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Advances in climate change education, challenges and policy insights

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Abstract

Climate change education (CCE) is undergoing a critical transformation as global educators and policymakers recognize its role in equipping individuals and communities to respond to the climate crisis. This paper synthesizes recent scholarly developments in CCE, highlighting a shift toward participatory, interdisciplinary, and action-oriented pedagogies that foster critical thinking, adaptive capacity, and environmental agency. Drawing on research from the past five years, the paper explores the implementation of innovative teaching methods, integration across disciplines and professional training, and the growth of online and hybrid platforms. It further identifies persistent challenges such as curricular fragmentation, teacher preparedness, and equity in learner engagement, and examines evolving policy frameworks that support region-specific, justice-informed, and advocacy-focused educational strategies. Advancing CCE requires a systemic reorientation of educational policies and practices to focus on resilience, equity, and transformative action in both formal and informal learning settings.

Keywords: Climate education; climate policy; educational strategies; experiential learning; place-based approaches.

JEL Codes: A14; I30; Q00; Q51; Q56; Q59.

1. Introduction

Climate change education (hereafter CCE) has emerged as a foundational component of global responses to the environmental crisis, with recent developments emphasizing its role not merely in disseminating knowledge but in fostering the capacities required for critical engagement, adaptive behaviour, and sustainable civic action (Stevenson *et al.*, 2017; O'Brien & Leichenko, 2020). Contemporary approaches prioritize interactive, interdisciplinary, and transformative pedagogies that extend beyond conventional science instruction to foster systems thinking, socio-emotional resilience, and environmental stewardship (Leite, 2024; De Maeyer *et al.*, 2022).

Programs now aim to empower learners as agents of change, integrating place-based and action-focused learning models that have been shown to improve student motivation and climate-related competencies, especially among marginalized populations (Bae *et al.*, 2025). These pedagogical shifts reflect a growing recognition that education must move beyond knowledge transmission to include experiential and participatory dimensions that encourage real-world problem-solving and justice-oriented reflection (Even *et al.*, 2023).

However, major challenges persist. These include fragmented curricula (White *et al.*, 2022), teacher training gaps (Carson & Dawson, 2020), resistance to interdisciplinary approaches (Eilam, 2022), and cognitive or motivational barriers that inhibit learner engagement (Rudd *et al.*, 2020; Gal, 2024). Moreover, policy responses often lag pedagogical innovation, resulting in an implementation gap that undermines transformative potential (Marston *et al.*, 2025; Osberg & Wamsler, 2022).

The current paper presents a concise review of the most recent advances in CCE and elaborates on the emerging challenges that complicate its integration. We then examine policy frameworks that support transformative CCE and conclude with practical recommendations for aligning educational systems with climate resilience and justice.

2. Latest advances on climate education

Recent advancements in climate education showcase a growing shift toward dynamic, applied, and learner-centred models. These models are designed to bridge the gap between knowledge acquisition and real-world action by embedding climate literacy within practical and social contexts. CCE in formal education is shifting

toward more active, relevant, and action-oriented approaches, whereas it focuses on engaging students as agents of change, integrating climate topics across disciplines, and building skills for real-world problem-solving and adaptation.

2.1. Innovative Teaching Methods

Contemporary approaches to climate change education emphasize participatory and action-focused learning, transformative and holistic pedagogies, and inquiry-based research projects, all of which collectively foster critical thinking, adaptive capacity, and empowered engagement with real-world climate challenges.

Hands-on, participatory programs such as student-led environmental initiatives, interactive simulations, and community-based projects have shown promise in improving students' scientific understanding, personal efficacy, and academic performance. These interventions are particularly impactful among historically marginalized student populations, fostering both cognitive gains and increased aspirations for careers in Science, Technology, Engineering, and Mathematics (STEM) (Weinberg & Trott, 2020).

Programs increasingly use place-based, participatory, and action-focused methods to make climate science relevant and engaging. Activities like interactive games, digital storytelling, and youth-led community projects help students connect climate change to their lives and communities, boosting interest in science and confidence in taking action (Weinberg & Trott, 2020). There is a push for CCE to drive a holistic transformation of schooling, integrating sustainability into curricula, teaching methods, and assessment. This approach aims to build students' capacity to understand and act on climate change, not just learn about it (Leite, 2024). Transformative learning frameworks encourage students to question values and engage in real-world problem-solving (Leite, 2024; Bae *et al.*, 2025).

Emphasis is placed on developing action competence, not just knowledge, but also the willingness and capacity to act for sustainability. Classroom experiences significantly influence students' readiness and motivation to engage in sustainable behaviours (De Maeyer *et al.*, 2022). Extended, inquiry-driven research experiences enable students to grapple with the complexities of climate science and sustainability. These programs support the development of systems thinking, evidence-based reasoning, and long-term adaptive capacity. While shifts in affective domains like risk

perception may be subtle, the cognitive gains are clear and sustained (Riede *et al.*, 2021).

CCE is moving beyond rote learning to foster critical thinking, argumentation, and problem-solving skills. For example, teaching students to construct arguments about climate change's social and scientific aspects improves their ability to justify decisions with evidence and enhances their understanding of complex issues (Riede *et al.*, 2021). Programs that involve students in research-oriented projects and collaboration with experts help build cognitive adaptive capacity, including risk perception, adaptation knowledge, and forward-thinking skills. Instruction that emphasizes structured argumentation helps learners critically evaluate scientific evidence, consider multiple perspectives, and formulate reasoned positions on climate-related dilemmas. This skill is especially valuable in underserved contexts, where students may face additional barriers to scientific engagement (Carson & Dawson, 2020).

Finally, recent research highlights a shift toward fostering mitigation behaviours, willingness to act, and critical reflection on social and justice aspects of climate change (Kroufek *et al.*, 2022; Breitenmoser *et al.*, 2022). Socioemotional and justice-informed frameworks are gaining traction, integrating mental health, climate justice, and intersectionality into lessons (Even *et al.*, 2023; Bae *et al.*, 2025).

2.2. Online and Hybrid Climate Change Education

Online and hybrid modules are increasingly central in climate change education, offering scalable, flexible, and innovative approaches to teaching and engagement. Key trends include the adoption of Massive Open Online Courses (MOOCs), integration of digital tools, gamification, and a shift toward interdisciplinary and transformative learning models.

MOOCs are widely used to reach diverse learners, promote community engagement, and facilitate knowledge sharing across institutions and countries. Frameworks for MOOC development emphasize pedagogical quality and capacity building for educators, supporting harmonized curricula in higher education globally (Kumer *et al.*, 2022; Scolobig & Balsiger, 2024).

The use of digital tools including virtual reality has grown, with evidence showing these technologies enhance sustainability awareness and student engagement

in climate change topics (Hajj-Hassan *et al.*, 2024). Game-based and role-play modules are emerging as effective strategies to foster cognitive and behavioural engagement, making climate change education more interactive and impactful. These approaches are used in both digital and hybrid formats, though research notes the need for longer-term interventions and broader demographic reach (Hamari *et al.*, 2021; Hügel & Davies, 2024).

There is a strong trend toward integrating online and offline learning, with students and educators expressing a preference for blended approaches that combine the flexibility of digital modules with the benefits of in-person interaction (Zhou *et al.*, 2023). Curricula are increasingly interdisciplinary, incorporating social, economic, and emotional dimensions of climate change (Halkos and Nomikos, 2021). This shift aims to empower students as agents of change and foster critical, creative, and systems thinking (O'Brien & Leichenko, 2020; Bimo *et al.*, 2024).

Online modules have demonstrated significant improvements in student understanding of climate change and sustainability, with high completion rates and positive feedback on relevance and applicability (Taylor *et al.*, 2022; Hajj-Hassan *et al.*, 2024). These types of modules support the development of teaching capacity, especially in higher education, and facilitate the dissemination of best practices across institutions (Kumer *et al.*, 2022; Zhou *et al.*, 2023; Scolobig & Balsiger, 2024).

2.3. Integration Across Disciplines and Professional Training

Climate change education is increasingly recognized as essential across disciplines and professional training. Integration efforts focus on embedding climate literacy, interdisciplinary collaboration, and practical skills into diverse curricula, but face challenges such as rigid structures, resource limitations, and the need for faculty development.

Faculty from various disciplines collaborate to revise courses, share strategies, and enhance climate change pedagogy. This approach improves both faculty preparedness and student climate literacy, though ongoing support and training are needed for effective assignment design and assessment (DeCamp, 2024). Climate change topics are incorporated into existing courses, often through case studies, data analysis, and real-world examples. Elective courses allow for more flexibility, while required courses face constraints due to established competencies (Ogunseitan, 2022).

Narrative and Embodied Learning: Courses use story telling, narrative analysis, and embodied pedagogy to connect climate science with emotional engagement and action, fostering perspective-taking and empowerment across disciplines, including chemistry (Groom et al., 2025).

Disciplines such as agriculture, biology, and environmental studies use hands-on and interdisciplinary projects, but face barriers like inflexible curricula and insufficient interdisciplinary cooperation. Students and faculty call for more practical, mandatory and locally relevant climate education (Diem *et al.*, 2024). Health sciences and other professional fields are beginning to integrate climate change as a cross-cutting competency, but gaps remain, especially in low- and middle-income countries where colonial legacies and lack of climate literacy among educators hinder progress (Ogunseitan, 2022; Stull *et al.*, 2023; Hossain & Mazumder, 2024). Furthermore, there is a growing movement to integrate justice frameworks into climate change education, emphasizing equity, community engagement, and the inclusion of diverse perspectives across formal and informal learning settings (Even *et al.*, 2023; Bastías *et al.*, 2023).

3. Emerging challenges on climate education

CCE is vital for preparing individuals and communities to understand and respond to the climate crisis. Despite its importance, educators and institutions face significant challenges in delivering effective, engaging, and actionable climate change education across different age groups and disciplines.

3.1. Curricular and Pedagogical Challenges / Curriculum Integration and Disciplinary Debates

Climate content is often confined to science or geography courses, which restricts its integration into broader interdisciplinary learning. This fragmentation constrains opportunities for interdisciplinary learning and reduces student exposure to the complex interplay between environmental, social, and economic systems (Peel *et al.*, 2017). Climate change is present in science and geography curricula in many countries, but often as scattered content or context for other topics, rather than as a standalone subject (White *et al.*, 2022). There is debate over whether climate change

should be a cross-curricular theme or a distinct discipline to ensure depth and coherence in learning (Eilam, 2022).

Deep-seated misconceptions remain widespread. While tools like refutation texts are helpful, they must be complemented by active learning strategies, formative assessment, and contextualized explanations to correct misinformation (Cordova *et al.*, 2017). Despite their effectiveness, participatory and action-oriented models remain underutilized due to resource constraints, lack of institutional support, and time pressures within standardized curricula. However, most curricula still prioritize knowledge over action, indicating a gap between policy and practice (White *et al.*, 2022; Kroufek *et al.*, 2022; Breitenmoser *et al.*, 2022).

3.2. *Teacher Preparedness and Professional Development*

Teacher preparedness and professional development are essential for effective climate change education, but several barriers can limit their success. Key challenges include limited access to targeted training, especially in disadvantaged schools, and the need for more comprehensive professional development programs. Teachers, particularly in disadvantaged settings, often have few opportunities for specialized training in climate change science and related teaching strategies (Carson & Dawson, 2020). Less experienced teachers may lack confidence or experience in teaching complex socioscientific issues like climate change, making professional development even more critical.

Professional development workshops may be brief and not fully integrated into ongoing teaching practice, limiting their long-term impact. Teachers may struggle to incorporate new strategies, such as argumentation about climate change, into existing curricula without sustained support. Effective climate change education requires teachers to help students justify their decisions with scientific evidence, a skill that may not be fully developed without targeted professional development (Carson & Dawson, 2020).

3.3. *Student Engagement and Cognitive Barriers*

Student engagement in climate change education is shaped by both motivational and cognitive factors, with significant barriers arising from emotional responses, socioeconomic background, curriculum design, and cognitive biases.

Effective engagement requires integrating emotional, cognitive, and action-oriented approaches, while addressing barriers such as feelings of powerlessness, knowledge gaps, and unequal access to resources.

Students are more engaged when they perceive climate change as relevant to their lives and believe they can make a difference. Programs that foster agency and connect learning to real-world action increase engagement and confidence in science (Rudd *et al.*, 2020). Students from lower socioeconomic backgrounds often have less knowledge about climate change, are less worried about its impacts, and participate less in pro-environmental behaviours, even when opportunities are provided. School environment and resource availability are critical in bridging these gaps (Walshe *et al.*, 2025; Weinberg & Trott, 2020). Overly content-heavy curricula and low visibility of climate change topics limit engagement. Participatory, place-based, and action-focused pedagogies, as well as experiential learning, are effective in fostering positive engagement and hope rather than fear (Gal, 2024; Rushton & Walshe, 2025).

Many students experience feelings of powerlessness, fear, and betrayal when learning about climate change, especially if education focuses solely on the problem without empowering solutions. These emotions can have lasting effects on attitudes and behaviours (Rudd *et al.*, 2020; Davison & Jones, 2020). Students may rely on cognitive shortcuts such as anchoring and contrast effects when reasoning about climate change, which can lead to misconceptions or oversimplified predictions (Holt & Howell, 2023). Younger students tend to focus on personal experiences, while older students engage more with broader environmental contexts, indicating the need for age-appropriate approaches (Abhijith *et al.*, 2023).

4. Policy dynamics

Climate change education is increasingly recognized as a vital tool for building societal resilience and driving action on climate issues. Policymakers and educators are exploring how to integrate climate change education into policy frameworks to address diverse community needs, foster adaptive capacity, and empower future leaders. CCE is increasingly recognized by policymakers as a cornerstone of climate resilience, with implications for national adaptation strategies, sustainable development goals, and public health frameworks.

4.1. Policy Integration

Integrating climate change education into policy frameworks requires a systemic, multi-level approach that embeds climate literacy across all educational stages and professional sectors, supported by formal policy and legal structures. Climate change education should be coordinated and institutionalized, not limited to school curricula. It must be embedded at all levels, primary, secondary, higher education, and professional learning using indicators and assessment tools to guide implementation and adaptation to local contexts and legal systems (Fazlagić *et al.*, 2021; Marston *et al.*, 2025). Effective integration involves mainstreaming climate objectives into all sectoral policies, linking practical solutions with internal (mindset, values) and external (curriculum, projects) dimensions. This requires frameworks that address both personal transformation and systemic change (Osberg & Wamsler, 2022; Bristow & Wamsler, 2022).

Policies should support curriculum designs that foster democratic engagement, critical thinking, and anti-oppressive practices, enabling students to connect climate issues with broader social justice and sustainability goals (Bastías *et al.*, 2023; Even *et al.*, 2023). Policies should also encourage teaching methods that are personally relevant, participatory, and action-oriented, such as deliberative discussions, community projects, and direct interaction with scientists (Chaves *et al.*, 2019; Marston *et al.*, 2025).

Policies should be adaptable to local contexts and responsive to ongoing research and feedback from educators and learners (Fazlagić *et al.*, 2021; Marston *et al.*, 2025), while integration should be supported by clear indicators, assessment tools, and cross-sector collaboration (Fazlagić *et al.*, 2021; Osberg & Wamsler, 2022; Marston *et al.*, 2025). Justice-driven and participatory approaches enhance the effectiveness and inclusivity of climate education (Bastías *et al.*, 2023; Even *et al.*, 2023). In brief, policy recommendations involve:

- Mandate climate education in national education systems and legal codes (Fazlagić *et al.*, 2021; Marston *et al.*, 2025),
- Teacher Training and Competencies orembed climate literacy in teacher education and ongoing professional development (Marston *et al.*, 2025),
- Justice and equity focus to ensure that climate education addresses social justice and equity (Even *et al.*, 2023; Bastías *et al.*, 2023),

- Mindset and Values Transformation to incorporate inner dimensions (values, beliefs) into policy and practice (Osberg & Wamsler, 2022; Bristow & Wamsler, 2022), and
- Multi-sectoral and Lifelong Learning to extend climate education to all ages and professions (Fazlagić *et al.*, 2021; Bristow & Wamsler, 2022)

4.2. *Tailored Educational Initiatives & Regional Approaches*

Tailored educational initiatives and region-specific policies in climate change education are strategies that adapt teaching and policy approaches to the unique needs, perceptions, and vulnerabilities of different communities. These approaches make climate education more relevant, engaging, and effective by connecting it to local realities and involving community members.

Programs use local examples, hands-on activities, and community projects to help students relate climate science to their daily lives. For example, after-school programs with interactive activities and youth-led climate action increased children's engagement, confidence, and interest in science, especially among underrepresented groups (Weinberg & Trott, 2020). Initiatives where students collaborate with experts and conduct their own climate adaptation projects foster critical thinking, adaptation knowledge, and problem-solving skills. These approaches go beyond standard curricula and help build cognitive adaptive capacity in adolescents (Riede *et al.*, 2021). Educational efforts that consider how people in different regions perceive climate change and its effects (such as crop diseases or water shortages) can better address local concerns and motivate action (Phuyal *et al.*, 2025).

Policies informed by regional climate data and community perceptions can target the specific environmental and health challenges faced by different areas, from lowlands to mountainous regions (Phuyal *et al.*, 2025). Effective policies encourage the involvement of local stakeholders in designing and delivering climate education, ensuring that initiatives are culturally appropriate and address the community's distinctive needs (Phuyal *et al.*, 2025). Region-specific policies aim to provide equitable climate education across diverse landscapes, helping all communities build resilience to climate change (Phuyal *et al.*, 2025).

Place-based, participatory, and action-oriented climate education programs significantly increase children's engagement with science, improve attitudes toward science, and inspire aspirations for STEM careers. These approaches make science more relevant and empower students to take climate action in their communities (Weinberg & Trott, 2020). Yet, long-term climate change education programs can enhance adolescents' knowledge, critical thinking, and forward-thinking skills related to climate adaptation, even if changes in risk perception are less evident. Such programs are more effective than standard curricula in developing adaptive capacity (Riede *et al.*, 2021).

4.3. *Advocacy and Policy Skills Development*

Integrating advocacy and policy skills development into climate change education is essential for empowering learners to take meaningful action and influence policy. The research highlights that practical, experiential, and interdisciplinary approaches are most effective for building these skills.

Structured workshops using real-world policy scenarios, advocacy templates, and group exercises significantly improve students' readiness and ability to advocate for climate-related policies. These activities help students practice preparing advocacy documents and presentations, boosting their confidence and awareness of advocacy opportunities (Herzog *et al.*, 2023). Field learning journeys and community-based projects connect students with local climate challenges, fostering environmental stewardship, advocacy orientation, and collaborative problem-solving skills. Grounding education in local contexts makes advocacy and policy skills more relevant and actionable (Owusu *et al.*, 2025).

Embedding climate change, advocacy, and policy content across disciplines like nursing, medicine, and atmospheric science ensures that students develop both scientific understanding and the ability to communicate and advocate for policy change (Ye *et al.*, 2024). Assignments that require persuasive and narrative communication help students practice public discourse and advocacy, making them more effective in influencing policy and public opinion (Labosier & Fay, 2019).

Programs that train youth in advocacy build confidence, optimism, and a sense of ownership, which are crucial for sustained engagement in policy processes. Intergenerational dialogue and collaboration with stakeholders further enhance agency

and civic engagement (Botchwey & OConnell, 2023; Middleton & Wodika, 2020; Gray & Okada, 2023; Rushton, 2024). Developing leadership and partnership skills prepares students to work with diverse groups, including policymakers, educators, and community members, to drive climate action (Ye *et al.*, 2024; Owusu *et al.*, 2025).

5. Conclusion

Climate change education is rapidly evolving into a multidimensional field that integrates cognitive, emotional, and action-oriented learning to meet the complex demands of the climate crisis. The last five years have witnessed significant innovations, particularly in participatory teaching methods, interdisciplinary integration, and the expansion of digital learning platforms. These developments are supported by growing evidence that transformative, justice-informed, and locally grounded approaches foster deeper learner engagement, critical thinking, and adaptive capacity. Despite these gains, the full potential of CCE is constrained by persistent structural challenges, including fragmented curricula, limited teacher training, insufficient policy support, and inequitable access to resources and opportunities.

Overcoming these barriers demands a systemic rethinking of education policy, practice, and infrastructure. This includes embedding climate literacy across all levels of education, prioritizing professional development, and aligning curricula with broader societal goals such as sustainability, equity, and civic empowerment. For CCE to serve as a catalyst for climate resilience and social transformation, it must be contextually responsive, forward-looking, and rooted in both scientific understanding and democratic engagement. Advancing such a vision will require coordinated action across educational institutions, governments, and communities.

It is really important to mention that the environmental damages have a long-run character with various synergistic effects (Halkos 1993a,b; 1994, 1998) and a relevant uncertainty in defining the optimal pollution levels (Halkos and Kitsou, 2015) as well as the effects on weather related environmental hazards. This emphasizes the importance of understanding the problem well in all its dimensions leading to actions towards sustainability.

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