Learning Approach to Climate Change Education as a Framework for Sustainability Education: A Systematic Review of Literature

Syarifatul Luthfia [a, *]

[a] SD Al-Irsyad Banyuwangi

* Corresponding author: syarifatulluthfia @gmail.com

ABSTRACT: Earth's society is facing a complex problem, it is climate change. This phenomenon has caused significant impacts on human life, such as water crises, natural disasters, health problems, food shortages, and other socio-economic challenges. Educational must contributes to this important matter. Therefore, the development of a sustainable educational framework to address this issue is imperative. Education is a strategic field to influence individuals, particularly students to develop knowledge, skills, and the capacity to adapt and mitigate to climate change. Based the importance of sustainable education to face climate change problems, needed to study about the approach of climate change-related learning. The aim of this research is to gain an in-depth insight into the various approaches of Climate change Education (CCE) application in primary and secondary school. This study used a systematic literature review method to collect and analyse data from 28 articles relevant to the topic under study. So far, there hasn't conducted study about the approach climate change learning with SRL (Systematic Review of Literature) methode from 2015 to 2024 from diverse prespectives. Results of the study classified various of approaches, there are curriculum, professional development, learning model, interdicipliner, project, and community approach. This research shows that climate change education involves not only students and teachers but also the local community. The implications of the results of this study are useful for the development of climate change education as sustainability education.

Keywords: climate change education, sustainability education, climate change learning, personal development, curriculum

INTRODUCTION

The climate crisis is the greatest social challenge of the 21st century. It requires mitigate and adapt actions climate change to reduce greenhouse emissions [1]. Climate change is a threat to current and future generations because it influences animal, crop types and yields, vegetation patterns, and cropping season's length [2] and the phenomenon represents a significant threat to the development and health over the last century. It threatens respiratory, cardiovascular and renal wich may be triggered by heat waves or air pollution [3]. Therefore, ducational researchers from several diciplinary and methodological traditions must contribute to this most important matter.

Education at all school levels is essential to face the challenges of climate change for a better living environment in the future [1]. Education plays a pivotal role in this endeavour, particularly through the formal education system and other avenues of public enlightenment [4], to ensure that future generations are equipped with the knowledge and awareness to make informed decisions. It is therefore considered that education is the most effective method for transforming a people's social, psychological, physical, political, intellectual and developmental characteristics. The curriculum is the means by which this transformation is achieved [2]. Education has the potential to influence attitudes and shape commitments and actions throughout the lifespan. The successful mitigation and drawdown of global CO_2 levels will require a structural approach, with education representing a crucial element of social infrastructure [5]. Climate change would seem to some to be a pressing issue which American schools

should take up as a topic of inquiry [6]. The most significant potential contribution of education to effective climate change adaptation is its capacity to facilitate preparation for and learning from climate impacts [7]. Education for Sustainable Development (ESD) is fundamental topic for educational institutions in Philippines. Knowledge can modify behavior, raising awareness wich may affect self-efficacy in decreasing the impact of human activity [8].

Teaching climate change is a challenge for teachers. Developing a deep understanding about climate change is challenging for teacher because the underlying scientific principles are complex, and understanding why scientists that Earth's global climate is changing is also complex. To gain better understanding, students need to engage in epistemic cognitive processes that reflect scientific reasoning used to connect evidence and explanations [9]. Based of it, the aim of this research is to gain an in-depth insight into the various approaches of Climate change Education (CCE) application in primary and secondary education. This study employs the Systematic Literature Review (SLR) method to gather, analyze, and synthesize data from various relevant articles spanning from 2015 to 2024. The novelty of this research lies in the comprehensive and systematic SLR approach employed to explore various overview of CCE approaches. The study provides an overview of curriculum, personal development, learning model, interdisciplinary, project, and community (indigenous community) approaches.

RESEARCH METHODS

The study utilized the Systematic Literature Review (SLR) method, which entailed the identification, examination, evaluation, and interpretation of all research studies gathered and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) as a tool and guide for assessing systematic reviews. In the field of health, systematic reviews and meta-analyses are instrumental tools for producing reliable summaries of healthcare information for clinicians, decision makers, and patients. The PRISMA statement was developed to enhance the reporting of systematic reviews and meta-analyses [10, 11]. The PRISMA statement was developed with the specific purpose of enhancing the reporting of systematic reviews that incorporate network meta-analyses. The PRISMA statement is a reporting guideline designed to optimize the comprehensiveness of reporting in systematic reviews and meta-analyses [12].
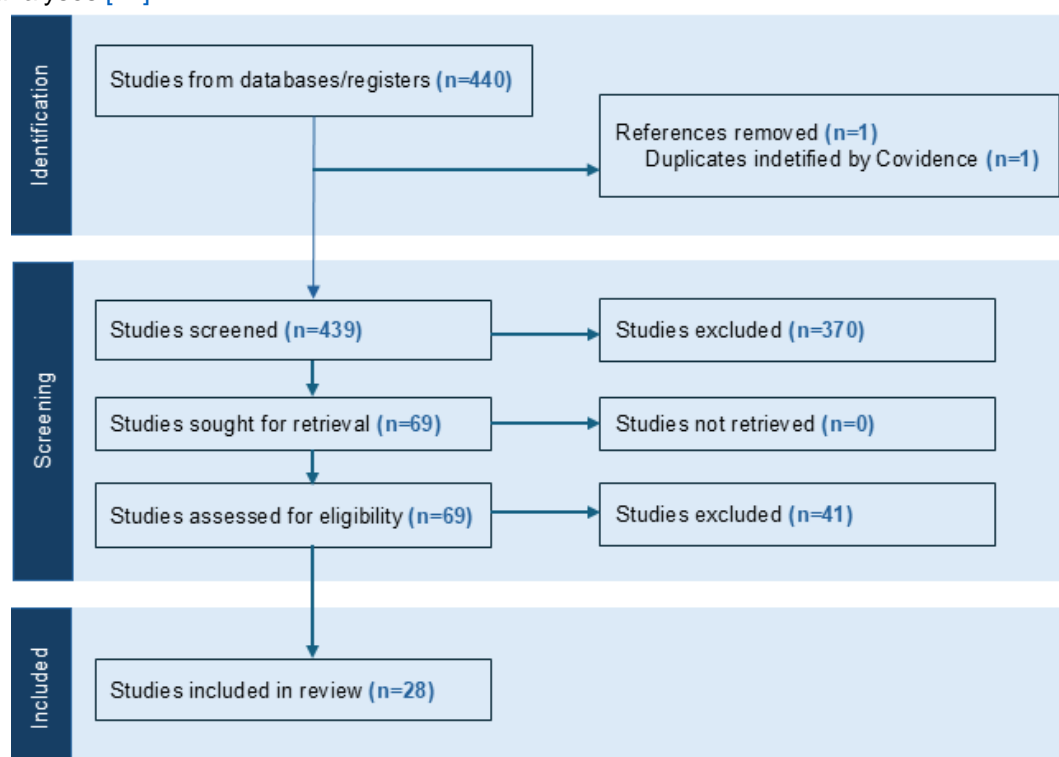

FIGURE 1. Flow diagram illustrating the process of selecting scientific studies according to the PRISMA guidelines

The SLR method with PRISMA helps researchers to gain in-depth insights into various approaches to implementing Climate Change Education (CEC). The data and findings presented in this study are based on a systematic and balanced analysis of relevant sources. The key search term was used, the keyword is climate change education* OR sustainable education* OR learning* OR teaching* OR curriculum* OR approach* NOT university from 2015 to 2024. A total of 440 studies were screened from Google Scholar, Scopus, and Springer through Harzing's Publish or Perish application. There are 28 relevant articles were identified and collected by the researcher. Twenty-eight articles were selected based on their alignment with Climate Change Education (CCE) learning approaches or strategies in schools worldwide. The selection criteria included relevance to formal education, a focus on primary and secondary levels, and empirical evidence supporting the effectiveness of these approaches. The researcher excluded the university level, thus the study is limited to the early childhood, primary and secondary education levels. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) schema is presented in Figure 1.

RESULT AND DISCUSSION

The twenty-eight relevant articles were identified and summarised into a graph in Figure 2 and the researcher will explain for each approach.
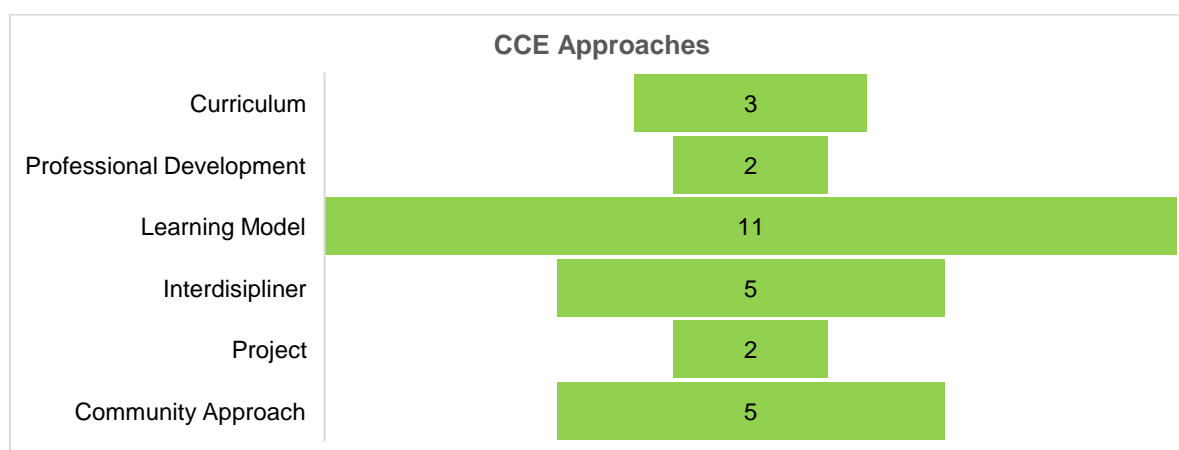

FIGURE 2. CCE approaches in the world 2015-2024

3.1 Curriculum

The following Table 1 presents the results of an analysis of 3 articles on the CCE curriculum.

TABLE 1. CCE curriculum

Titles	Results	References
Bicycle model on climate change education: presenting and evaluating a model	The research posits that the bicylce curriculum contributes to CCE (Wheels: knowledge and thinking skills; Frame: identity, values, and worldview; Chain and pedals: action; Saddle: motivation and participation; Brakes: operational barriers; Lights: hope and emotion; Handlebar: future orientation)	[13]
The views of teachers in England on an action-oriented climate change curriculum	The majority of teachers in the UK (51%) favour a cross-curriculum approach involving six or more subjects, which would deliver CCE (interdisciplinary CCE). Teachers favour action-based and social justice CCE (Climate Change Education) curriculum. These include mitigation projects such as conservation, local tree planting and family advocacy. Local campaigns (e.g. legal demonstrations) are considered appropriate in the primary/middle school transition period	[14]

Titles	Results	References
A Structural Model of Future-Oriented Climate Change Optimism in Science Education: PISA Evidence from Countries with Top Environmental Protection Index	PISA data shows that 15-year-old students from Denmark, the UK and Finland show low levels of optimism about the future of climate change. This is partly influenced by informal science literacy including multimodal and multimedia texts. Therefore, there is a need to develop a future-orientated climate education optimism curriculum. Optimism is based on an attitude of hope and anticipation	[15]

The first study for the curriculum aspect is presented in the form of a bicycle model. The CCE model is imaged as a bicycle that requires all of it parts function together and needed a user to be constant motion. The bicycle model was well presented had highlighted the essential aspects of CCE and putting these parts together to form one entity (knowledge and thinking skills; identity, values, and worldview; action; motivation and participation; operational barriers; hope and emotion; future orientation) [13]. In line with this model, Cheung [15] stated that the Optimism Curriculum as a further insight into developing future-oriented CCE. Future-oriented optimism curriculum encompassing hope and anticipation the climate future. Background Developed this curriculum based on the outcome of 15-year-old students' optimism about climate change future was conducted on the PISA in Denmark, UK and Finland. Based on this finding, students' hope and anticipation about climate change needs to be developed and a future-oriented optimism curriculum is part of the solution.

In addition, CCE's interdisciplinary curriculum was action-based and social justice was another good insight [14]. A social justice curriculum was recommended in the 21st century [16]. Howel and Allen [17] found that the social justice implications of climate change have been recognised by educators in the UK. Social justice principles had significant benefits such as personal reflection, challenge, and evaluation [18]. Trott [19] outcome study showed that young people recommended an emphasis on equity and action-oriented CCE to equip all learners with the knowledge and skills to make an active contribution to climate change.

3.2 Professional Development

The following Table 2 presents the results of an analysis of 2 articles on the professional development.

TABLE 2. Professional Development on CCE

Titles	Results	References
Climate Change Professional Development: Design, Implementation, and Initial Outcomes on Teacher Learning, Practice, and Student Beliefs	The Climate Change Academy is a hybrid professional development programme, combining face-to-face and online learning, designed to equip formal and informal science teachers at the primary and secondary levels with the knowledge and skills to effectively teach climate change. The programme's outcomes demonstrate that it has enhanced climate learning and pedagogical strategies for teaching climate change.	[20]
Marine Science, Climate Change, and the Next Generation Science Standards: Understanding the Knowledge and Perspectives of K-8 New Jersey Teachers	The findings indicated that educators lacked the requisite preparedness to effectively address climate change in the classroom. On a scale of 0-10, the average teacher confidence in their ability to teach climate change was 5.1, while the average interest in learning about effective climate change teaching was 7.8. In light of the aforementioned findings, this research proposes the following recommendations: 1. The design of a teacher professional development experience through the NGSS website should engage with crosscutting concepts, science practices, and core areas. 2. The NGSS standards should identify clear examples of climate change. 3. Present clear descriptions of climate change science phenomena and activities	[21]

The teaching of climate change requires a high level of preparation on the part of educators, given the magnitude of the challenge it presents to the planet. A significant number of educators find the subject of climate change challenging to teach due to their limited understanding of the scientific principles involved and the prevalent perception of controversy or threat to personal beliefs, which is often misplaced [22]. Professional development (PD) in the teaching of climate change is an essential element in the acquisition of conceptual knowledge by both teachers and students [23] The results of the study showed that professional development could enhance teachers' knowledge and skills to teach climate change effectively. Teachers can design effective pedagogical strategies for teaching climate change. The government should contribute for CCE and provide programme or website to develop professional development or material content [20, 21].

3.3 Learning Model

The following Table 3 presents the results of an analysis of 11 articles on the learning model.

TABLE 3. Learning model of CCE

Titles	Learning Model	Aspects	References
Enhancing Primary School Students' Knowledge about Global Warming and Environmental Attitude Using Climate Change Activities	A 5E learning cycle approach (engagement, exploration, explanation, elaboration, and evaluation)	Knowledge and attitude	[24]
Western Australian High School Students' Understandings about the Socioscientific Issue of Climate Change	A inquiry-based module (included activities used analogy, perdiction-observation-explanation, direct investigation, and argumentation)	Knowledge (interconnection concepts)	[25]
Climate change games as tools for teaching and engagement, Games and climate literacy, Gamification to prevent climate change: A review of games and apps for sustainability	Gamification	Attitudes	[26, 27, 28]
Designs for learning about climate change as a complex system	PF (Productive Failure)	Student's interest on Climate change topic	[29]
Immersive Virtual Reality Field Trips Facilitate Learning About Climate Change	Immersive Virtual Reality (IVR)	Knowledge and attitude	[30]
Understanding Climate Change Topics Critically Through Android-based Module for Student	Android-based modules with the Search, Solve, Create, and Share (SSCS)	Critical thinking-skills	[31]
Assessing the Impact of Weather and Climate Curriculum on Youth Science Comprehension	The integration of inquiry-based learning and experiential education	Knowledge	[32]
Application of Immersive Virtual Learning to Understanding Climate Change Concepts and Thinking Process Skills	Immersive Virtual Learning (IVL)	Knowledge and thinking skills	[33]

Titles	Learning Model	Aspects	References
Enhancing Critical Thinking On Climate Change: TPACK Implementatition in PBL With Digital Posters	The integration of the PBL (Problem-Based Learning Model) and digital poster within the TPACK (Technological, Pedagogical, and Content Knowledge)	Critical thinking-skills	[34]

A review of the literature suggests that educators can improve the different aspects and there are knowledge, attitudes, interest in the CCE topic, thinking skills especially critical thinking. This learning models supports the objectiv of CCE. The objective of environmental education is not merely to enhance the knowledge base of individuals, but also to facilitate the development of sustainable societies by fostering changes in environmental attitudes and behaviours. The results of the study provide insight for teachers to apply various learning models which are summarised in Table 3.

3.4 Interdisciplinary
The following Table 4 presents the results of an analysis of 5 articles on the interdisciplinary.

TABLE 4. Interdisciplinary of CCE

Titles	Results	References
Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit	The socio-scientific issue (SSI) model offers a constructive approach for secondary students to develop robust conceptual frameworks concerning the interconnections between the carbon cycle and climate change.	[35]
Preparing engineering students for collaborative project-work Piloting an online course on PBL and project management	The SCA (Science, Camera, Action) programme is an climate change learning based on participatory art. It was conducted after school for 15 weeks. The programme employed the photovoice method, which is a form of action research. This involved the use of digital photography to identify problems, facilitate team and social discussion, and encourage change in action.	[36]
Learning about climate change in, with and through art	The utilisation of art as a pedagogical tool has the potential to facilitate transformative and profound learning in the context of climate change education.	[37]
Analysis of Needs for Development of Android-Based Socioscientific Issues Teaching Materials on the Topic of Climate Change to Improve Students' Decision-Making	The findings of the study indicated that students' capacity to make informed decisions regarding climate change remains limited, with their decisions largely influenced by their personal perspectives. In light of these findings, it is imperative to develop socio-scientific materials based on Android for the context of climate change, with the aim of fostering the decision-making abilities of students.	[38]
An educational project exploring the synergy between art and science to improve understanding and awareness of climate change	Students' understanding of climate change phenomena and actions can be enhanced through arts and science-based learning approaches. Through an arts and science integration workshop from March to May 2024, students were invited to imagine climate change and create artistic worlds through interactive photos and virtual maps. This process involves both scientific and artistic processes.	[39]

The finding of the study indicated that integrating interdisciplinary or intradisciplinary approaches from diverse sources of knowledge, such as social and natural sciences, is a complex yet crucial endeavour in climate change research and the development of climate change action strategies [40]. A number of interdisciplinary journals have demonstrated that CCE can be integrated with the arts or humanities [36, 37, 39]. Abalos [39] posited that strong synergi of scientific and artistic perspectives on climate change can evoke a sense of moral responsibility in students, motivating them to engage in proactive action through suprising and fun way experience and emotions in learning process. The CCE topic for young people is perceived as being of an abstract, distinct, and complex nature, and contributes to the development of feelings of sadness, hopelessness, and anxiety. Those engaged in the teaching and facilitation of young people, as well as those engaged in research, can utilise the potential of the arts [37].

A socio-scientific approach could be employed in the context of climate change education [35, 38]. Socio-scientific issues can creates ideal context for bridging science and lived experience of students [41]. Socio-scientific Issue (SSI) is a new trend in science education to promote the science literacy. Science lietarcy promotes a potential learning alternative that involves the aspects of science and society. The resolution of SSI cannot be achieved through the exclusive application of scientific knowledge. Rather, it necessitates the integration of diverse social elements and viewpoints [42]. The phenomenon of climate change is a complex context, comprising both scientific knowledge and social aspects. The SSI can be an effective approach to teaching about it.

3.5 Project
The following Table 5 presents the results of an analysis of 2 articles on the project of CCE.

TABLE 5. Project of CCE

Titles	Results	References
Education for what? Shaping the field of climate change education with children and young people as co-researchers	The Climate Change + Me project, which is government-funded and supported, provides children and young people with the opportunity to adopt a proactive stance on climate change and environmental issues.	[43]
You and CO_2: a Public Engagement Study to Engage Secondary School Students with the Issue of Climate Change	The "You and CO_2" programme is a STEAM initiative that aims to foster self-reflection among students on environmental issues and encourage them to engage in positive social action. Upon completion of the programme, students are tasked with producing digital fiction, thereby affording them the opportunity to engage in creative exploration.	[44]

CCE can teach through project-based learning [44, 41]. Project-based learning involves students working on vital and engaging real-world challenges over an extended period of time. The study's findings indicate that CCE can be effectively implemented through projects, motivating students and social to adopt proactive and socially engaged approaches to addressing climate change [43, 44].

3.6 Community Approach
The following Table 6 presents the results of an analysis of 5 articles on the community approaches of CCE.

TABLE 6. Community approach of CCE

Titles	Results	References
What Is Climate Change Education?	The co-curricular initiative and community approach represents a potential solution to the issue of time constraints within the curriculum and the	[45]

Titles	Results	References
	integration of climate change learning in the classroom.	
The status of Indigenous knowledge, environmental issues and climate change in science education: Talanoa from Ha 'apai (Tonga) and Port Vila (Vanuatu)	The indigenous communities of Ha'pai and Port Villa are committed to upholding their cultural and ancestral values. In light of this, educational institutions have the potential to develop an inclusive curriculum that incorporates local cultural values in order to address the challenges posed by climate change and natural disasters.	[46]
A case for climate justice education: American youth connecting to intragenerational climate injustice in Bangladesh	This study promotes climate change education as applied contextual learning (from abstract to real phenomena) and calls it a social justice approach. Students carry out this programme by visiting slum settlements in Dhaka, Bangladesh. Students directly learned, interviewed, surveyed and directly felt the impact of climate change.	[47]
Climate change education in the humanities classroom: a case study of the Lowell school curriculum pilot	Humanities-based CCE can increase students' literacy and enthusiasm for climate change. In addition, the focus on action or solutions can be strengthened by incorporating authentic and meaningful action projects in local communities. Examples such as field trips, reforestation projects, developing school-community collaborations enhance project-based learning that has meaningful impact.	[48]

A review of several academic journals has revealed a variety of insights related to the CCE through a community approach. The studies conducted by [46] indicated that the CCE could be effectively taught through an indigenous community-based approach. Indigenous which also known as traditional or local knowledge refers to place-based knowledge rooted in the culture and traditions of a particular community. The study by [49] demonstrated that indigenous knowledge constituted a significant repository of information and practices for enhancing adaptive capacity in the Pacific region in the context of climate change. Furthermore, it could also foster conservative attitudes within the community. The findings of study showed that connection between indigenous communities and ancestral territories, emphasised the significance of upholding indigenous sovereignty over land for sustainable adaptation to climate change. Relational learning is important as a form education, fostering resilience rooted in preserving traditional practices and spaces [50]. Based on that, it given insight for us that utilising indigenous community for CCE is one good suggestion to consider.

CONCLUSION

The success of CCE (Climate Change Education) learning in schools must pay attention to various aspects, namely curriculum, teacher self-development, learning approaches, and utilizing the community. CCE cannot only be taught in one subject, but must be integrated with various subjects at school (multidisciplinary). The government should give serious attention to CCE such as providing websites, materials, and professional development training for teachers like in the UK. Cooperation between school and community is also important to encourage meaningful CCE learning for students through various projects with the community. For researchers, an area that still needs to be explored or that needs to be investigated further is indigenous communities for CCE learning to improve the ability of communities to adapt and mitigate this phenomenon. The findings of this study review contribute to

the advancement of knowledge especially for governments, school policy holders and teachers. CCE cannot be implemented if the government does not support or establish a system that cares about the environment and sustainable lifestyles.

REFERENCES

[1]   J. Kranz, M. Schwichow, P. Breitenmoser, and K. Niebert, "The (Un)political Perspective on Climate Change in Education—A Systematic Review," *Sustainability (Switzerland)*, vol. 14, no. 7, Apr. 2022, doi: 10.3390/su14074194.

[2]   A. H. Ahmed, O. A. Ibrahim, and M. W. Agunbiade, "Integrating Climate Change and Smart Agriculture Contents into Nigerian School Curriculum," *Indonesian Journal of Curriculum and Educational Technology Studies*, vol. 10, no. 1, pp. 1–8, Apr. 2022, doi: 10.15294/ijcets.v10i1.50938.

[3]   J. Maxwell and G. Blashki, "Teaching about climate change in medical education: an opportunity," *J Public Health Res*, vol. 5, p. 673, 2016, doi: 10.4081/jphr.2016.673 .

[4]   Nwankwoala, "Causes of Climate and Environmental Changes: The need for Environmental-Friendly Education Policy in Nigeria," *Journal of Education and Practice*, vol. 6, no. 30, pp. 224–234, 2015, [Online]. Available: https://eric.ed.gov/?id=EJ1081366

[5]   C. Kwauk and O. Casey, "Approaches to quality education for climate action A new green learning agenda Approaches to quality education for climate action," 2021. Accessed: Feb. 19, 2025. [Online]. Available: https://www.brookings.edu/wp-content/uploads/2021/01/Brookings-Green-Learning-FINAL.pdf

[6]   D. Long and J. Henderson, "Climate change as superordinate curriculum?," *Research in Education*, vol. 117, no. 1, pp. 73–87, Nov. 2023, doi: 10.1177/00345237231160080.

[7]   N. W. Feinstein and K. J. Mach, "Three roles for education in climate change adaptation," *Climate Policy*, vol. 20, no. 3, pp. 317–322, Mar. 2020, doi: 10.1080/14693062.2019.1701975.

[8]   M. I. C. Valencia, "Introducing Education For Sustainable Development (ESD) In The Educational Institutions In The Philippines," *Journal of Sustainable Development Education and Research*, vol. 2, no. 1, pp. 51–57, 2018, doi: 10.17509/jsder.v2i1.12358.

[9]   D. Lombardi, E. M. Nussbaum, and G. M. Sinatra, "Plausibility Judgments in Conceptual Change and Epistemic Cognition," *Educational Psychologist*, vol. 51, no. 1, pp. 35–56, Jan. 2016, doi: 10.1080/00461520.2015.1113134.

[10]   N. Panic, E. Leoncini, G. De Belvis, W. Ricciardi, and S. Boccia, "Evaluation of the endorsement of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement on the quality of published systematic review and meta-analyses," *PLoS One*, vol. 8, no. 12, Dec. 2013, doi: 10.1371/journal.pone.0083138 .

[11]   J. Wen, Y. Ren, L. Wang, Y. Li, Y. Liu, M. Zhou, P. Liu, L. Ye, Y. Li, and W. Tian, "The reporting quality of meta-analyses improves: A random sampling study," *J. Clin. Epidemiol.*, vol. 61, no. 8, pp. 770–775, 2008, doi: 10.1016/j.jclinepi.2007.10.008.

[12]   B. Hutton *et al.*, "The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: Checklist and explanations," *Ann. Intern. Med.*, vol. 162, no. 11, pp. 777–784, Jun. 2015, doi: 10.7326/M14-2385.

[13]   H. Cantell, S. Tolppanen, E. Aarnio-Linnanvuori, and A. Lehtonen, "Bicycle model on climate change education: Presenting and evaluating a model," *Environ. Educ. Res.*, vol. 25, pp. 1–15, 2019, doi: 10.1080/13504622.2019.1570487.

[14]   P. Howard-Jones, D. Sands, J. Dillon, and F. Fenton-Jones, "The views of teachers in England on an action-oriented climate change curriculum," *Environ. Educ. Res.*, vol. 27, no. 11, pp. 1660–1680, 2021, doi: 10.1080/13504622.2021.1937576.

[15]   K. K. C. Cheung, "A structural model of future-oriented climate change optimism in science education: PISA evidence from countries with top environmental protection index," *Res. Sci. Educ.*, pp. 1–21, 2024, doi: 10.1007/s11165-024-10164-7.

[16]   T. Moloi, M. Matabane, C. Simuja, B.-I. Seo, and B. Tarman, "Constructing a Social Justice Curriculum Policy in the 21st Century", *REPAM*, vol. 5, no. 3, p. i-iv, Dec. 2023., doi: 10.46303/repam.2023.36.

[17] R. A. Howell and S. Allen, "Significant life experiences, motivations and values of climate change educators," *Environ Educ Res*, vol. 25, no. 6, pp. 813–831, Jun. 2019, doi: 10.1080/13504622.2016.1158242.

[18] H. A. Neville, "Social Justice Mentoring: Supporting the Development of Future Leaders for Struggle, Resistance, and Transformation," *Couns Psychol*, vol. 43, no. 1, pp. 157–169, Dec. 2014, doi: 10.1177/0011000014564252.

[19] C. D. Trott, "Envisioning action-oriented and justice-driven climate change education: Insights from youth climate justice activists," *Children & Society*, 2024, [Online]. Available: https://api.semanticscholar.org/CorpusID:267948349

[20] N. Shea, C. Mouza, and A. Drewes, "Climate Change Professional Development: Design, Implementation, and Initial Outcomes on Teacher Learning, Practice, and Student Beliefs," *J Sci Teacher Educ*, vol. 27, pp. 235–258, 2016, doi: 10.1007/s10972-016-9456-5.

[21] L. Madden, L. Ammentorp, N. Magee, and G. Taylor, "Marine Science, Climate Change, and the Next Generation Science Standards: Understanding the Knowledge and Perspectives of K-8 New Jersey Teachers," *Current: The Journal of Marine Education*, vol. 38, no. 1, pp. 3–15, 2023, doi: 10.5334/cjme.7.

[22] E. Plutzer and A. L. Hannah, "Teaching climate change in middle schools and high schools: investigating STEM education's deficit model," *Clim Change*, vol. 149, no. 3, pp. 305–317, 2018, doi: 10.1007/s10584-018-2253-8.

[23] A. Drewes, J. Henderson, and C. Mouza, "Professional development design considerations in climate change education: teacher enactment and student learning," *Int J Sci Educ*, vol. 40, no. 1, pp. 67–89, Jan. 2018, doi: 10.1080/09500693.2017.1397798.

[24] M. Karpudewan, W. Roth, and M. N. S. Abdullah, "Enhancing Primary School Students' Knowledge about Global Warming and Environmental Attitude Using Climate Change Activities," *Int J Sci Educ*, vol. 37, p., 2014, doi: 10.1080/09500693.2014.958600.

[25] V. Dawson, "Western Australian High School Students' Understandings about the Socioscientific Issue of Climate Change," *Int J Sci Educ*, vol. 37, no. 7, pp. 1024–1043, 2015, doi: 10.1080/09500693.2015.1015181.

[26] J. Wu and J. Lee, "Climate change games as tools for teaching and engagement," *Nat Clim Chang*, vol. 5, pp. 413–418, 2015, doi: https://doi.org/10.1038/nclimate2566.

[27] M. Fung, L. Tedesco, and M. Katz, "Games and climate literacy," *Nat. Geosci.*, vol. 8, p. 576, 2015, doi: 10.1038/ngeo2499.

[28] B. D. Douglas and M. Brauer, "Gamification to prevent climate change: A review of games and apps for sustainability," *Curr. Opin. Psychol.*, vol. 42, pp. 89–94, 2021, doi: 10.1016/j.copsyc.2021.04.008.

[29] M. J. Jacobson, L. Markauskaite, A. Portolese, M. Kapur, P. K. Lai, and G. Roberts, "Designs for learning about climate change as a complex system," *Learn Instr*, vol. 52, pp. 1–14, 2017, doi: 10.1016/j.learninstruc.2017.03.007.

[30] D. M. Markowitz, R. Laha, B. P. Perone, R. D. Pea, and J. N. Bailenson, "Immersive Virtual Reality Field Trips Facilitate Learning About Climate Change," *Front Psychol*, vol. 9, p., 2018, doi: 10.3389/fpsyg.2018.02364.

[31] T. Anggraeni and T. Aminatun, "Understanding Climate Change Topics Critically Through Android-based Module for Student," *Indonesian Journal of Curriculum and Educational Technology Studies*, vol. 7, pp. 80–88, 2019, doi: 10.15294/ijcets.v7i2.32146.

[32] T. Dormody, P. Skelton, G. Rodriguez, D. DuBois, and D. Vanleeuwen, "Assessing the Impact of Weather and Climate Curriculum on Youth Science Comprehension," *J Agric Educ*, vol. 62, p. 2021, 2021, doi: 10.5032/jae.2021.03153.

[33] A. Al Mufida, A. Widodo, and R. Solihat, "Application of Immersive Virtual Learning to Understanding Climate Change Concepts and Thinking Process Skills," *Jurnal Penelitian Pendidikan IPA,* vol. 8, no. 3, p., 2022, doi: 10.29303/jppipa.v8i3.1673.

[34] S. Efwinda, I. Puspita, P. Damayanti, A. Hakim, M. Syam, "Enhancing Critical Thinking On Climate Change: TPACK Implementation in PBL with Digital Posters," *Edusains*, vol. 15, no. 2, p., 2023, doi: 10.15408/es.v15i2.33230.

[35] L. Zangori, A. Peel, A. Kinslow, P. Friedrichsen, and T. D. Sadler, "Student development of model-based reasoning about carbon cycling and climate change in a socio-scientific issues unit," *J Res Sci Teach*, vol. 54, no. 10, pp. 1249–1273, 2017, doi: 10.1002/tea.21404.

[36] C. Trott, "Reshaping our world: Collaborating With Children For Community-Based Climate Change Action," *Action Research*, vol. 17, pp. 42–62, 2019, doi: 10.1177/1476750319829209.

[37] J. Bentz, "Learning about climate change in, with and through art," *Clim Change*, vol. 162, no. 3, pp. 1595–1612, 2020, doi: 10.1007/s10584-020-02804-4.

[38] S. I. Putri, I. Hamidah, and W. Liliawati, "Analysis of Needs for Development of Android-Based Socioscientific Issues Teaching Materials on the Topic of Climate Change to Improve Students' Decision-Making," *Jurnal Penelitian Pendidikan*, vol. 9, no. 10, p., 2023, doi: 10.29303/jppipa.v9i10.3694.

[39] M. Ábalos, I. Ortega López, B. Rodríguez-Fonseca, and M. Gil Gayo, "An educational project exploring the synergy between art and science to improve understanding and awareness of climate change," in *Int. Conf. Socioecos 2024: Climate Change, Sustainability and Socio-Ecological Practices*, Jun. 2024, pp. 744–760, doi: 10.1387/conf.socioecos.2024.

[40] J. Kieslinger, P. Pohle, V. Buitrón, and T. Peters, "Encounters between experiences and measurements: The role of local knowledge in climate change research," *Mt Res Dev*, vol. 39, no. 2, pp. R55–R68, May 2019, doi: 10.1659/MRD-JOURNAL-D-18-00063.1.

[41] T. D. Sadler, Ed., *Socio-scientific issues in the classroom: Teaching, learning and research*. 1st ed. Dordrecht, Netherlands: Springer, 2011, doi: 10.1007/978-94-007-1159-4.

[42] M. U. Genisa, B. Subali, Djukri, A. Agussalim, and H. Habibi, "Socio-scientific issues implementation as science learning material," *Int. J. Eval. Res. Educ.*, vol. 9, no. 2, pp. 311–317, Jun. 2020, doi: 10.11591/ijere.v9i2.20530.

[43] A. Cutter-Mackenzie and D. Rousell, "Education for what? Shaping the field of climate change education with children and young people as co-researchers," *Child. Geogr.*, vol. 17, no. 1, pp. 90–104, 2018, doi: 10.1080/14733285.2018.1467556.`

[44] J. A. Rudd, R. Horry, and R. L. Skains, "You and CO2: A public engagement study to engage secondary school students with the issue of climate change," *J. Sci. Educ. Technol.*, vol. 29, pp. 230–241, 2020, doi: 10.1007/s10956-019-09808-5.

[45] R. B. Stevenson, J. Nicholls, and H. Whitehouse, "What is climate change education?," *Curric. Perspect.*, vol. 37, pp. 67–71, 2017, doi: 10.1007/s41297-017-0015-9.

[46] E. P. Luey, R. Manning, and S. Ratuva, "The status of Indigenous knowledge, environmental issues and climate change in science education: Talanoa from Ha'apai (Tonga) and Port Vila (Vanuatu) secondary schools," *Journal of Interdisciplinary Research*, vol. 8, no. 1, pp. 588 – 609, 2024, doi: 10.26021/15181.

[47] S. R. Stapleton, "A case for climate justice education: American youth connecting to intragenerational climate injustice in Bangladesh," *Environ. Educ. Res.*, vol. 25, no. 5, pp. 732–750, 2018, doi: 10.1080/13504622.2018.1472220.

[48] A. Siegner and N. Stapert, "Climate change education in the humanities classroom: a case study of the Lowell school curriculum pilot," *Environ Educ Res*, vol. 26, no. 4, pp. 511–531, 2020, doi: 10.1080/13504622.2019.1607258.

[49] A. A. Granderson, "The role of traditional knowledge in building adaptive capacity for climate change: Perspectives from Vanuatu," *Weather, Climate, and Society*, vol. 9, no. 3, pp. 545–561, Jul. 2017, doi: 10.1175/WCAS-D-16-0094.1.

[50] R. Datta, "Relationality in Indigenous Climate Change Education Research: A Learning Journey from Indigenous Communities in Bangladesh," *Australian Journal of Environmental Education*, vol. 40, no. 2, pp. 128–142, 2024. doi: 10.1017/aee.2024.13.