Working paper

CERF's up!

The Climate-Education Research Framework

Akanksha Bapna[1], Nicholas P. Simpson and Sarah Colenbrander[2]
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Summary

Climate change has direct impacts on education, and education in turn plays a pivotal role in enabling climate change mitigation and adaptation. Deeper understanding of the bidirectional relationship between education and climate change is critical to understanding the full range and severity of impacts of climate change on students, educators and education infrastructure, systems and outcomes. This relationship is complex, with a host of social, economic, political and biogeochemical factors in addition to mediating factors and feedback loops that affect the causal pathways and make outcomes unpredictable. Yet current education and climate change practice, policy and research do not account for these complexities.

The Climate-Education Research Framework (CERF) presents a systematic approach to understanding this climate change–education nexus. The framework elucidates key relationships between climate change and education, while connecting different education levels and types with key climate change themes of adaptation, mitigation and loss and damage. The CERF offers a strong research architecture rooted in systems thinking and an approach that can help disaggregate the complex interactions between climate change and education, and support the design of effective and scalable policies and interventions to improve education and climate change outcomes.

1 Corresponding author: a.bapna@odi.org.uk

2 ORCiDs of authors: Akanksha Bapna: 0009-0006-4025-3231; Nicholas Simpson: 0000-0002-9041-982X; Sarah Colenbrander: 0000-0002-3214-8064

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About

About the authors

Akanksha Bapna is a Senior Research Fellow at ODI. Her research interests include using causal inference methods to understand the impact of education programs at scale. Akanksha is building the research agenda at the intersection of Education and Climate Change. She holds a Ph.D. in Biochemistry from the University of Cambridge, and a Masters' degree in International Education Policy from Harvard University.

Nick Simpson is a Senior Research Fellow in the Climate and Sustainability team at ODI. His research focuses on climate-resilient development pathways for Africa, Just Energy Transition Partnerships, and the intersections of climate change with education, heritage, cities, health and security research. Nick holds a PhD, an MPhil in Society, Environment and Sustainability, and a Postgraduate Certificate in Education all from the University of Cape Town.

Sarah Colenbrander is the Director of ODI's Climate and Sustainability programme. She leads a multi-disciplinary team focused on transforming agricultural, energy and urban systems to reach net-zero emissions, as well as mobilising the finance to achieve these transitions. Sarah holds a Masters in Environment and Development from Trinity College, Dublin. She is a guest lecturer at the University of Oxford, University College London and the University of Manchester.

Contents

About / i

Display items / iv

1 **The climate change–education nexus** / 1

How climate change affects education / 3

How education affects climate change / 5

Complexity of the relationship between climate change and education / 7

2 **CERF – the Climate-Education Research Framework** / 11

Why a new framework? / 11

The Climate-Education Research Framework (CERF) / 12

Systems thinking / 16

3 **Conclusion** / 17

References / 18

Display items

Boxes

Box 1 Education in the international climate change discourse / 1
Box 2 Defining adaptation and mitigation / 5
Box 3 Complex links between climate change and risk to learning capacity / 9

Tables

Table 1 Examples of cross-cutting research questions at the climate change–education nexus / 14

Figures

Figure 1 Timeline of key education discussions in the international climate change discourse / 2
Figure 2 Climate risk to learning capacity under compound extreme heat-drought climate event / 9
Figure 3 The Climate Change – Education Research Framework (CERF) / 13

1 The climate change–education nexus

Globally, the incidence of both rapid- and slow-onset weather events, as well as environmental degradation, is accelerating due to climate change. This is having significant impacts on humans and nature (IPCC, 2023). These impacts also affect education, one of the critical aspects of human life.

Education plays an important role in shaping the behaviours and norms that influence lifestyles, economic choices and opportunities, policies and political participation, and thus the carbon footprint of social and economic activity. It is necessary for the development of human and social capital and the attainment of human potential. It also plays a critical role in both climate change mitigation and adaptation (Behrer and Holla, 2023). Education can address inequalities exacerbated by climate change and reduce vulnerability to climate-related shocks and stresses (Caruso et al., 2023; IPCC, 2022; Striessnig et al., 2013) and is increasingly being recognised in international climate change discussions (Figure 1 and Box 1). Climate change places education and education systems at significant risk. Here we describe the relationship between education and climate change and demonstrate a close nexus between the two. Not only does climate change impact education; education also impacts climate change. There are complex causal pathways and links between the two, which can have a range of intended and unintended consequences. Recognition of the link between climate change and education is necessary to drive practice, policy and research to address this important intersectoral issue.

Figure 1 Timeline of key education discussions in the international climate change discourse

*Note: Timeline not to scale

Box 1 Education in the international climate change discourse

International climate negotiations have begun to pay closer attention to the links between education and climate change. Article 6 of the UN Framework Convention on Climate Change (UNFCCC, 1992) underscores the significance of education, training and public awareness in addressing climate change. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are urged to promote and facilitate educational and public awareness programmes at national, subregional and regional levels. The Paris Agreement (2015), in its preamble and Articles 11(1) and 12, reaffirms the importance of education, training and public awareness, and encourages cooperation at all levels to effectively combat climate change (UNFCCC Paris Agreement, 2015).

Recognising the need for public access to information on climate change, public participation and training for scientific, technical and managerial personnel, the Action for Climate Empowerment (ACE) initiative and ACE negotiations aim to empower society to engage in climate action through elements such as education, public awareness and international cooperation, formalised in the Glasgow Work Programme (UNFCCC Glasgow Work Programme, 2021). The Berlin Declaration on Education for Sustainable Development (2021) emphasises the significance of education for sustainable development at a global level (UNESCO, 2022a). Multiple reports produced by the IPCC emphasise both the impacts of climate change on education, and the importance of climate change literacy (IPCC, 2022; 2023).

COP28 has introduced thematic areas on Youth, Children, Education and Skills aligned with the Sustainable Development Goals (SDGs) (COP 28, 2023), and a declaration on the common agenda for education and climate change is to be introduced by the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Greening Education Partnership. The partnership recognises the disproportionate impact of climate change on children; emphasises the role of education for sustainable development; and calls for enhanced climate change education to support transitions to low-carbon economies. The declaration also acknowledges financing gaps and encourages collaboration between climate and education funds. Commitment areas focus on adaptation, mitigation and investment in education to build climate-resilient societies and foster global collaboration in addressing the climate crisis (UNESCO, 2022b).

How climate change affects education

Climate change can disrupt education and knowledge systems directly, through exposure to physical hazards such as floods or extreme heat (Mudavanhu, 2014; Turek-Hankins et al., 2021), or indirectly, through impacts on other aspects of human life that in turn affect education, such as health, food systems and migration (Fambasayi and Addaney, 2021; O'Neill et al., 2022). The adverse impacts of climate change on education may be experienced at all levels, from early childhood education to higher education, as well as on Indigenous and non-formal education. Marginalised groups are likely to be disproportionately affected by climate change impacts (Birkmann et al., 2022), as environmental risks intersect with social drivers of vulnerability such as low income, gender and disability (O'Neill et al., 2022).

Loss and damage is experienced when communities and countries experience harm from climate change impacts (IPCC, 2022; Mechler et al., 2020). Loss and damage can be economic, such as the loss of resources, goods and services that can easily be monetised. There are also forms of loss and damage that are more difficult to quantify or measure solely in economic terms. This may include loss of life, health, human mobility, territory, biodiversity and ecosystems, knowledge and practices and cultural heritage (Steadman et al., 2022).[1] The following section outlines how climate change can lead to educational losses across three domains: by reducing access to and disrupting learning; reducing learning capacity; and affecting the transmission of Indigenous and local knowledge (IK&LK).

Reduced access and disruption of learning

Extreme heat or flooding events may disrupt learning by limiting attendance, destroying educational infrastructure, damaging transport infrastructure and closing schools (Behrer and Holla, 2023; Cho, 2017; Graff Zivin et al., 2018). Teaching and learning may be disrupted due to teacher absence (a long-standing issue across education systems) (Muralidharan et al., 2017; Sprague et al., 2023). High temperatures, low rainfall and flooding, especially in the growing season, may lead to agricultural losses that cause parents to remove children from school to assist income generation. Children can also be taken out of school during labour-intensive seasons such as cropping (Sprague et al., 2023). Displacement and migration due to climate-related events or environmental degradation can interrupt education and lead to reduced access to education

1 The Warsaw International Mechanism for Loss and Damage was established at COP19 (2013) in Warsaw, Poland to address loss and damage associated with impacts of climate change, including rapid- and slow-onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change (UNFCCC Warsaw International Mechanism, 2013).

systems (IDMC, 2021; UNESCO, 2020). There could be increased burdens to learning such as linguistic barriers and loss of a sense of inclusion resulting from migration and displacement (IDMC, 2021; UNESCO, 2020).[2]

Reduced learning capacity may result from extreme heat conditions (Behrer and Holla, 2023; Graff Zivin et al., 2018; Park et al., 2020) or disruption to food supply chains, impacting nutrition (including through school feeding programmes) (Sprague et al., 2023). It is well established that undernutrition in early years associated with poor harvests and weather-related food supply interruptions can impair cognitive development and learning potential (Trisos et al., 2022). Climate change can also have negative impacts on psychological well-being and induce PTSD (post-traumatic stress disorder), depression, anxiety, phobias, sleep disorders and attachment disorders, and increase substance abuse (Burke et al., 2018). Extreme heat also corresponds with a documented increase in behavioural infractions that can exacerbate racial, ethnic and socioeconomic disparities (McCormack, 2023) and affect learning capacity. Compound heat waves and droughts can lead to cascading biophysical, economic and societal impacts on nutrition, food prices and mental health and the erosion of asset bases (IPCC, 2023), which can all impact learning capacity.

Loss of Indigenous and local knowledge (IK&LK)

Indigenous and local knowledge systems are the cumulative body of knowledge, practices and beliefs developed through adaptive processes and handed down through generations by cultural transmission (Nakashima and Krupnik, 2018; UN Convention on Biological Diversity, 2007). IK&LK have the potential to support mitigation and adaptation (Tanyanyiwa, 2019), enhance the management of natural hazards and ability to cope with climate variability and contribute to sustainable land management, the identification of longer-term climate changes and a more holistic response to climate change, including human relationships with nature (IPCC, 2019). Climate change-related slow-onset and extreme weather events lead to losses in these knowledge systems (Pearson et al., 2021). For example, local farming systems that rely on traditional knowledge of weather and climate-related factors are being challenged by climate change, impacting anticipatory action by farmers (Tripathi and Singh, 2013). While IK&LK may not lie within the formal definition of education systems, they form a substantive proportion of knowledge and education for many populations most vulnerable to climate change and are crucial to understanding human interactions with nature (Ajayi and Mafongoya, 2017). Impacts on IK&LK must therefore be included within the accounting of educational loss and damage.

2 According to the Internal Displacement Monitoring Centre, in 2018, 17.2 million people were internally displaced due natural disasters. In 2020, the number of people displaced due to natural disasters and extreme weather events jumped to 30.7 million, with this increase largely being attributed to climate change (IDMC, 2021).

Box 2 Defining adaptation and mitigation

Adaptation: Adaptation describes adjustments in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects. It encompasses changes in processes, practices and structures to reduce climate change risk, moderate potential damage or benefit from opportunities associated with climate change impacts (UNFCCC Glasgow Work Programme, 2021; UNFCCC Paris Agreement, 2015). Adaptation is enshrined in Article 7 of the Paris Agreement, wherein parties to the agreement concur that 'adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions.' The 2015 Paris Agreement established a Global Goal on Adaptation to enhance adaptive capacity, strengthen resilience and reduce vulnerability to climate change 'with a view to contributing to sustainable development and ensuring an adequate adaptation response' in the context of the mitigation goal of keeping temperature rise to a maximum of 2°C or 1.5°C' (UNFCCC Glasgow Work Programme, 2021; UNFCCC Paris Agreement, 2015).

Mitigation: Mitigation describes the reduction in current or projected atmospheric concentrations of greenhouse gas (GHG) emissions, thereby limiting the global average temperature increase relative to pre-industrial levels. Mitigation encompasses efforts to reduce the volume of emissions released into the atmosphere (for example from fossil fuel combustion, industrial processes or land use change) and to absorb GHG already in the atmosphere (for example through restoring carbon-rich ecosystems or deploying carbon capture and storage technologies). Under the UNFCCC, and notably under the Kyoto Protocol of 1998, developed countries have set economy-wide caps for their national emissions, while developing countries have generally focused on specific programmes and projects. The UNFCCC requires 'all Parties, keeping in mind their responsibilities and capabilities, to formulate and implement programmes containing measures to mitigate climate change (UNFCCC, 1998).'

How education affects climate change

In the context of climate change, education includes general education as well as types of education that have specific utility for climate action, including climate literacy, IK&LK and green skills (Birkmann et al., 2022; Simpson et al., 2021). Both general education and climate-linked education are important for enhancing climate change adaptation capacity, raising ambition on mitigation and minimising loss and damage (Angrist et al., 2023; Birkmann et al., 2022). Adaptation and mitigation are explained in greater detail in Box 2.

Effect of education on climate change mitigation

General education

General education can have direct or indirect impacts on GHG mitigation. With respect to direct impacts, the education sector produces emissions through land use, construction activities and energy use, and travel associated with educational activities (Chantry, 2021; McCowan, 2023; Shields, 2019).[3] In relation to indirect impacts, the education system is responsible for social norms, culture and individual choices and behaviours, which may impact emissions through influencing the demand for goods and services, and social and political engagement, both of which have profound implications for GHG emissions (Creutzig et al., 2022). Education systems can encourage unsustainable patterns of consumption and production by either explicitly or implicitly promoting the commodification of nature. They can also discourage unsustainable lifestyles (for example, by incorporating Indigenous epistemologies to improve knowledge about the local environment and nature and emphasise their inseparability from non-humans) (Acharibasam and McVittie, 2023). Secondary and higher education show correlations with increased use of solar panels or decisions to purchase electric cars (Cordero et al., 2020; Yao et al., 2020) and greater education levels have the potential to nudge voting patterns in favour of climate policies (Angrist et al., 2023) (although the causal mechanisms vary greatly across different contexts). Higher education can reduce barriers to individual understanding of climate change science (Fagan and Huang, 2019).

Climate change education and literacy

Climate change literacy encompasses knowledge of climate change as well as understanding of the anthropogenic impact on environmental and climate systems. Anthropogenic understanding is linked to greater levels of concern and climate action (IPCC, 2022; Lee et al., 2015; Simpson et al., 2021; Trisos et al., 2022). Climate literacy is also an important factor in combating climate misinformation and disinformation (UK Government Office of Science, 2023; van der Linden et al., 2017). Lack of education can leave individuals vulnerable to manipulation over action on climate change (Walters, 2018). Climate change education can also drive civic engagement and policy change, as well as emission reduction behaviours and investments at the individual level (Wynes and Nicholas, 2017).

3 There are opportunities to decarbonise the provision of education, for example through using green building materials in the construction of new schools; using clean energy sources for schools' electricity and heating; ensuring that other supplies are sourced sustainably (e.g. paper from plantations rather than forests, school meals from regenerative agriculture systems rather than conventional farming); and expanding mass transit, cycling and walking infrastructure around schools to discourage car use. It is also worth noting that many universities have large endowments, which are still invested in and profit from fossil fuel companies (Hestres and Hopke, 2020). Education systems can therefore also reduce emissions by decarbonising their assets, either through divestment or stewardship.

Green skills

Green skills (acquired via education systems) are important for building the capabilities necessary for the widespread deployment and long-term maintenance of low-carbon measures. Uptake of renewables, for example, requires a wide range of capabilities for a diverse range of actors: engineers who can adapt and install clean power systems and the more sophisticated transmission and distribution infrastructure, regulators who can govern electricity markets rather than vertically integrated utilities, lawyers and judges who can handle complex contracts, and firms that can develop new business models and supply chains for new technology (Colenbrander et al., 2015; Gençsü et al., 2020; Simalenga, 2011).

Effect of education on climate change adaptation

The IPCC assesses that public education together with effective communication and early warning can reduce the adverse impacts of climate change (Birkmann et al., 2022). Education levels are strongly correlated with both adaptive capacity and climate change literacy (Ara Begum et al., 2022; Simpson et al., 2021), as well as greater awareness of the risks of climate change and available support (Angrist et al., 2023). School education can influence an individual's exposure to hazards as well as sensitivity or susceptibility to those hazards (Wamsler et al., 2012) through shaping their risk perceptions, knowledge sharing and problem-solving abilities (Birkmann et al., 2022). Within school education, primary and secondary education have both been identified as effective strategies for decreasing vulnerability to climate change (Striessnig et al., 2013), while secondary, technical and higher education are important for upskilling for adaptation (Gençsü et al., 2020). Individuals who understand human-caused climate change tend to pursue more education or specific training to better adapt to experienced or anticipated climate impacts (Angrist et al., 2023).[4]

Complexity of the relationship between climate change and education

Both education and climate change involve socio economic and natural systems, and the interaction of these systems can have complex outcomes (Simpson et al., 2021). In the previous section, we outlined the relationship between education and climate change – highlighting the bidirectional effects of one on the other. In this section we demonstrate how this interaction is made more complex by contextual and temporal variations in the relationship between education and climate change, interacting variables, unexpected mediating factors, unpredictable outcomes, causal loops and heterogenous impacts through examples.

4 These specific examples are only from the North American context and further research is needed to generalise these claims.

- **Contextual and temporal variance**
  There is temporal and spatial variance in the relationship between climate change and education, leading to complexities in mapping causal pathways. Analysis of the relationship between income levels and emissions shows that the causal direction could be from emissions to income, income to emissions or bidirectional, depending on the inter- as well as intra-national context (Coondoo and Dinda, 2002; Grubb et al., 2006). Higher per capita incomes correspond with higher levels of education (Patrinos and Psacharopoulous, 2018). However, higher per capita incomes also correspond with higher per capita emissions, but only up to a certain level of economic development (particularly if consumption-based carbon accounting methods are used) (Edenhofer et al., 2014). There are further nuances in the variation across income groups[5] and across timeframes (Yao et al., 2020). For example, individuals who choose to pursue more education are, by revealed preference, forward-looking and thus more concerned with the future consequences of climate change. Therefore, time preferences of more educated individuals (hyperbolic discounting (a psychological bias where individuals prioritise immediate rewards and satisfaction over future rewards) or lack thereof) may drive pro-climate beliefs rather than the education itself (Angrist et al., 2023).

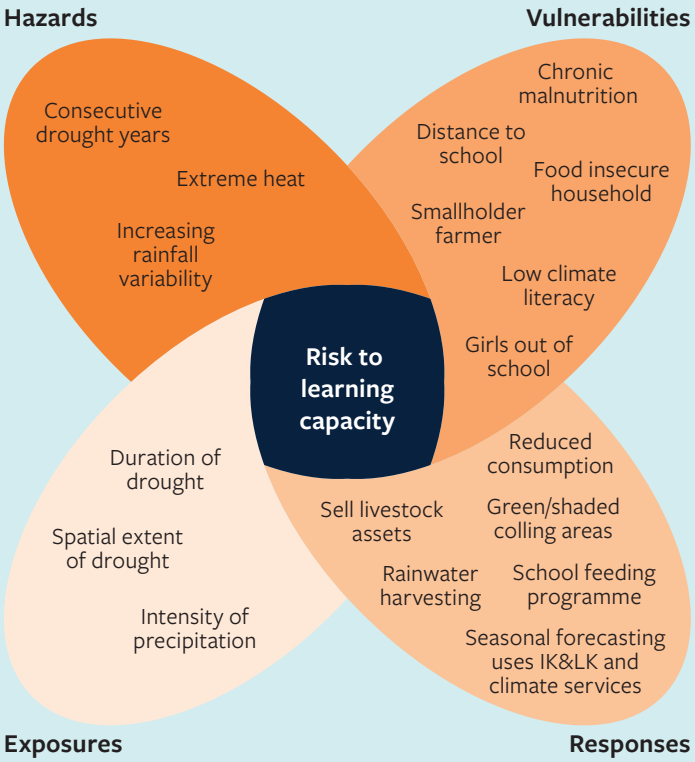
- **Interacting variables**
  Education can interact with political views and ideology in predicting climate risk perceptions, as recent studies have demonstrated (Lee et al., 2015). In the US, for example, greater educational attainment is correlated with increased perceptions of climate risks among liberals and Democrats, but lower perceptions of climate risks among conservatives and Republicans (Lee et al., 2015). The possibility of risks interacting is further outlined in Box 3.

- **Mediating factors**
  Research shows that climatic conditions experienced in utero and during early childhood affect educational attainment at ages 12 to 16. For example, experiencing higher-than-average temperatures is associated with fewer years of schooling in Southeast Asia, but early-life rainfall is positively associated with better education attainment in West and Central Africa (Randell and Gray, 2019). In this instance, the climate change–education nexus is mediated by physical health considerations.

5 Within income groups, there is considerable variation in the relationship between education and carbon emissions across countries. For example, studies in the US and 23 countries in Europe have found GHG emissions increase with higher levels of income but decrease with increasing levels of education (Baiocchi et al., 2010; Nielsen et al., 2021). In China, across lower-income groups, higher levels of education corresponded to higher GHG emissions, but in higher-income groups, income level was a much stronger determinant of emissions than education (Wang et al., 2020; Zhang et al., 2023).

Box 3 Complex links between climate change and risk to learning capacity

Figure 2 Climate risk to learning capacity under compound extreme heat-drought climate event



The causal pathways between drivers of climate change risks and learning are complex. Climate-linked hazards, vulnerability, exposure and responses interact with each other in various ways and impact learning capacity under extreme climate events (IPCC, 2022; 2023; Simpson et al., 2021).

- **Unpredictable outcomes**

  Not all education has the same impact, making its effects on climate action and climate change difficult to predict. For example, it is clear that climate change awareness is linked to greater climate concern (Lee et al., 2015; Yale Program on Climate Change Communication, 2022). However, research targeting fourth-grade children in Chile found that some school-based environmental education programmes were successful in changing children's knowledge, attitudes and practices, but had no effect on parents' behaviour (Jaime et al., 2023). In another example, higher education is known to contribute to research towards understanding of greenhouse gases and the development of renewable energy. At the same time, research is also implicated in the development of technologies that enable the continued exploitation and use of natural resources (McCowan, 2023). Further, mental health is known to shape responses to climate change. For instance, knowledge of global warming and/or experiencing its impacts can lead to mental stresses, particularly for young children and adolescents who are predisposed to anxiety (Berry et al., 2018; Hickman, 2009). Climate anxiety can in turn become clinically maladaptive, and instead of driving positive adaptation, it may lead to chronic worry, restlessness, irritability, panic and sleep disturbance (Crandon et al., 2022).

- **Causal loops**
  IK&LK can play an important role in minimising environmental damage and supporting climate mitigation and adaptation (Executive Committee of the Warsaw International Mechanism for Loss and Damage, 2016). However, climate change puts IK&LK systems at risk by reducing their usefulness as ecosystems change and weather events outstrip past experience, reducing the in situ value of these knowledge bases (Ajayi and Mafongoya, 2017). For example, pastoralist communities in the Sahel have long used seasonal movements to manage climate variability and exploit natural resources sustainably. However, changing patterns of rainfall are contributing to increased migration into areas occupied by sedentary farmers (Nyong et al., 2007). This leads to loss of in situ IK&LK and further impacts on climate change as the knowledge of sustainable practices is lost.

- **Heterogeneous impacts**
  The factors which influence vulnerability and adaptation to climate change also directly impact access to education. These factors compound to create disproportionate impacts on certain groups (Ayanlade et al., 2023), such as individuals with low income, migrant status and disability (Ayanlade et al., 2023; Birkmann et al., 2022). Climate change disproportionately impacts women and girls due to existing gender inequalities (Atkinson and Bruce, 2015; Fry and Lei, 2021; Pankhurst, 2022; Sprague et al., 2023). It places children at great risk (UNICEF, 2021), reduces family income and exacerbates existing barriers to girls' education (Sims, 2021), while placing the burden of adaptation on women (Pankhurst, 2022; Project Drawdown, 2020). For example, a common response to consecutive droughts for smallholder farmers in Africa is to reduce consumption, sell livestock assets and pull girls out of school (Ndlovu and Mjimba, 2021). These responses can buffer short-term economic impacts, but compound the vulnerability of already insecure households, compromising nutrition and disrupting the education of girls (Sosanya et al., 2024). Conversely, education is a stronger determinant of adaptive capacity to climate change for women than for men (Wamsler et al., 2012).

2 CERF – the Climate-Education Research Framework

In this section, we present the Climate-Education Research Framework (CERF). The CERF offers a simple yet structured approach to research at the climate change–education intersection. The framework links five education levels (Early Childhood, School, Tertiary, Sector Level and Non-formal/Indigenous education) with three climate change thematic areas (Adaptation, Mitigation and Loss and Damage), providing a robust architecture for research underpinned by systems thinking.

Why a new framework?

As interest in the climate change–education nexus grows, a number of analytical frameworks have emerged. However, these frameworks do not consider the full complexity of the relationships between climate change and education. The CERF draws on some of their strengths while addressing a range of limitations. The framework is open to iteration as research at the intersection develops. Several existing frameworks are outlined in this section.

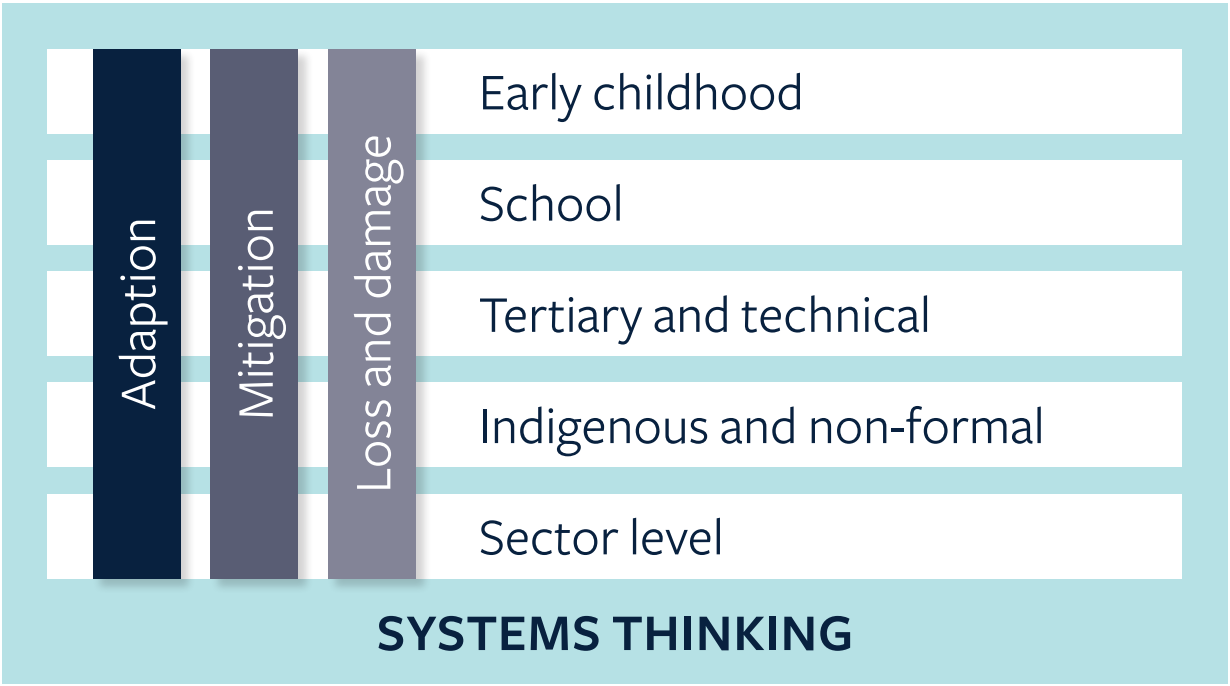
The Global Partnership for Education (GPE) framework outlines meaningful relationships between various factors of the education system, and also outlines various aspects of climate-related factors that can be addressed, but the framework does not make causal connections between the two. It takes an input-driven approach to nature-based education without considering the reverse causality of the impact of education on climate change. It also does not account for the impact on adaptation vs. mitigation and does not include indigenous knowledge (Kagawa and Selby, 2022), which are aspects addressed in the CERF. The analytical framework for informed action by the Institute for Development Impact has a comprehensive set of indicator/indicator types that can be used to determine relationships between climate, socioeconomic, education and contextual factors (Hiebert and Ord, 2023), but the framework does not consider *a priori* causal complexities. The CERF accounts for complex causal pathways, time variance and heterogeneous effects. The UK Foreign, Commonwealth and Development Office Framework specifically centred around girls' education and climate change outlines a complex host of factors involved at the nexus, but does not describe directionality or causality across the two (FCDO, 2022). Directionality and causality are core pillars of the CERF. Lastly, McCowan's theoretical framework on the impact of universities on climate change tackles higher education, but does not include early childhood education, school and non-formal education or IK&LK, which the CERF addresses. The McCowan framework considers mitigation and adaptation pathways, but does not address the time variance or causal loops between them (McCowan, 2023). The CERF addresses this gap.

The Climate-Education Research Framework (CERF)

As we have seen in previous sections, climate change and education are inextricably linked in complex ways. Climate change impacts education and education can contribute to climate change mitigation and adaptation. This interaction warrants nuanced investigation across many dimensions.

Here we propose the CERF – a framework that links three key climate change thematic verticals of Adaptation, Mitigation and Loss and Damage to five key cross-cutting education areas of Early Childhood Education, School Education, Tertiary or Higher Education, Sector Level and Indigenous Knowledge and Non-formal Education. The CERF has been developed to support the design of research to understand how different education levels shape culture, social norms and individual choices, and how these interact with governance and structural factors to inform low-carbon development paths and equip people to adapt to the impact of climate change (Creutzig et al., 2022). It supports the generation of evidence that can demonstrate causal directionality and the variation of these impacts over different time frames, across levels of education, geographies, population and age groups, development contexts and changing climate contexts.[6]

Figure 3 The Climate-Education Research Framework (CERF)



6 For example, access to green shaded areas can provide relief from extreme heat and has positive wellbeing effects for learners (Jay et al., 2021). However, nature-based solutions may collapse at certain levels of warming (Hobbie and Grimm, 2020), with consequences for schools and universities that depend on trees and other vegetation to moderate temperatures.

In Table 1, we present an example of how the CERF can be used to design a robust research agenda and identify research gaps. Using the links across the climate and education verticals, the CERF can also be used to develop theories of change for interventions designed at the climate change–education nexus. The set of questions presented in Table 1 have emerged through a series of conversations and discussions with key stakeholders in the education and climate change sectors over the course of several months, as well as through a broad exploration of the literature. However, we recognise the need to create a detailed evidence gap map for the purpose of prioritisation of the research agenda.

Through the analysis of the connection between climate change and education, three thematic verticals of Adaptation, Mitigation and Loss and Damage emerge. These verticals have are also key areas for negotiation in international climate change dialogue and form the core pillars of the CERF. Education levels in the CERF been identified based on the universally accepted differentiation of formal education as identified by UNESCO (ISCED, 2011). In addition, because of the close association of IK&LK with climate change as a form of knowledge outside of the formal education system, it has been included as a cross-cutting education level in combination with non-formal education, which is increasingly being recognised globally (ISCED, 2011). Education levels have been outlined distinctly because, while there is overlap in the kinds of research questions that may be asked of each level, there are differences in the kinds of indicators, outcomes and methodologies that will be required. Additionally, the nuances of these different education levels, if clearly highlighted, will allow for the disaggregation of causal pathways and heterogenous effects. For example, having a clear research agenda that separates school from tertiary education can help in understanding the impact of different levels of education on mitigation vs. adaptation (as outlined in the previous section).

Table 1 Examples of cross-cutting research questions at the climate change–education nexus

Adaptation	Mitigation	Loss and Damage
Early Childhood Education		
How should the ECE curriculum be designed to enhance children's resilience and adaptive capacity?	Does inculcating a love for nature impact long-term consumption patterns? If so, do these changes in consumption patterns impact net CO_2 emissions?	What are the impacts of climate change during early childhood on cognition? How can any cognitive loss and damage be addressed through education?
How should teachers be retrained to meet the needs of the new curricula?		
School Education		
What curricula and pedagogies are most effective in imparting climate change education for adaptation?	What are the structural and environmental factors needed to support education-led behaviour change to mitigate climate change?	What is the long-term impact on cognitive losses due to CC? What are the implications for people's participation in social and economic activity as a result of these cognitive losses?
What socioemotional learning competencies (SEL) are needed to build individual resilience to extreme weather events and other climate-related hazards?	Does climate change education change behaviour? If so, do these behaviour changes impact consumption patterns or voting patterns?	What are the impacts of climate change on learning loss? What is the impact of learning loss on life-long earnings and other metrics of wellbeing?
What SEL and technical skills are needed to empower young people to collectively organise to demand investments in adaptation?	What pedagogies are most effective in imparting climate change education for mitigation?	
What SEL and technical skills are needed to ensure graduates are ready for climate change-driven changes in job markets?	Does inculcating a love for nature impact long-term consumption patterns?	
Tertiary Education		
What SEL and technical skills are needed to build individual and community resilience to shocks and stressors?	How should STEM education be best promoted to address mitigation?	What are the impacts of climate change on learning loss? What is the impact on life-long learning and earning loss?
What SEL and technical skills are needed for the large-scale deployment of adaptation measures?	What is the impact of HE on consumption patterns?	How does climate change impact the demographic of the learning cohorts? Are some vulnerable groups impacted more than others?
	What technical skills are necessary for the large-scale deployment of low-carbon measures?	

Table 1 Examples of cross-cutting research questions at the climate change-education nexus (contd.)

Adaptation	Mitigation	Loss and Damage
Indigenous and Non-formal Education		
How can intergenerational knowledge systems transmit adaptation knowledge?	How can non-formal education teach climate literacy? What kinds of pedagogies should be used?	What kinds of Indigenous knowledge are at risk of loss due to climate change? How may this be conserved and transmitted?
What kinds of non-formal teaching can support adaptation? How does it differ at different levels of education?	How can Indigenous knowledge transfer support mitigation goals? How might this knowledge be transmitted?	Can non-formal systems support education losses due to climate-related meteorological events?
How can the education sector ensure learning for out of school children?		
Sector Level		
How can schools become more resilient to climate shocks? How can we create resilient infrastructure and feeding programmes?	What kinds of traditional knowledge systems can support the education sector in mitigating climate change?	What is the economic and non-economic loss to the education sector due to climate change?
How do we measure the vulnerability of school systems to climate shocks?	Can schools be designed to be greener and low-carbon at scale? How can schools become sustainable carbon sinks?	What is the cost of inaction on climate change on productivity and key development outcomes?
What support can schools provide to enhance resilience to climate change for vulnerable communities?	What is the carbon cost of using technology for learning?	What kinds of taxation/financing can be considered to compensate for climate change-led losses to education?
What does the future of work look like under different climate scenarios? What kinds of skills will be required to adapt to CC?	Does curriculum change impact net carbon output? If so, how and across what time frame?	What cultural losses are associated with forced displacement due to climate change?
How can technology support learning losses caused by extreme weather events?	What aspects of a climate change curriculum could be most effective in mitigating net CO_2 emissions?	How can the education sector protect vulnerable and marginalised populations?
How can evidence be translated into education policy?		

Systems thinking

It is clear that the relationship between climate change and education is complex – temporal and spatial variance, interacting variables, mediating factors, unpredictability of outcomes, causal loops, heterogeneous impacts and mediating factors all make it challenging to predict the outcomes of inputs and policies. These features of the climate change–education nexus therefore lend the field to analytical ideas underpinned by systems thinking.[7] Systems inquiry challenges linear research approaches to complex problems such as the isolated impacts of education on climate change or vice versa. It compels us to examine indirect causes and unintended consequences. Systems thinking tools such as causal loop diagrams and network mapping combined with nimble evaluations and portfolio-based approaches can support the understanding of the climate change–education intersection (UNDP, 2022). In the field of climate change and mental health, for example, systems thinking has been proposed as a crucial analytical tool and as useful for elaborating key social–ecological interactions (Berry et al., 2018). Systems thinking is increasingly being recognised as vital to understanding public beliefs and attitudes about climate change and could support the adoption of beliefs and attitudes indirectly by helping the development of a sustainable ecological ethic (Ballew et al., 2019).

7 A system is a 'complex of interacting elements such that the system cannot achieve its purpose without the element, and the element by itself cannot replicate the system's functions' (Bertalanffy, 1969; Betts, 1992). A system has the ability to change and adapt (Meadows, 2008). An element is a necessary but not sufficient component of a system, and the behaviour of the whole cannot be summed up from the isolated elements.

3 Conclusion

The interconnectedness of education and climate change highlights the need for a robust analytical framework to guide research and inform effective interventions. This working paper proposes the Climate-Education Research Framework (CERF) as a systematic approach to understanding and addressing this complex nexus. The CERF recognises the bidirectional nature of the relationship. It also underscores the fact that the causal pathways and contextual and temporal dynamics of this relationship are understudied.

Given the urgency of the problem and the need to evidence some of these research questions rapidly, an interdisciplinary approach will be called for. For example, the vast literature on displacement, migration and education in emergencies could provide data and insights on what works in climate change-linked emergencies. In applying the CERF, it also needs to be recognised that scalability and external validity may need to be redefined for climate change–education research as climate-linked problems are likely to be hyper-localised or super-generalised. For example, while temperature increases negatively impact student learning outcomes in some locations, it could be an energy conserving mechanism in other geographical contexts.

Employing CERF as a research framework to identify and address evidence gaps will support the development of evidence-based interventions that empower policy-makers, individuals and communities to build resilience, mitigate climate impacts and promote a more sustainable future.

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