Integrating Environmental Sustainability into Educational Innovation for Eco-Literate and Climate-Resilient Learning Systems

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Abstract
In the context of the climate crisis, efforts must be made to redesign all levels of Education. Education must be designed to enable functional skills rather than the transfer of content knowledge related to the environment. The barriers of traditional ways of learning have contributed to the disconnections in knowledge, as well as the lack of fostering critical skills like systems thinking, foresight and adaptability, which are important for creating adaptive and resilient communities and institutions. This manuscript seeks to address this significant barrier by proposing the Climate-Resilient Learning System (CRLS) Framework. The CRLS framework threads together the most impactful Educational Innovation for Sustainability (EIS) initiatives, eco-literacy, and climate change adaption. The CRLS framework creates a pathway for educational institutions to facilitate climate-resilient learning. In order for the CRLS to be successfully delivered, it requires the infusion of innovative pedagogy (e.g. digital climate modelling; as part of community action research) throughout the curriculum, institutional governance, and institutional operations of the campus. The CRLS framework is an innovative idea in that it aims to enhance action competency and systemic change, providing a well-developed, replicable framework that can be used to change educational organizations into sustainable innovation centers. This is a direct contribution to the priorities of Sustainable Development Goals (SDGs) in the form of producing eco-literate citizens who are able to create quantifiable environmental, social, and economic changes.

Keywords
Educational Innovation, Eco-Literacy, Climate Resilience, Sustainable Development Goals (SDGs), Systemic Change, Green Education

Introduction
The world population's health is steadily characterized by the extensive and rapidly growing effects of climate change [1]. Alterations in weather patterns around the earth, temperature increase, and extreme weather events are posing severe direct and indirect impacts on human health throughout the globe, which is impacting not only the transmission of disease vectors and food security, but also mental health and air quality. The health sector, being the first line of defense, is at the edge of responding and halting these crises [8]. This requires a professional workforce, not just clinically competent, but also environmentally literate and possessing the systems-thinking and action-competence that is necessary to enhance sustainability and resilience in health systems in all countries around the world [9].

An overview of the literature available indicates that there is a very strong gap between this desperate requirement of a climate-ready workforce and the present level of professional education [2][3]. Although in the literature it is universally acknowledged that environmental education is essential to sustainable practices, the evidence suggests that climate change education (CCE) is not sufficiently covered and regularly built into the health professions curriculum [4][12]. The existing educational system usually leaves graduates that do not meet the necessary level of readiness to address the health issues that are directly connected to climate change and introduce sustainable solutions to the practice [2][5][6].

This is a serious deficiency of integration of CCE-lacking pedagogy and CCE-lacking curriculum. Other research efforts in the past have tended to be very limited either in identifying knowledge gaps or evaluating attitudes in general; thus, there has been a dearth of evidence-based based systematic advice on how best CCE can be incorporated into various health training programs. Such a shortage is a risk to the capacity of health systems to sustain functionality and adaptability to the growing environmental demands [4][16][17]. Consequently, coordinated, novel methods are required to generalize the existing findings in the world and transform them into practical, evidence-based solutions to the curriculum developers and policymakers [6].

Considering the acute necessity and the existing gap in the guidance on the comprehensive pedagogical approach, the key goal of the given integrative review is to answer the following question:
What can be done to incorporate climate change education as a systematic way of bringing environmental sustainability to the healthcare profession and the curricula of health professions successfully [10].
The general objective of this review is to accomplish the following:

- To summarize existing evidence on effective content and pedagogy of CCE in health professional training at an international level.
- To determine the important thematic areas (e.g. policy, advocacy, practice) of CCE integration.
- At this, a conceptual framework should be suggested to frame the implementation of climate-resilient curricula development and adoption of the policy.

Key Contributions

- Launches the Climate-Resilient Learning System (CRLS) Framework, which is a novel framework of system modelling, integrating eco-literacy, creative pedagogy, and institutional governance to create climate-ready schools.
- Summarizes the findings of 41 studies to determine 5 underlying thematic areas, including: curriculum redesign, action-competence pedagogy, governance, campus-as-living-lab, and health systems integration, and serves as an empirical basis of CRLS.
- Makes eco-literacy and action competence the two key learning outcomes, where systems thinking, foresight, and anticipatory skills are the key values of adapting to climate.
- Suggests the three-pillar model (Curricular Integration, Innovative Pedagogy, Institutional Governance) which operationalizes sustainability education outside the classroom knowledge.
- Introduces the Anticipate-Absorb-Adapt cycle as a dynamic process of establishing resilience in institutions and securing permanent adaptation to climatic changes.
- Provides a template of replicating educational change, leading universities and training institutions to be sustainable innovation centers in line with Sustainable Development Goals.

Six sections are used to structure the paper. Section 1 presents the issue of poor climate change education and the necessity of systemic change in the educational system. Section 2 provides a review of the theoretical basis of eco-literacy, Educational Innovation for Sustainability (EIS), and the idea behind Climate-Resilient Learning Systems. Section 3 describes the integrative review methodology applied in order to create the CRLS Framework. The results are introduced in Section 4, and five thematic domains influencing sustainable education systems are found. Section 5 explains how these themes positioned on the CRLS pillars, focusing on innovative pedagogy, governance, and campus operations as forces of resilience. Lastly, Section 6 sums up on the importance of the CRLS model, and strategizes the future research and institutional application.

II. Theoretical Foundations and Literature Review
In response to the educational and curricular challenges outlined in the introduction, this paper is grounded in three core, interrelated concepts: Eco-Literacy, Educational Innovation for Sustainability (EIS), and the need for a Climate Resilient Learning System [11][13]. These concepts shift the focus from simply transmitting knowledge to the need for systemic transformation and the attainment of action competence, a vital educational innovation.

2.1 Defining Eco-Literacy and Action Competence
The underpinning theory of this work is Eco-Literacy, which is the culmination of all levels of environmental awareness until the fully developed sense of Eco-Literacy. This involves understanding the interdependence and relationships of human systems (social, economic, political) with and within ecological systems. This understanding is vital for supporting a sustainable lifestyle. However, Eco-Literacy remains ineffective without Action Competence, which is a more complex, pedagogical goal that involves the learner's ability to define a problem, devise multiple options, and have the means to enact a solution in the real world. In the case of health

professionals, this involves higher-order cognitive skills of Systems Thinking (analyzing relationships and interconnections of disparate elements, e.g., sectoral emissions and health outcomes) and Foresight with Anticipatory Skills (shifting the focus of education to adaptation from climate change aftermath to proactive adaptation).[14][21]

2.2 Educational Innovation for Sustainability (EIS)

For climate change education to be effective and achieve the goal of systemic sustainability, it must be underpinned by Educational Innovation for Sustainability (EIS) [22]. For this paper, EIS is defined as the adoption of fundamentally new pedagogical, curricular or institutional practices that increase a learning system's capacity to respond to environmental challenges [7][23]. Innovation in this case goes beyond incremental change and aims for systemic change for several reasons: Integration of technology using digital simulations and modeling; breaking away from siloing traditional subjects to engage in trans disciplinarity; and looking beyond student learning to also transform university governance and culture for systemic change. Literature reflects that EIS universally, and for the learning environment itself, as top-down and bottom-up processes interwoven. Sustainable principles being taught should be modeled in the environment [24].

2.3 The Concept of a Climate-Resilient Learning System (CRLS)

The integration of advanced Eco-Literacy with Systematic EIS strategies leads to the core conceptual outcome of this paper: Climate-Resilient Learning System (CRLS). A CRLS is an educational model designed to climate-proof a learning system that, with the rapid climate changes, maintains and adapts core functions [15]. Specifically, a CRLS learning system is able to alter its curriculum to focus on anticipated future climate challenges, absorb teaching and research climate shocks, and adapt form and content under disruptive climate changes and local sustainability challenges.

Creating resilient educational institutions, including flexible infrastructure and responsive educational programs will mean that CRLS will produce human capital (the graduates) that will be the first to defend broader societal and health system resilience [18]. This type of innovation within the system is considerably more advanced compared to stagnant and vulnerable curricula [19].

2.4 Synthesis.

The literature is clear on the value of educational innovation and the importance of eco-literacy [20]. However, there is still a definitional gap in integrating and synthesizing the principles into one cohesive, actionable framework that institutions can adopt systemically, considering the pace of climate change. The literature is disparate, with some citing examples of teaching innovations in isolation from one another, and others proposing policy shifts while failing to provide a complete vision of resilient integration of the three key pillars (curriculum, infrastructure, and governance) that provide the fundamentals of educational resilience. This study will address this gap using the CRLS Framework, which will result in an educational innovation model that demonstrates an educative resilience that is sustainable and measurable [25].

III. Methodology: Development of the Innovative Framework

The proposal of the Climate-Resilient Learning System Framework is the primary contribution of this paper. This framework was developed using an organized process of integrative reviews. This methodology aimed to try to combine various evidence-based practices from the disparate fields of environmental education and research on the institutional adaptations, rather than being limited to a traditional summary of literature. This is essential to ensure that the resulting framework reduces the complex issues associated with the innovation gap illustrated in the first section.

3.1 Research Design: Integrative Review

This research used the Integrative Review method; this makes sense in order to synthesize theoretical and empirical literature from different research traditions that are inquiring into climate pedagogy, climate science, and institutional governance. We took a systematic approach comprising five iterative stages to the method: (1) Problem Identification (Section 1); (2) Literature Search (described below); (3) Evaluation of Data, (4) Analysis of Data; and (5) Presentation of Findings (Section 4). The review was also synthesized primarily to answer questions about what was needed to change so educational systems moved from a vulnerable, brittle framework, to an anticipatory, self-adjusting model of systems educational resilience to the impacts of climate change.

3.2. Search Strategy and Data Synthesis

Multiple primary academic databases were the focus of a comprehensive and meticulous search. From these, the published literature for the period of January 2014 to August 2024 was accessible. The intersection of the three primary concepts was the target of the Boolean-restricted keyword search. The three main concepts were: ("climate change education" OR "eco-literacy"), ("health professionals" OR "curriculum" OR "higher education"), and ("sustainability" OR "resilience" OR "innovation"). After implementing the search strategy this produced 41 articles included in our analysis and provided qualitative papers reported within the study. The retrieved articles were subjected to thematic analysis, thereby engaging with the findings of individual studies and forming broad themes. In particular, we concentrated on identifying innovative climate change education teaching strategies, systemic barriers to implementation, and model institutions with climate change education. This was used to elaborate on the proposed framework.
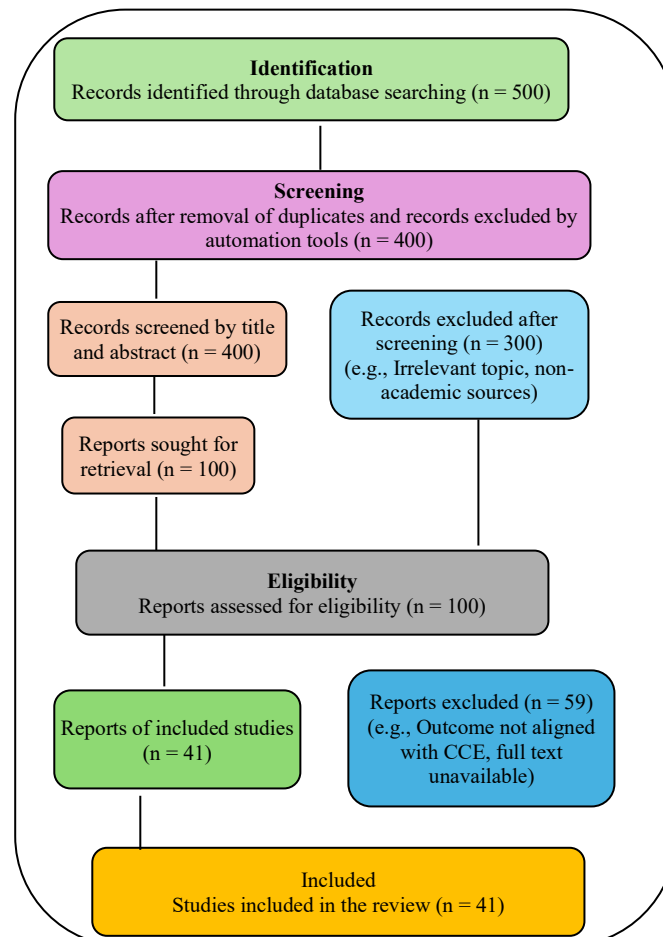

Figure 1: PRISMA Flow Diagram of the Integrative Review Process
The PRISMA Flow Diagram outlines the entire article selection process Figure 1. The first search across various databases yielded 500 records. After removing duplicates and automated exclusions, 400 records proceeded to the title and abstract screening. Of these, 300 were disregarded for being irrelevant or non-academic publications. Following this stringent process, 100 reports remained for full-text retrieval and eligibility determination. Against the inclusion and exclusion criteria, 59 reports were eliminated because of non-CCE-aligned outcomes and full texts that were absent. Ultimately, 41 studies formed the basis of the final integrative review and the synthesis of data.

3.3. The Climate-Resilient Learning System (CRLS) Framework Development (Figure 1)
The new CRLS Framework was created by merging essential themes identified during the review. It is a model that organizes the integration of climate resilience across three key, related areas: Curriculum, Pedagogy, and Institutional Governance. This development process intentionally shifted from the general need for Eco-Literacy to the practical establishment of a resilient institutional structure.

Curricular Integration

Content Domains:

- Climate Health Impacts

Innovative Pedagogy

Methods & Innovation:

- Project-Based Learning (PBL)
- Digital Simulation

Institutional Governance

Policy & Support:

- Policy & Resource Allocation
- Faculty Development (FIS)

CLIMATE-RESILIENT LEARNING SYSTEM (CRLS)

ANTICIPATE (Proactive Curriculum Adjustment)

ABSORB (Maintain Functionality During Shocks)

ADAPT (Continuous Improvement & Evolution)

Foundation: Eco-Literacy & Action Competence

Systems Thinking (Interconnectedness)
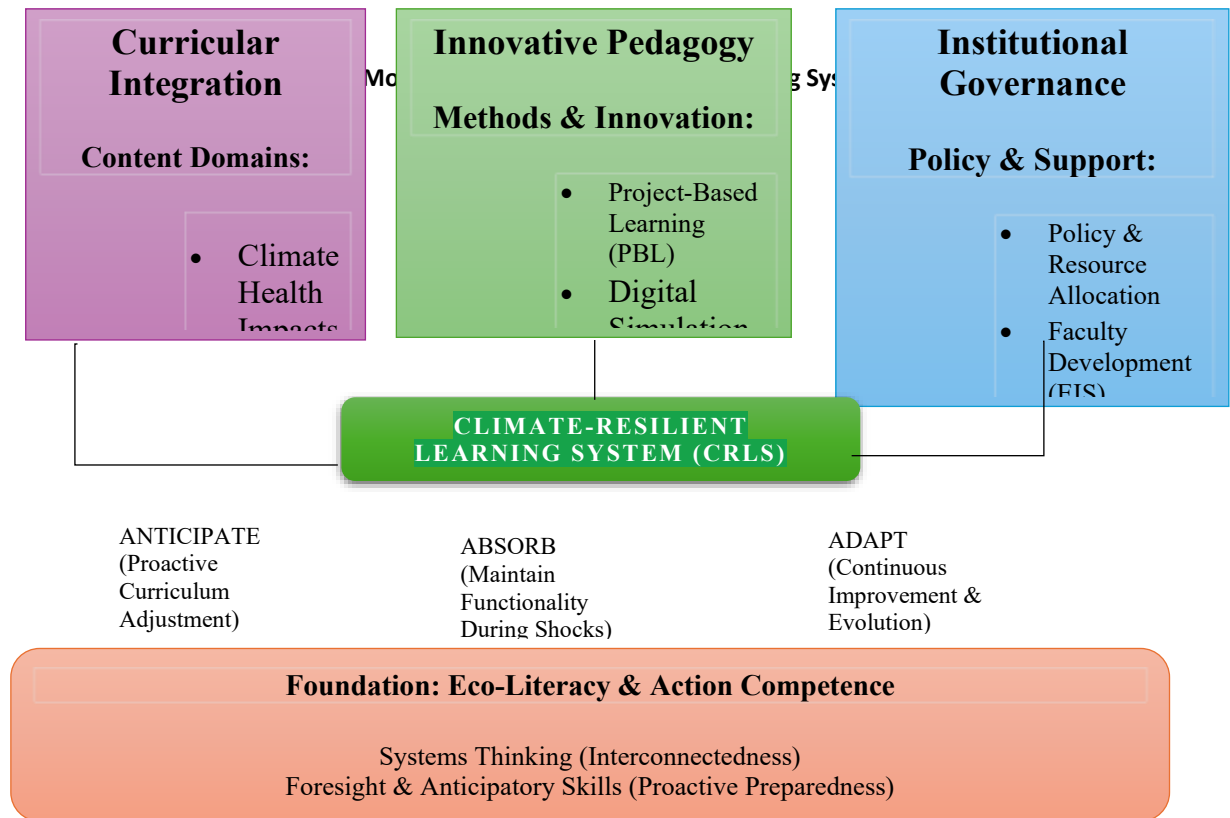Foresight & Anticipatory Skills (Proactive Preparedness)

Figure 2 illustrates that systemic resilience is an organizational outcome and is much more than merely revising a curriculum.

The Foundation focuses on advancing essential learning outcomes, which are Eco-Literacy and Eco-Action Competence. This includes competence in Systems Thinking, which involves understanding and connecting relationships, and Foresight & Anticipatory Skills that include elements of proactive readiness. These concepts are fundamental to the three Integration Pillars. The first of the three Pillars is Curricular Integration, which speaks to what is taught. It looks to establish that climate change education (CCE) isn't simply a bolt-on but is consciously and continuously integrated throughout the curriculum in CCE-related lessons (e.g., on climate health impacts, advocacy, and sustainable practices in healthcare). The second Pillar, Innovative Pedagogy, is concerned with how subjects are taught. It prioritizes active learning and intentional classroom strategies that foster action competence (for example Project-Based Learning, community action research, and research-driven participatory data-driven climate modelling). The third Pillar, Institutional Governance, speaks to where learning occurs. In this pillar, the preferencing of policies should favor consideration of resource distribution and the climate of the organization to better enable CCE to enhance student learning in a governance style that serves students and supports climate action learning. The three pillars are interdependent and culminate in the Central outcome of transforming the institution to a Climate-Resilient Learning System, wherein it engages in anticipating, absorbing and adapting processes. The purpose of this cycle is to cycle and, ultimately, to strengthen the system continually to produce eco-literate, action-competent graduates.

3.4. Search Strategy and Data Synthesis
The literature search was comprehensive, conducted from the years 2014-2024, and included many databases, including, but not limited to, PubMed, Scopus and ERIC. The initial search was based on the intersection of the three main clusters of keywords: "climate change education" OR "eco-literacy"; "health professionals" OR "curriculum" OR "higher education"; "sustainability" OR "resilience" OR "innovation." This search produced a final total of 41 publications included for the data analysis stage. Studies were analyzed thematically, whereby we compared and thematically integrated study findings to develop key broad themes. Particular focus was given to innovative and novel teaching approaches, barriers to implementation, and effective organizational models that helped integrate climate change education to the broader curriculum- as this helped to determine components of the framework which was developed.

IV. Results

In this review, 41 published articles concerning climate change education, eco-literacy, and sustainability were researched and summarized on current practices and institutional needs in higher education. Data were thematically analyzed from the curriculum, pedagogical approaches, institutional framework, and faculty development on teaching and learning education practice.

4.1. Thematic Domains of Educational Sustainability Integration

Through qualitative analysis, five priority themes were critically analyzed to delineate the enabling conditions for institutionalizing sustainable development in education systems.

Table 1: **Thematic Domains**

Domain No.	Thematic Domain	Description
I	Interdisciplinary Curriculum Redesign	This study indicates that the expansion of environmental studies beyond the traditional boundaries of science and geography classrooms can occur in English language teaching and humanities courses and build eco-literacy in a wider student audience overall.
II	Pedagogy for Action Competence	Education goals need to evolve from awareness activities to include Critical Reasoning Skills and a greater emphasis on Systems Thinking. The pedagogical approach needs to be premised on problem-based curriculum development in a hands-on, active, and outcomes-based framework.
III	Mandatory Institutional Policy & Governance	Successful integration requires robust top-down support. This includes aligning a school's vision and mission, strategic plan, accreditation standards, faculty promotion processes, and the allocation of resources with a shared vision of sustainability.
IV	Utilizing the Campus as a Living Laboratory	The campus must function as a model teaching environment. Instruction and student research must directly involve operational projects related to green construction, waste management, and energy projects.
V	Health and Professional Systems Integration	Climate-resilient practice and future-oriented graduate training must account for the health impacts of climate change, especially in health professional training programs.

Analysis generated five overarching themes, displayed in Table 1, which constitute the basis upon which the proposed CRLS framework is built.

V. Discussion

The results displayed in this integrative analysis indicate that the needs generated by the worsening climate emergency cannot be met by fragmented awareness-based environmental education. Collectively, the five thematic categories reaffirm the need for a solid, comprehensive, and action-driven empirical underpinning that the proposed CRLS Framework is designed to offer in this paper. These domains align with the three foundational pillars and the central resilience cycle which underpin the CRLS.

5.1. Mapping Themes to the Climate-Resilient Learning System (CRLS) Pillars

The themes discovered through this process should not be viewed as distinct findings. Instead, they are interconnected and can be synthesized under the three strategic pillars of the CRLS framework: Innovative Pedagogy, Institutional Governance, and Campus Operations.

Table 2: Mapping Themes

CRLS Pillar	Corresponding Thematic Domains	Strategic Function
Innovative Pedagogy	I, II, V	To graduate action-competent, eco-literate citizens capable of interdisciplinary problem-solving and professional resilience.
Institutional Governance	III	To ensure sustainability goals are mandated, funded, and rewarded at the highest levels of the institution's strategic and operational decision-making.
Campus Operations	IV	To transform the physical and administrative campus environment into a functional model of sustainability and a hands-on pedagogical asset (a "Living Laboratory").

The table 2 depicts mapping themes. The need for simultaneous action across all institutional dimensions demonstrates systemic integration across all five thematic domains of results and three strategic pillars of the CRLS framework.

5.2. The Imperative of Innovative Pedagogy

Domains I, II, and V shift the teaching philosophy paradigm. The integration of Eco-Literacy interweaving the environment into core curriculum disciplines, including English Language Teaching, taught within the environment, elevates the need of equity in environmental responsibility along with other core literacies, whereby environmental literacy is lacking and is not to be categorized as a specialization. This broad framework guides Domain II towards the ultimate pedagogical goal of Action Competence. Action competence is more than knowledge retention; students acquire critical reasoning, forethought, and collaborative problem-solving competencies essential for real-world solution design and implementation. Domain V, Health Systems Integration, articulates the need for action competence and system thinking in anticipation of and response to climate-related public health emergencies as a core responsibility of nursing and medical graduates.

5.3. Systemic Change Through Governance and Operations

The importance of Domain III (Mandatory Institutional Policy & Governance) comes from the need to change from optional to essential constituent strategy integration. Such governance supports consolidating policy and climate goals and lends legitimacy and support for the reallocation of educational resources. Again, the integration of the Campus Operations Pillar, outlined in Domain IV, is necessary: teaching institutions must model the lessons they teach. Utilizing the campus as a Living Laboratory provides teaching institutions an opportunity to engage in authentic, emergent, and local case studies for students to establish their systems thinking and action competence, thus bridging the gap between practice and theory.

5.4. The Primary Outcome: The Anticipate-Absorb-Adapt Cycle

The blending of the three pillars mentioned will help the institution be a Resilient Learning System. The dynamism and ongoing resilience of that system will occur by moving through the cycle of Anticipate, Absorb, and Adapt.

Table 3: **Primary Outcome**

CRLS Resilience Cycle	Description	Educational Function
Anticipate	Proactively identifying future climatic threats (e.g., changes in disease vectors, resource scarcity) and educational needs.	Foresight training, systems thinking, and scenario planning are incorporated into the curriculum.
Absorb	The ability of the institution to resist or manage initial climate-related shocks without catastrophic failure.	Enabled by strong institutional governance (Domain III) and resilient campus operations (Domain IV), such as alternative energy sources or updated emergency protocols.
Adapt	The ability to make systemic changes in response to previous shocks or newly expected hazards, which drives curricular and operational innovation.	Driven by feedback loops between institutional policy, new instructional practices, and assessments of learning outcomes and campus performance.

Table 3 exhibits the three phases of CRLS core resilience cycles, which show how the system works in a dynamic fashion to facilitate ongoing adjustments to climate hazards.

VI. Conclusion

Due to the unfolding climate crisis, educational approaches must move towards more systemic and purposeful action on climate resilience as opposed to the current and disjointed forms of climate crisis education. This integrated review has identified the fundamental building blocks for this development and has resulted in the Climate-Resilient Learning System Framework. The insights are consolidated into five thematic areas and show the extent of the undertaking required to incorporate environmental sustainability in the integration of various disciplines. For Eco-Literacy to permeate all disciplines, a more radical interdisciplinary curriculum reform (Domain I) must take place alongside a pedagogy for action competence (Domain II) that fosters critical thinking and problem solving for real-world challenges, and this must be secured at the level of Mandatory Institutional Policy & Governance (Domain III) and action reinforced by the transformation of the campus into a Living Laboratory (Domain IV). The incorporation of Health and Professional Systems (Domain V) prioritizes climate resilience as an indisputable core competency area for all graduates. The research synthesized in the first three pillars of Innovative Pedagogy, Institutional Governance and Campus Operations offers CRLS an integrated,

scalable model. The model's expected potential relies on the ongoing and constantly changing cycle of Prepare, Absorb, and Adapt, as education systems develop in conjunction with global ecological uncertainty. Future research within the CRLS framework should be centered on the empirical validation of the CRLS model, designing and implementing an assessment tool for Action Competence in the non-traditional areas of humanities and ELT, linear measurement of the Living Laboratory approach on student outcomes, and developing strategic plans to align institutional accreditation and faculty review with the Mandates in the CRLS model. Implementing this model offers a pathway for higher education to fulfil its commitment to contribute to the Sustainable Development Goals, educating globally eco-literate and climate resilient citizens.

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