	1	7346	405	0.918	0.912	0.101	0.105 (0.103;0.107)
	2	1868	401	0.983	0.981	0.055	0.048 (0.046;0.051)
	3	1767	399	0.984	0.982	0.054	0.047 (0.045;0.049)

Note. $N = 1561$. chi-square, χ^2 ; degrees of freedom, df; comparative fit index, CFI; Tucker–Lewis index, TLI; standardized root mean square residual, SRMR; root mean square error of approximation, RMSEA.

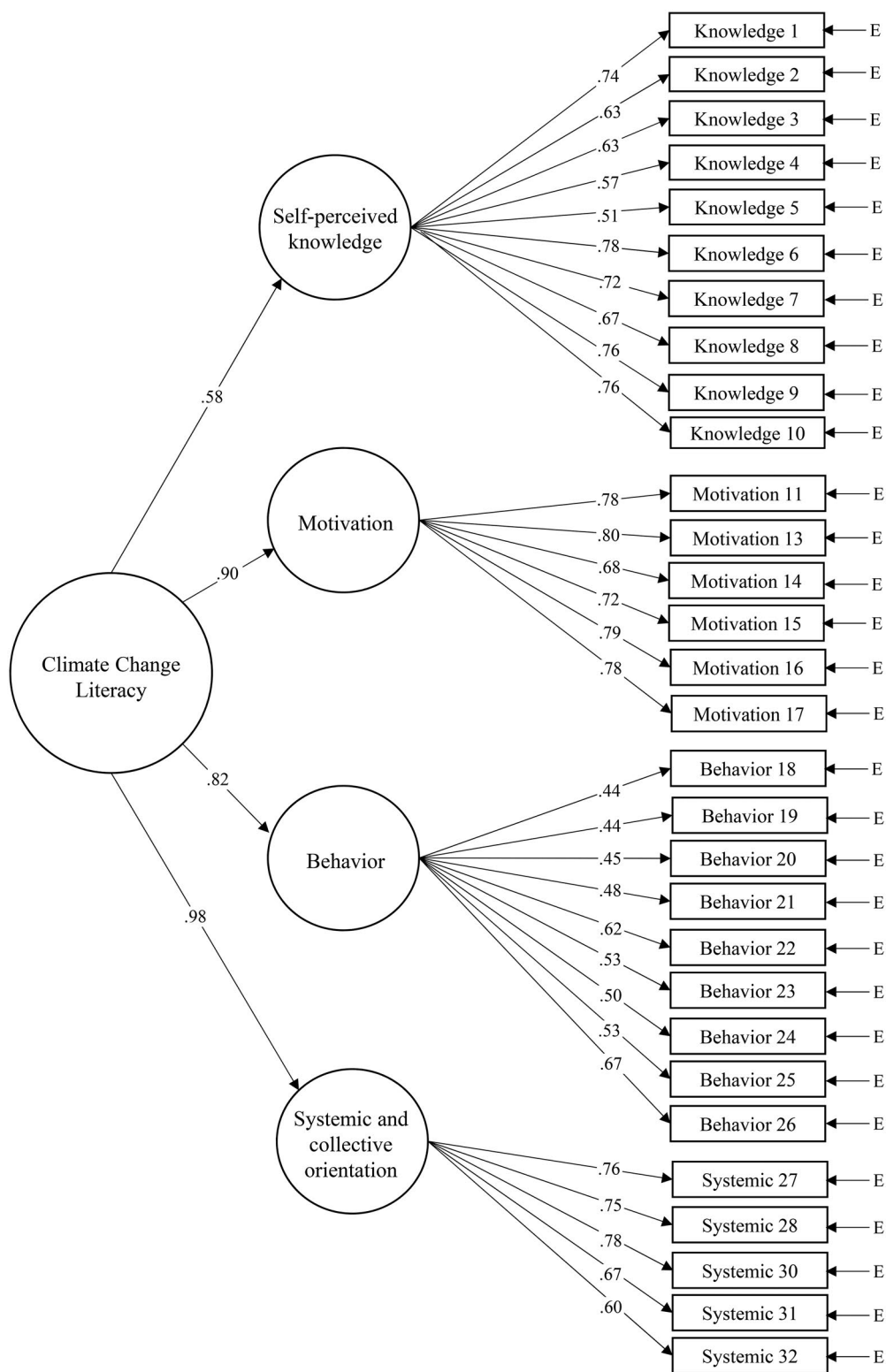


Figure 4. Standardized factor loadings of Model 2 based on confirmatory factor analysis.

3.3.2. Scale descriptives and reliability

Table 4 presents the mean scores, standard deviations, skewness, kurtosis, Cronbach's α and McDonald's Ω coefficients for each scale. Item response distributions from phase II are enclosed in [Supplementary Material D](#). All response categories were generally utilized with only few items showing low use of some response categories. Item 13 and 15 displayed a low use of 'strongly disagree' (2.7% and 2.8%) and 'somewhat disagree' (5.8% and 2.8%), whereas most responses in item 20 were skewed towards the highest category 'always or almost' (79.4%). The Motivation domain exhibited a relatively high mean scale score ($M=3.15$, $SD = 0.60$), while mean scores of the remaining scales were between 2.31 and 2.65 (scale range = 1 to 4). Skewness and kurtosis values were between -0.942 and 0.905 with the range between 0 and 1 suggesting approximate normality within each scale. The global CCL scale demonstrated excellent internal reliability ($\alpha=0.905$, $\Omega=0.903$). Most subscales showed satisfactory internal consistency with α -values between 0.703 to 0.905 and Ω values between 0.696 to 0.903. Although the McDonald's Ω for the Behavior domain was slightly below the threshold of 0.70, it was considered acceptable given its α -value above this threshold. The ICCs for test-retest reliability indicated excellent stability for the global CCL scale ($ICC = 0.90$) and high reliability for the 4 subscales (ICC range = 0.80 – 0.84), indicating high test-retest reliability.

3.3.3. Convergent validity: associations with the FLQ-sc sustainable food literacy subscale

Table 5 shows the results from the 5 linear mixed model regressions investigating the associations between all scales and the FLQ-sc sustainable food literacy subscale. Consistent with our hypotheses, all models demonstrated positive and significant associations between the various CCL scales and the FLQ-sc subscale, indicating that

Table 3. Factor inter-correlation matrix.

	1	2	3	4	5
1. Self-perceived knowledge	1				
2. Motivation	0.393*	1			
3. Behavior	0.391*	0.570*	1		
4. Systemic and collective orientation	0.492*	0.674*	0.515*	1	
5. Total CCL	0.731*	0.827*	0.746*	0.863*	1

Note. $N=1561$, * = correlation is statistically significant at a 0.01 significance level (2-tailed).

Table 4. Scale descriptives and reliability tests.

Scale	Mean (SD)	Min-Max	Skewness (SE)	Kurtosis (SE)	α	Ω	ICC (95% CI)
Self-perceived knowledge (10 items)	2.57 (0.64)	1.00–4.00	−0.108 (0.06)	−0.043 (0.123)	0.866	0.867	0.822 (0.843;0.910)
Motivation (6 items)	3.15 (0.60)	1.00–4.00	−0.942 (0.06)	0.905 (0.123)	0.819	0.823	0.802 (0.756;0.840)
Behavior (9 items)	2.55 (0.48)	1.00–4.00	−0.022 (0.06)	0.075 (0.124)	0.703	0.696	0.844 (0.807;0.873)
Systemic and collective orientation (5 items)	2.31 (0.55)	1.00–4.00	−0.604 (0.06)	0.080 (0.124)	0.789	0.790	0.817 (0.774;0.852)
Total CCL (30 items)	2.65 (0.45)	1.00–3.91	−0.428 (0.06)	0.395 (0.124)	0.905	0.903	0.901 (0.878;0.920)

Note. $N=1561$ (mean, min-max, skewness, kurtosis, α , Ω), $N=372$ (ICC). All scales range from 1 to 4.

Table 5. Linear mixed models adjusted for gender, age, and school class cluster with FLQ-sc sustainable food literacy subscale as dependent variable.

Scale	N	β (95% CI)	p-value
Self-perceived knowledge	1582	0.227 (0.172;0.282)	<0.001*
Motivation	1575	0.477 (0.431;0.522)	<0.001*
Behavior	1564	0.383 (0.346;0.421)	<0.001*
Systemic and collective orientation	1561	0.340 (0.295;0.385)	<0.001*
Total CCL	1561	0.353 (0.318;0.388)	<0.001*

Note. * = correlation is statistically significant at a 0.05 significance level (2-tailed).

Table 6. Indices for the model fit of the three models across gender and SES based on confirmatory factor analysis at the configural, metric and scalar level.

Scalar model	χ^2	df	CFI	TLI	SRMR	RMSEA (95%CI)
Original CFA (Model 2)	1868	401	0.983	0.981	0.055	0.048 (0.046;0.051)
Configural invariance						
SES	2705	1203	0.982	0.980	0.063	0.049 (0.047;0.052)
Gender	2040	802	0.985	0.984	0.059	0.045 (0.043;0.047)
Metric invariance						
SES	3238	1261	0.976	0.975	0.066	0.055 (0.053;0.058)
Gender	2217	831	0.983	0.983	0.061	0.046 (0.044;0.049)
Scalar invariance						
SES	3073	1371	0.980	0.981	0.063	0.049 (0.047;0.051)
Gender	2344	886	0.983	0.983	0.059	0.046 (0.044;0.048)

Note. $N=1561$. chi-square, χ^2 ; degrees of freedom, df; comparative fit index, CFI; Tucker–Lewis index, TLI; standardized root mean square residual, SRMR; root mean square error of approximation, RMSEA.

higher scores in the CCL subscales and global scale were related to higher scores in the FLQ-sc subscale.

3.3.4. Measurement invariance

Measurement invariance analyses demonstrated acceptable model fit indices across the configural, metric and scalar models for both gender and SES (Table 6). This indicates that the bifactor model with an underlying global factor (Model 2) exhibits consistent factor structures across gender (CFI range = 0.976–0.982, TLI range = 0.975–0.981, SRMR range = 0.063–0.066, and RMSEA range = 0.045–0.046), and SES (CFI range = 0.983–0.985, TLI range = 0.983–0.984, SRMR range = 0.059–0.061, and RMSEA range = 0.045–0.046). The stability of model fit across the 3 levels of invariance supports the assumptions of configural, metric and scalar invariance, suggesting that any observed group differences in scores reflect true differences rather than measurement bias.

4. Discussion

This study addressed an important gap in the development and validation of questionnaires measuring CCL in children. Using both qualitative and quantitative approaches across 2 phases with a total of 1691 pupils, we developed and validated the 30-item *Climate Change Literacy Questionnaire* (CCLQ) for children aged 10 to 11 in a Danish context. The psychometric analyses showed that a bifactor model with a global CCL factor and 4 domain-specific factors provided the best fit to the empirical data (Boateng et al. 2018). The first-order standardized factor loadings for the

4 subscales - Self-perceived knowledge (0.58), Motivation (0.90), Behavior (0.82), and Systemic and collective orientation (0.98) - showed acceptable, statistically significant levels, indicating robust relationships between each domain and the underlying global factor. Although the Self-perceived knowledge domain exhibited a somewhat lower first-order loading (0.58), it remained within the acceptable range, confirming its meaningful contribution to the overall construct. Results from Pearson's R correlation analyses also showed positive, moderate associations between all subscales and positive, strong associations between subscales and the global scale, indicating that each subscale captures unique but conceptually related aspects of CCL. These findings are consistent with development and validation studies of CCL-related instruments, which demonstrate a need for instruments that measure climate change competences across multiple domains, including among pre-teens (Azevedo and Marques 2017; Horry et al. 2023; Ortega-Quevedo et al. 2024). Based on this, we encourage the examination of CCL through both the global scale and the 4 subscales. However, the CCLQ should not be interpreted as an exhaustive measure of all possible outcomes of climate change education, nor as a direct test of objective factual knowledge or advanced systems thinking. Rather, it provides a validated age-appropriate measure of CCL for research and evaluation of climate change education in Danish primary school settings.

The reliability of all scales indicated acceptable to excellent levels, with the Behavior domain showing a slightly lower Ω -coefficient (0.696) yet an acceptable α -value (0.703). This was not considered problematic as values slightly below the threshold of 0.70 are generally accepted in initial stages of developmental research (Streiner 2003). Moreover, Cronbach's α and McDonald's Ω tests deliver only snapshots of the internal consistency reliability, whereas the high test-retest reliability across all scales provided support for the temporal consistency of the questionnaire. In general, our results broadly align with the reliability reported for the 6 climate capability subscales in Horry et al. (2023), which encompasses knowledge, scepticism, behavior, role of governance, information seeking and self-efficacy in adolescents aged 12 to 15 (Horry et al. 2023). The observed positive and significant associations between all CCL scales and the FLQ-sc sustainable food literacy subscale underscored a meaningful convergent validity of our proposed measurement model, particularly in relation to everyday practices such as food consumption, waste and sustainability-oriented decision-making. In other words, children with higher CCL were also likely to exhibit higher sustainable food literacy, which is consistent with the conceptual relatedness of CCL and sustainable food literacy, further validating the utility and relevance of the CCL construct.

The focus on children aged 10 to 11 is important because climate-related perceptions, concerns and misconceptions may emerge before adolescence, while children's conceptual understanding, emotional responses and perceived agency are still developing. CCL in late primary education thus needs to be understood in relation to children's everyday experiences, cognitive capacities, social contexts and opportunities for agency. Previous research suggests that children in primary education can engage meaningfully with climate change as a socio-scientific issue, but that their understanding of causes, consequences and possible responses may still be developing (Lee et al. 2020; Sjöblom et al. 2022). Systematic reviews further show that climate change education in primary education often addresses knowledge, actions, experiences and attitudes, and that effective approaches tend to be personally relevant,

participatory and action-oriented (Monroe et al. 2019; Nepraš, Strejčková, and Kroufek 2022). This supports the need for age-appropriate assessment tools that examine dimensions of CCL meaningful in late primary education, rather than relying on measures developed for adolescents or adults.

Several domain-specific findings warrant interpretation in relation to the age group, self-report format and existing climate change education literature. Self-perceived knowledge should not be interpreted as an objective test of climate change knowledge, but as an indicator of children's perceived understanding, confidence and familiarity with climate change causes, consequences and possible responses. Although the items do not objectively assess factual correctness, their content aligns with distinctions between system knowledge (item 1 to 5), action knowledge (item 6 to 8) and effectiveness knowledge (item 9 to 10). This distinction is important as climate-relevant knowledge involves not only factual knowledge, but also whether climate change is perceived as understandable and connected to actions in everyday contexts (Bofferding and Kloser 2015). We expected a high mean scale score within this scale as children today face a more potent focus on climate change in both the media and educational system. Interestingly, this was not the case, which may indicate a lack of knowledge transfer between the increased media attention and educational attempts to formalize teaching on climate change. Most pupils in phase II (55.9%) found it very difficult or difficult to mention examples of how their own actions affect the climate (indicator of knowledge), whilst a majority (75.1%) also somewhat agreed or strongly agreed that it is important to them to learn about climate change (indicator of motivation). This pattern suggests a possible gap between children's motivation to learn about climate change and their self-perceived ability to connect climate change with their own actions. It also indicates that climate change education may need to connect children's interest in learning about climate change with concrete, age-appropriate explanations of causes, consequences and possible responses.

The final measurement model supported the inclusion of Motivation and Behavior as two distinct subscales. Aligned with the existing literature, the Motivation domain reflects children's values, concern and motivational orientation toward climate change learning and action (Kollmuss and Agyeman 2002; Monroe et al. 2019; Rousell and Cutter-Mackenzie-Knowles 2020). The relatively high Motivation mean score ($M = 3.15$, $SD = 0.60$) may indicate that children in this age group and context are already motivated to act against climate change, but may also lead to ceiling effects in future evaluation studies. Similarly, the Behavior domain reflects children's self-reported engagement in concrete everyday practices relevant to climate change and not an objective measure of the climate impact of their actions. The domain should also be interpreted in light of children's potentially limited autonomy over household consumption decisions. The finding that many children reported never or rarely proposing climate friendly actions to their families (57.9%), indicates a lack of climate-related child-agency within families, even when motivation is relatively high. This is in contrast with recent evidence suggesting that students who learn about climate change mitigation may encourage their families to adopt more sustainable practices (Leve, Michel, and Harms 2023). There may be various explanations to why most children in our sample do not have such conversations with their families, e.g. their young age, yet it implies a need for future research to explore the dominant barriers as well as

opportunities to overcome them. Moreover, everyday behaviors may be motivated by several reasons simultaneously, and children may not always be able to identify a single underlying motive. The stem ‘for the sake of the climate’ was thus used to indicate climate-related orientation rather than to establish climate concern as the sole cause of the behavior.

Finally, Systemic and collective orientation should be interpreted as children’s emerging awareness that climate change extends beyond individual behavior and involves social, collective and cross-contextual dimensions and not an indicator of advanced systems thinking. This interpretation is consistent with climate change education literature emphasizing the importance of other-regarding orientations such as empathy and concern for others (Kollmuss and Agyeman 2002), as well as sociopolitical and psychosocial dimensions of climate change as critical for generating feelings of personal responsibility and motivating pro-environmental behaviors (Bouman et al. 2020; Monroe et al. 2019). Interestingly, the first-order factor loading (0.98) of this domain in Model 2 indicated the strongest relationship between this domain and the global factor, suggesting that interdependence, collective responsibility and perceived agency is closely related to the broader CCL construct operationalized in the CCLQ. The scale adds to the existing literature by highlighting the age-appropriate awareness of the systemic influences, thus introducing more cross-contextual approaches as a distinct element of CCL in children (Kwauk and Casey 2022).

4.1. Strengths and limitations

The findings of this study should be interpreted in the context of its methodological strengths and limitations. A key strength lies in the iterative and rigorous 2-phase development and validation process, which combined conceptual specification, item development, pretesting, focus groups, expert assessment, EFA and psychometric validation in an independent sample. This provided complementary sources of evidence for item relevance, comprehensibility, content validity, and internal structure. The high response rates, large validation sample and successful recruitment of schools and classes strengthened the study by accounting for the clustering of pupils within school classes. Although self-report measures may introduce an increased variability in respondent interpretation, this was mitigated through a pilot phase as well as measurement invariance analyses, which demonstrated a consistent factor structure across SES and gender, providing support for the validity of comparing scores between these groups, as differences were unlikely due to measurement bias.

Nevertheless, given that the measurement of CCL in children aged 10 to 11 remains an emerging field, further confirmation of item and domain relevance, factor structure and reliability in other representative samples is warranted. The CCLQ is a first attempt to conceptualize and operationalize CCL in Danish primary school children, it is not intended to assess all possible outcomes of climate change education, nor does it include separate validated subscales for other potentially relevant distinct constructs such as objective factual knowledge, hope, self-efficacy, climate justice or civic engagement (Horry et al. 2023; Kwauk and Casey 2022; Ojala 2012). Some of these constructs are conceptually reflected in the existing domains, e.g. through items concerning children’s perceived contribution to climate-related solutions, and awareness of climate

change consequences for people's health and lives but were not included as separate subscales due to conceptual breadth and cognitive burden of the questionnaire.

From a methodological perspective, we cannot guarantee that children who did not provide an informed consent to participate or who did not complete the full questionnaire were generally less interested in climate change, leading to a self-selection bias and slight overestimation of the level of e.g. motivation in our sample. Even though this study found measurement invariance across SES, the overrepresentation of children from higher SES groups may limit generalizability due to selection bias. Additionally, the absence of a predictive validity assessment restricts conclusions regarding the questionnaire's ability to forecast any future outcomes related to CCL. Related to this, the cross-sectional design of the study limits insights into the longitudinal stability of the instrument. To adequately assess the questionnaire's ability to capture changes over time, it should be administered in an experimental or longitudinal study design. However, given the rapid cognitive developments in this age group, longitudinal study validation of the CCLQ is potentially less critical as different age cohorts may require adapted items and factor structures that can accurately distinct between the needed literacy competences at different age groups.

The use of scaled self-report responses with children aged 10 to 11 also requires careful interpretation as they may introduce response bias and affect reliability measures. Methodological research suggests that children can use scaled response formats, but that response quality depends on developmentally appropriate item wording, item concreteness, clear verbal labelling, the number of response options and pre-testing with the target group (Borgers, Sikkels, and Hox 2004; Mellor and Moore 2014; Rebok et al. 2001). Related instruments such as Climate Change Attitude Survey also demonstrated appropriate validity and reliability despite its use of Likert-type items for middle school students (U.S. grade 5 through 8) (Christensen and Knezek 2015). In contrast, evidence also suggests that children aged 6 to 13 may have trouble using Likert-type scales to express internal thoughts, feelings, and beliefs, influenced by variables such as age, concreteness of items, and format of the Likert-type scale (Mellor and Moore 2014). This limitation was addressed through age-appropriate wording, pretesting and focus group cognitive interviews, through which the respondents showed a preference for the scaled response options above open-ended questions. Focus groups also revealed that some students preferred a 'Don't know' response category. However, we decided to omit it in line with previous research recommendations (Mondak and Davis 2001) while acknowledging the risk of that it may compromise the reliability and validity of the measurement (Chambers and Johnston 2002). The omission of negatively worded items from the final scale also supports the importance of minimizing cognitive burden in this age group (Marsh 1986). As Likert-type scales have consistently provided meaningful outcomes, even when averaged across groups of respondents (Fayers and Machin 2007), and as skewness and kurtosis in our studies indicated that observations within each scale were normally distributed, the use of scaled response options was considered pertinent.

Finally, although focus groups were conducted in the development phase to examine children's comprehension of items, examples and response categories, no additional cognitive interviews were conducted after the final psychometric item reduction. This sequence is consistent with scale development guidance, where cognitive

interviewing and pretesting are commonly used before large-scale psychometric evaluation (Boateng et al. 2018). However, psychometric evidence does not fully replace qualitative evidence on how children interpret individual items. This should be considered particularly when adapting the CCLQ to other languages, educational settings or cultural contexts.

4.2. Implications for practice and research

A valid and reliable measure of CCL in children has several applications for researchers, practitioners and politicians. The CCLQ may be used to monitor changes over time; investigate demographic and cultural correlations with CCL; assess the relationship between CCL and related outcomes; evaluate and compare the efficacy of programs and interventions designed to enhance climate change competences within educational and other contexts; and inform policy development in this field. As the CCLQ for children includes both a global CCL scale and 4 subscales, it may help researchers and educators examine not only whether an intervention is associated with changes in overall CCL, but also which domains appear most responsive to educational initiatives. We recommend that the CCLQ is used for group-level evaluation and not as an assessment tool of individual CCL scores.

For practice, the domain-specific patterns observed in this study suggest that climate change education for children aged 10 to 11 should not focus on factual knowledge or motivation alone. Children may be motivated to engage with climate change while still perceiving gaps in their own understanding or not exhibit corresponding behaviors. Educational initiatives may therefore benefit from connecting children's motivation with concrete, age-appropriate explanations of climate change causes, consequences and possible responses as well as examples of concrete mitigation and adaptation actions. The CCLQ may support this work if future longitudinal and intervention studies are able to detect changes over time or clarify whether different types of educational practice influence different dimensions of CCL.

We acknowledge the need for further refinement and adaptation as CCL is shaped by cultural, educational, political and social factors, and the psychometric properties of the scales may thus differ across contexts. A narrative synthesis of studies on youth perceptions on climate change found that levels of belief, concern, and willingness to take action differs across age and geographical placement (Lee et al. 2020). Since children's interpretation of items may depend on language, educational context and everyday practices, use of the questionnaire outside Denmark requires formal translation, cultural adaptation and cognitive testing before psychometric validation (Beaton et al. 2000). This would make it possible to examine whether the factor structure and score interpretation are supported across contexts and whether children's CCL differs across educational, cultural and social settings. English item wording of the CCLQ is therefore provided for reporting purposes only.

The CCLQ would benefit from additional target group and expert consultation, including for the Systemic and collective orientation domain, which was introduced at a later stage in the development phase. Other instruments for this age group

have used more objective measures of knowledge (Ortega-Quevedo et al. 2024), and future studies may thus examine whether self-perceived and objective knowledge measure distinct aspects of children's CCL. Further refinement of the Motivation scale may be relevant if future studies confirm clustering near the ceiling, e.g. by exploring items that discriminate more finely between children's varied motivations in relation to climate change. Moreover, the finding that many children reported never or rarely proposing climate-friendly actions to their families suggests that future research should examine how children's CCL relates to family practices, communication and opportunities for participation in climate-related decisions. Previous studies have identified political affiliation as a significant predictor of climate change concern and scepticism (Tobler, Visschers, and Siegrist 2012) as well as climate-related attitudes amongst adults (Zia and Todd 2010), indicating a need for examining the role of parent's political affiliations on their children's CCL. Another aspect of CCL highlighted by previous research is the influence of media literacy and communication skills (Johnston 2020; Tobler, Visschers, and Siegrist 2012). It can be discussed whether media literacy and communication skills are relevant for the age group of this study, however, with the increased use of social media at even younger ages (Bozzola et al. 2022), it may be deemed relevant to further investigate.

Since the field of climate change education and CCL is continually adding new perspectives, the CCLQ should be understood as an initial contribution to a broader measurement agenda in climate change education. Our thorough development and validation process may inspire follow-up studies which aim to further conceptualize CCL in this age group. At the same time, the present study provides a scoring method which has the potential to facilitate consistent administration across different settings and support further research into how CCL develops among children in late primary education.

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Author contributions

CRedit: **Marie Caroline Vermund**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing; **Glen Nielsen**: Conceptualization, Methodology, Supervision, Writing – review & editing; **Anna Stage**: Investigation, Project administration, Writing – review & editing; **Alberte Laura Oest Müllertz**: Formal analysis, Investigation, Writing – original draft, Writing – review & editing; **Peter Elsborg**: Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Data availability statement

The anonymized data that support the findings of this study are available from the corresponding author upon reasonable request.

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