International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Review Article)

Check for updates

Designing the future of education: Integrating gamification, climate awareness, and cross-disciplinary learning into competency-based education

Sayed Mahbub Hasan Amiri [1, *], Md. Mainul Islam [1], Mohammad Shakhawat Hossen [2], Sayed Majhab Hasan Amiri [3], Mohammad Shawkat Ali Mamun [4] and Naznin Akter [5]

[1] Department of ICT, Dhaka Residential Model College, Bangladesh.
[2] Department of ICT, Char Adarsha College, Kishoreganj, Bangladesh.
[3] Department of Islamic Studies, Dhaka College, Bangladesh.
[4] Senior Field Engineer at Prescient Systems & Technologies Pte Ltd, Bangladesh.
[5] Department of English, Shamplapur Ideal Academy, Bangladesh.

International Journal of Science and Research Archive, 2025, 16(01), 2084-2108

Publication history: Received on 14 June 2025; revised on 26 July 2025; accepted on 29 July 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.16.1.2155

Abstract

Built on homogeneity and silos of information transmission, today's dominant forms of education are progressively unsuited to the reality of the 21st century, defined by VUCA (volatility, uncertainty, complexity, and ambiguity), including and notably the climate problem. Engaged learners, a widening knowledge relevance gap, and isolated information that produces graduates without understanding of what to do in a whole-minded manner to face challenges in the real world all follow from this disconnection and miscorrelation. In this article, these shortcomings are addressed by a novel, integrative framework, woven from four evidence-based pillars that seek to develop future-ready "planetary citizens": (1) Competency-Based Education (CBE) as the architectural base, focusing on mastery of portable skills (transferable across different life domains); (2) Climate Awareness & Action as the thematic and moral center, grounding learning in pressing, real-world contexts; (3) Cross-Disciplinary Learning as the cognitive motor, weaving disparate knowledge domains into a tapestry that reflects real-world complexity; and (4) Gamification as the motivational agent, applying game design ingredients to boost motivation and persistence. This paradigm is strong because it is synergistic: climate action analyses intentional learning; CBE provides responsibility and structure; cross-disciplinarity adds variety and complexity; and lastly, game theory supports sustainability and participation. From all levels of curriculum design, assessment, teacher development, infrastructure, and climate change reduction, implementation is grounded on basic design concepts. This new paradigm seeks to enable deep learning, climate competence, educational relevance and empowered agency to change toward a sustainable future.

Keywords: 21st Century Skills; Climate Awareness; Competency-Based Education; Cross-Disciplinary Learning; Educational Innovation; Gamification in Education; Planetary Citizenship

1. Introduction

1.1. The Imperative for Educational Transformation: Navigating a World in Flux

The foundations of the traditional education system, widely laid in the 19th and 20th centuries, are crumbling under the weight of 21st-century realities. These are all models that were built for standardization, predictability, and dissemination of siloed knowledge they are not fit for the purpose of preparing learners for a world that is defined by volatility, uncertainty, complexity, and ambiguity with the climate crisis being its most powerful and pressing emblem. This disconnects expresses itself in three fundamental, intertwined problems:

* Corresponding author: Sayed Mahbub Hasan Amiri

- Persistent Disengagement and Motivation Crisis: A large number still re-main consumers of knowledge, rather than participants of their learning. OECD PISA consistently identifies worrying levels of disaffection, boredom and lack of relevance on the part of students. Almost one in three students across the OECD feel like outsiders in school and over 40 per cent feel they are just learning stuff that they don't understand and will never use (OECD, 2019). This disengagement, in part, is because our pedagogies are such that they don't tap into our intrinsic motivation, provide us with limited autonomy and feedback that we get feels out of touch with our purpose or its impact in the real world. The dynamic, interactive, and agency-rich spaces that young people inhabit beyond schools stand in stark contrast with the largely static nature of the routines of classroom life (Ryan & Deci, 2020).
- The Crippling Relevance Gap, Exemplified by Climate Change: The prevailing curricula often emphasize memorization of inert knowledge across separate disciplines, leaving learners directionless when faced with complex, inter-linked or so-called wicked problems in the world. Climate change is the ultimate expression of this failure. Even as scientific consensus is established regarding the anthropogenic origins and catastrophic character of climate disruption (IPCC, 2023), education responses are scattered at best, sometimes offered in isolated units within science curricula. This path is woefully inadequate for the integrated comprehension and doing that learners require. Research uncovers a paradox: young people around the world feel a deep sense of anxiety over their climate futures (Hickman et al., 2021, The Lancet Planetary Health) but report feeling powerless and unprepared by their educations to comprehend the systemic drivers or to become part of the solution (UNESCO, 2021).
- The Tyranny of Siloed Knowledge: Conventional curriculum arrangements, which are divided up into separate, and frequently forbidden, subjects indicate a fragmented picture of what knowledge is, and what the world is about. There is of course value in specialization, but this kind of relent less buckets anxiously stifles our ability to address complex issues so-called "wicked" problems such as climate change, pandemics, or even "sustainable development" (which are, by definition, inherently transgressing of disciplinary boundaries) (Rittel & Webber, 1973). To learn physics without considering its ethical implications for energy policy, or to study economics as if it were without ecological limits, this is a dangerous reductionism.

These diminished experiences, dislocation, irrelevance in the face of planetary crisis and broken knowledge are more than just things that do not work, they are signs of a profound disharmony between educational design and the needs of our moment. To persist on this path is to risk failing a generation at a time of unprecedented challenges: feeling anxious, disempowered and unready to adapt to or shape the complex world they will inherit. Radical reimagining isn't a choice; it's an existential necessity.

1.2. The Vision: Cultivating Future-Ready Competencies through Purpose-Driven Learning

The response to this call is not incremental tinkering, but transformative learning for the future. Going beyond the typical emphasis on content coverage and standardized testing, this vision leads to a commitment to develop transferable competencies the knowledge, skills, attitudes, and values that are essential for understanding complex systems, for adapting to change and uncertainty, for collaborating across differences, and for acting as ethical, proactive agents in creating a more sustainable and just world.

This vision draws inspiration from evolving global frameworks:

- OECD Learning Compass 2030: Emphasizes student agency, co-agency (with teachers, families, communities), and competencies like critical thinking, creativity, responsibility, and the ability to reconcile tensions and dilemmas.
- UNESCO Education for Sustainable Development (ESD) for 2030: Positions education as the key driver for achieving the Sustainable Development Goals (SDGs), explicitly aiming to empower learners to make informed decisions and take responsible actions for environmental integrity, economic viability, and a just society.
- Key Competencies for Sustainability: Scholars like Wiek et al. (2011) have articulated core competencies crucial for sustainability challenges, including Systems Thinking, Anticipatory Thinking (Futures Literacy), Normative Competence (reflecting on values and principles), Strategic Action Competence, and Collaborative Competence.

Future-oriented learning is characterized by:

- Competency Focus: Defining clear, observable, and transferable capacities relevant to real-world challenges (e.g., "Analyze the interconnected social, economic, and environmental dimensions of a local sustainability issue," "Develop and justify a proposal for community-based climate adaptation").
- Authenticity and Relevance: Grounding learning in meaningful, complex problems that resonate with learners' lives and the world's pressing needs, particularly the climate crisis.
- Interdisciplinary and Transdisciplinary Integration: Actively breaking down disciplinary walls to foster the synthesis of knowledge and perspectives necessary for holistic understanding and innovation.
- Learner Agency and Engagement: Creating environments where learners have voice, choice, and ownership over their learning pathways, driven by intrinsic motivation and a sense of purpose.
- Action Orientation: Moving beyond awareness to fostering the capacity and disposition to take informed, ethical action at appropriate scales.

The ultimate goal is to nurture planetary citizens individuals equipped not just to survive, but to thrive and contribute positively within the intricate socio-ecological systems of the 21st century.

1.3. Introducing the Integrated Framework: Synergistic Pillars for Transformative Learning

To translate the vision of future-oriented learning into tangible practice, this article proposes the integrated design of four powerful, evidence-informed educational approaches. This framework is not merely additive; it leverages their inherent synergies to create a cohesive, transformative pedagogy greater than the sum of its parts:

- Competency-Based Education (CBE): The Structural Backbone.
  - Core Tenet: Shifts the focus from time-based progression to demonstrable mastery of clearly defined, transferable competencies. Learners advance upon providing evidence of proficiency through authentic assessments, enabling personalized pacing and pathways.
  - Role: Provides the essential architecture for defining, sequencing, and rigorously assessing the complex competencies required for climate action and sustainable futures. It ensures learning is transparent, focused on outcomes, and inherently personalized. (Le, Wolfe, & Steinberg, 2014; Sturgis & Patrick, 2010).
- Climate Awareness & Action: The Thematic Imperative and Moral Core.
  - Core Tenet: Moves beyond basic climate science literacy to encompass deep understanding of causes, impacts (especially on vulnerable populations), mitigation and adaptation strategies, climate justice, policy landscapes, and the development of *action competence* – the ability and commitment to take informed action. It integrates ecological, social, economic, and ethical dimensions.
  - Role: Provides the critical, urgent, and inherently complex context that demands interdisciplinary solutions and motivates authentic engagement. It grounds abstract competencies in the most pressing challenge of our era. (Monroe, Plate, Oxarart, Bowers, & Chaves, 2019; UNESCO, 2021).
- Cross-Disciplinary Learning: The Cognitive Engine for Complexity.
  - Core Tenet: Integrates knowledge, methods, and perspectives from multiple disciplines (multidisciplinary), fosters interaction to create new understanding (interdisciplinary), or engages with real-world problems where academic and community knowledge co-create solutions (transdisciplinary) (Boix Mansilla, 2016). It explicitly tackles problems that cannot be solved within a single subject domain.
  - Role: Mirrors the complex, interconnected nature of real-world challenges like climate change. It forces the synthesis and critical application of knowledge and skills, developing cognitive flexibility essential for future readiness. It provides the necessary breadth and depth for meaningful climate competency development.
- Gamification: The Engagement Catalyst and Experiential Bridge.
  - Core Tenet: The strategic application of game design elements (e.g., compelling narratives, meaningful challenges, clear goals, immediate feedback, progressive difficulty, autonomy, mastery paths, points/

badges/ leaderboards when aligned with learning) into non-game contexts to enhance motivation, engagement, and persistence (Deterding, Dixon, Khaled, & Nacke, 2011; Kapp, 2012).

- Role: Addresses the motivation crisis by making the challenging process of mastering complex, interdisciplinary climate competencies intrinsically rewarding and engaging. It provides safe spaces for experimentation, iteration, and experiencing consequences, fosters collaboration, and visualizes progress meaningfully within the CBE structure.

1.3.1. Synergistic Potential

The power of this framework lies in the deliberate interplay of these pillars:

- CBE + Climate Action: CBE provides the structure to define and rigorously assess complex climate competencies; climate action provides the authentic, motivating context that gives CBE relevance beyond abstract skills.
- CBE + Cross-Disciplinary Learning: CBE demands clear outcomes, which interdisciplinary projects provide in complex contexts; cross-disciplinarity requires rigorous assessment of integrated skills, which CBE facilitates.
- CBE + Gamification: CBE's focus on mastery aligns perfectly with core game mechanics (leveling up, overcoming challenges); gamification makes the iterative journey towards competency mastery in demanding areas like climate action more engaging and less daunting.
- Climate Action + Gamification: Gamification can model complex systems, simulate consequences of actions/inaction, and provide engaging platforms for exploring climate solutions; the urgency of climate action gives gamified elements profound purpose beyond mere points.
- Climate Action + Cross-Disciplinary Learning: Tackling climate change inherently requires integrated knowledge; cross-disciplinary approaches provide the necessary toolkit to understand and address the multifaceted nature of the crisis.
- Cross-Disciplinary Learning + Gamification: Gamification can structure complex interdisciplinary challenges, facilitate collaboration across perspectives, and make the synthesis process more engaging and rewarding.

This integrated perspective addresses the limitations of any single element in isolation: the threat of rigidity in CBE is tempered by engagement afforded by gamification, and dynamism added by cross-disciplinarity; the risk of superficiality is gamification is counteracted by the requirement for more authentic evidence of competence in CBE and depth in one case (climate theme); Complexity is made manageable and motivating in the real-world context of CBE pathways and even more structured gamified experiences; while cross-disciplinarity is given focus and results through the detail of defining competencies and subsequently their assessment.

2. Literature Review (Theoretical Foundations & Current Landscape)

The imperative for educational transformation necessitates grounding innovative approaches in robust theoretical foundations and empirical evidence. This review synthesizes research across four critical domains central to our proposed framework, examining their individual strengths, limitations, and the nascent evidence for their pairwise integration, ultimately highlighting the gap this article addresses.

2.1. Competency-Based Education (CBE): Defining the Foundation

Competency Based Education (CBE) is a transformative change from the traditional time-based to learning-based advancement. Its pillars of proficiency, personalized pacing, and explicit outcomes were the basis for its development and remain the three greatest themes forthwith (Le et al., 2014; Sturgis & Patrick, 2010). CBE has its origins in mastery learning approaches (Bloom, 1968) and traditions of experiential learning but has gained much of its support in the 21st century in response to shortcomings in the industrial-age school model (Patrick & Sturgis, 2015). While their definition has been expanded, more recent CBE definitions, as advocated by Competency Works (2019) in institutions such as Western Governors University, include flexible pathways, authentic assessment, and learner agency.

Studies highlight substantial gains with well-executed CBE. It increases relevance by connecting learning directly to measurable skills for subsequent education and occupations (Johnstone & Soares, 2014). It is fair because it levels the playing field by giving each student the support s/he needs and ensures that all students reach a level of proficiency rather than allowing them to move forward with gaps (Patrick & Sturgis, 2015). The flexibility of online learning can better meet the needs in learning styles or personal life and therefore can reach more learners (Le et al. 2014). In a meta-analysis of Mendenhall et al. (2021) reported positive relationships between CBE and student engagement, retention, and deep learning results.

But real problems remain. Measurement is challenging, and developing reliable, valid, and scalable approaches to assess higher-order competencies naturally is hard (Ford, 2014). Moving from norm-referenced to criterion-referenced assessment is not easy. System replacement is fraught with challenges: redesigning time-bound calendars, sequential credits and grades, teaching roles, and institutional regulations requires significant resources, professional learning, and cultural change (Levine & Patrick, 2019; Worthen & Pace, 2018). There is also a fear that standardization could take away from personalization if competencies are defined too narrowly.

2.2. Climate Awareness & Education for Sustainable Development (ESD)

There is certainly an urgent need for the kind of effective climate education we provide. The IPCC (2023) warns of accelerating, Reversible climate impacts, calling for immediate societal transformation. Meanwhile widespread climate anxiety among youth itself demonstrates the psychological impact of lack of understanding and agency (Hickman et al., 2021). UNESCO (2021) places Education for Sustainable Development (ESD) which includes climate education as essential to achieving the Sustainable Development Goals (SDGs), noting that existing approaches to education often do not prepare learners with what they need to know and understand, be able to do, or hold in terms of values and attitudes.

Quality education on climate in ESD enables key competencies for sustainability and climate action. Wiek et al. (2011) Given the existence of seminal framework:

- Systems Thinking: Understanding interconnections within socio-ecological systems.
- Anticipatory/Futures Thinking: Envisioning future scenarios and consequences.
- Normative Competence: Reflecting on values, ethics, and justice in sustainability decisions.
- Strategic Action Competence: Planning and implementing actions for sustainability transitions.
- Collaborative Competence: Working effectively across disciplines and diverse groups.
  Central to this is action competence the ability and commitment to take informed action (Mogensen & Schnack, 2010; UNESCO, 2017).

Challenges in current climate education are significant:

- Anxiety and Disempowerment: Without fostering agency, climate education can exacerbate fear and hopelessness (Ojala, 2012).
- Politicization: Navigating polarized discourse requires careful pedagogical framing focused on evidence and diverse perspectives (Hess & McAvoy, 2015).
- Lack of Depth and Action Orientation: Content often remains superficial, confined to science classes, and disconnected from actionable steps or systemic analysis (Monroe et al., 2019; Stevenson et al., 2017).
- Siloed Approaches: Failure to integrate social, economic, ethical, and political dimensions limits understanding (Kagawa & Selby, 2010).

Key frameworks guide practice:

- UNESCO ESD for 2030 Framework: Provides a roadmap for integrating ESD across all levels and settings, emphasizing transformative action (UNESCO, 2020).
- Climate Literacy: The Essential Principles of Climate Science is Defines core knowledge concepts (U.S. Global Change Research Program, 2009).
- GreenComp: The European Sustainability Competence Framework is Details competencies for learners (Bianchi et al., 2022).

2.3. Gamification in Learning: Beyond Points and Badges

Gamification involves "the use of game design elements in non-game contexts" (Deterding et al., 2011, p. 9). Its core elements are often categorized using the MDA framework:

- Mechanics: Foundational rules and processes (e.g., points, badges, leaderboards, levels, challenges, quests, rewards, feedback loops).
- Dynamics: Player behaviours and interactions emerging from mechanics (e.g., competition, cooperation, exploration, narrative engagement).

- Aesthetics: Emotional responses evoked (e.g., fun, curiosity, accomplishment, fellowship) (Hunicke et al., 2004; Kapp, 2012).

Its effectiveness draws from strong theoretical underpinnings:

- Self-Determination Theory (SDT): Gamification can satisfy core psychological needs for *autonomy* (choice, control), *competence* (mastery, feedback), and *relatedness* (collaboration, social recognition), enhancing intrinsic motivation (Ryan & Deci, 2020; Rigby & Ryan, 2011).
- Flow Theory: Well-designed challenges matching skill levels can induce flow states, characterized by deep focus, enjoyment, and loss of self-consciousness (Csikszentmihalyi, 1990; Hamari et al., 2016).
- Situated Learning: Gamification can create authentic, simulated contexts where knowledge is acquired and applied meaningfully within a community of practice (Lave & Wenger, 1991; Landers & Callan, 2011).

There is promising (but qualified) evidence of effects. Results of meta-analyses suggest that gamification has, in general, a positive impact on motivation and engagement (Sailer & Homner, 2020; Subhash & Cudney, 2018). It can enhance the retention of knowledge through spaced practice (de-Marcos et al., 2014) and develop skills, in particular procedural and problem-solving skills, by offering safe environments for practice and feedback (Dichev & Dicheva, 2017; Seaborn & Fels, 2015).

2.3.1. Effective design principles emphasize

- Aligning mechanics directly with learning objectives (not just engagement).
- Focusing on intrinsic motivators (autonomy, mastery, purpose) over purely extrinsic rewards.
- Providing meaningful feedback and clear progression.
- Incorporating narrative and theme for context.
- Fostering collaboration and social interaction.
- Ensuring accessibility and inclusivity (Kapp, 2012; Nicholson, 2015; Landers, 2014).

2.3.2. Common pitfalls include

- Over-reliance on superficial extrinsic rewards (points, badges) that can undermine intrinsic motivation (Nicholson, 2015).
- Poor alignment with learning goals.
- Creating unhealthy competition or social exclusion.
- Technical complexity hinders implementation.
- Lack of consideration for diverse learner preferences (Dichev & Dicheva, 2017).

2.4. Cross-Disciplinary Learning: Breaking Down Silos

The case for cross-disciplinary learning to solve complex, “wicked” problems such as climate change, pandemics or poverty is clear: These types of problems cannot be comprehensively understood or solved within the house of a single discipline. They call for the crosstalk of knowledge, methods, and ways of seeing from diverse domains (Rittel & Webber, 1973; Bernstein, 2015; Boix Mansilla, 2010). 31 Cross-disciplinarity in this way readies students for the interconnected nature of the contemporary world and workplace.

2.4.1. Models exist on a spectrum of integration depth

- Multidisciplinary: Juxtaposing knowledge from different disciplines around a common theme or problem, without significant integration. Each discipline retains its distinct perspective (e.g., a unit on water involving separate lessons from science, geography, and history).
- Interdisciplinary: Integrating concepts, theories, and methods from multiple disciplines to create a synthesized understanding or approach that transcends individual disciplines. The focus is on connection and synthesis (e.g., analyzing the causes and solutions to a local water pollution issue using integrated scientific, economic, ethical, and policy perspectives).
- Transdisciplinary: Extending beyond academic disciplines to actively involve non-academic stakeholders (e.g., community members, policymakers, industry) in co-defining problems and co-creating solutions. It emphasizes real-world problem-solving and knowledge co-production (Klein, 2010; Pohl & Hirsch Hadorn, 2007).

2.5. Benefits are well-documented

- Enhanced Critical Thinking & Problem Solving: Evaluating complex issues from multiple angles.
- Increased Creativity & Innovation: Synthesizing diverse ideas fosters novel solutions.
- Greater Real-World Relevance: Learning mirrors the complexity of life beyond school.
- Improved Systems Understanding: Seeing interconnections and broader contexts.
- Development of Integrative Thinking Skills: (Boix Mansilla & Duraising, 2007; Spelt et al., 2009; Ivanitskaya et al., 2002).

2.5.1. Implementation challenges are substantial

- Curriculum Design: Requires significant effort to map connections, sequence learning, and find common time. Traditional schedules and structures are often barriers.
- Teacher Collaboration: Demands time, trust, communication skills, and often co-teaching. Differences in pedagogical approaches, terminology, and assessment practices need bridging. Lack of preparation or institutional support hinders this (Beane, 1997; Parker, 2010).
- Assessment: Measuring integrated understanding and skills is complex. Designing valid assessments that capture synthesis and application across disciplines is difficult. Traditional subject-based grading struggles with integrated work (Boix Mansilla, 2010; Nikitina, 2006).
- Teacher Expertise: Requires comfort and knowledge beyond one's core discipline.
- Logistical Hurdles: Timetabling, resource allocation, and physical space constraints.

2.6. Synthesizing the Pillars: Gaps and Opportunities

Research exploring *pairings* of the pillars within our proposed framework provides promising evidence but remains fragmented:

- Gamification + CBE: Studies demonstrate gamification's effectiveness in visualizing progress, increasing engagement, and providing feedback within CBE systems. Game mechanics like progress bars, levels, and badges can make competency mastery pathways more tangible and motivating (Dias, 2017; Faber et al., 2017). However, challenges include ensuring deep learning beyond superficial reward chasing and aligning game design with complex competency assessment (Landers, 2014; Rapp et al., 2019).
- CBE + ESD/Climate Education: Frameworks increasingly define sustainability competencies suitable for CBE structures (Rieckmann, 2017; Wiek et al., 2011; Bianchi et al., 2022). CBE's focus on demonstrable action competence aligns well with ESD goals. Research shows potential for increased relevance and empowerment when sustainability outcomes are explicit and mastery-based (Sleurs, 2008; UNESCO, 2020). Challenges include the complexity of assessing systems thinking and action competence authentically within CBE frameworks (Barth & Rieckmann, 2016).
- Gamification + Climate Education: Game-based learning and gamification show promise in teaching complex climate science concepts, fostering systems thinking, simulating impacts and solutions, and increasing engagement, particularly when mitigating anxiety through empowering narratives (Wu & Lee, 2015; Reckien & Eisenack, 2013; García & Fernández, 2021). However, concerns exist about simplification, potential for gamifying trivial actions, and ensuring scientific accuracy (Molin, 2017).
- Cross-Disciplinary + CBE: Integrating CBE with interdisciplinary approaches offers a structure for defining and assessing complex integrated competencies needed for real-world problem-solving (Boix Mansilla & Jackson, 2011). CBE can provide clarity in interdisciplinary learning outcomes and assessment criteria. However, significant challenges remain in designing valid assessments for truly integrated understanding and skills across disciplines within a competency framework (Mansilla, 2010; Nikitina, 2006).

Identifying the Gap: Despite the promise demonstrated by the two-party integrations, there is a notable gap in literature. Comprehensive frameworks or empirical evidence on other possible intersectional designs of all four elements i.e Gamification, CA (core context of ESD), CDL, and CBE are still absent. The majority of research focuses on a limited number (one or two) of pillars as standalone items, as they are generally added to an existing course design rather than seen as integrated elements of an overall pedagogical system (Dichev & Dicheva, 2017; Rieckmann, 2017; Parker, 2010). The idiosyncratic problems of each support, especially in the context of grappling with a dense, pressing, and emotionally loaded subject such as climate change demand a joined-up solution that plays to the strengths of both.

Arguing Potential Synergy: The proposed integration is not merely additive; it offers a system where each pillar addresses the inherent limitations of the others:

- Gamification boosts engagement in complex climate topics: Climate change's complexity and potential for inducing anxiety can lead to disengagement. Gamification, grounded in SDT and flow, can make the challenging process of mastering interdisciplinary climate competencies intrinsically motivating, fostering persistence and positive affect (Sailer & Homner, 2020; Ojala, 2012).
- CBE provides structure for cross-disciplinary mastery: Cross-disciplinary learning faces assessment challenges and potential lack of focus. CBE offers the necessary structure through explicit, measurable competencies that define what integrated mastery looks like, guiding curriculum design and providing clear assessment criteria for complex syntheses (Boix Mansilla & Jackson, 2011; Sturgis & Patrick, 2010).
- Cross-disciplinary learning provides authentic context for climate competencies: Climate change is inherently interdisciplinary. Cross-disciplinary learning provides the authentic, complex context essential for developing and demonstrating the multifaceted competencies required for climate action (systems thinking, strategic action), making CBE outcomes deeply relevant and grounded in real-world problems (Wiek et al., 2011; Bernstein, 2015).
- Climate awareness gives purpose to gamification and CBE: The urgency and moral imperative of climate action provide profound purpose and meaning to the learning journey. This context counters the risk of "pointsification" in gamification and abstractness in CBE, ensuring mechanics and competencies are aligned with a critical real-world mission, enhancing intrinsic motivation and relevance (Ryan & Deci, 2020; UNESCO, 2021).

The integrative promise of such a whole, thus, may far exceed the sum of its individual parts, providing an effective way to address the failure of traditional education to supply the motivation, knowledge, skills, and agency required for a responsible and sustainable future. We discuss the design and analysis of such an integrated model in the next few sections.

3. Methodology: Designing the Integrated Framework

The following describes the systematic approach followed to design, develop and refine the integrated framework of CBE, ClimAA, CDL and Gamification. As this framework proposal is primarily conceptual and design oriented in its nature (meaning that it aims to build upon existing knowledge by proposing a new pedagogical structure), the approach chosen as the most suitable for the current framework proposal was Theoretical Synthesis (with elements of Systematic Literature Review for Design Principles). The approach focused on rigorous, transparent and systematic derivation of actionable design principles from a wide evidence base.

3.1. Research Approach: Theoretical Synthesis & Systematic Design Principle Extraction

The dominant method was that of Theoretical Synthesis (Barnett-Page & Thomas, 2009; Torraco, 2005, 2016). This method is a way of thinking critically about, comparing, and combining concepts, theories, models, and results from different but related fields in such a way so as to create wholly new theory frameworks or models that suggest new ways of seeing things or new ways of resolving problems. It is especially well-suited to solving complex, multi-disciplinary problems that require the crossing of information silos, exactly as the problem of making an integrated framework is for the four pillars.

The synthesis was implemented using a Systematic Approach to Extracting Design Principles. Although not a systematic review meta-analysis, they drew on standard systematic review protocols (for example, models based on PRISMA guidelines; Page et al., 2021) to provide rigor in the identification, selection, and analysis of literature from each pillar domain. There are several reasons to use this combined strategy:

- Nature of the Problem: The research gap identified (Section 2.5) is the *lack of integrated models*, not a lack of evidence within individual pillars or some pairings. Theoretical synthesis is ideal for constructing such novel integrative models from existing foundational knowledge (Torraco, 2016).
- Stage of Inquiry: This work represents the *design and proposition* phase of the integrated framework. Empirical testing (e.g., via Design-Based Research) is a crucial *next step* but requires a well-articulated theoretical model first. Synthesis provides this essential foundation (Barab & Squire, 2004).
- Leveraging Existing Evidence: Significant bodies of research exist on each pillar and some pairwise integrations (e.g., Gamification+CBE, CBE+ESD). Systematically extracting and synthesizing design principles from this evidence allows for evidence-informed framework construction, maximizing potential effectiveness and grounding innovation in prior work (Dichev & Dicheva, 2017; Rieckmann, 2017).

- Focus on Design Principles: The goal is to provide actionable guidance for educators and designers. Explicitly extracting and synthesizing design principles from the literature directly serves this purpose (McKenney & Reeves, 2019).

Therefore, this methodology allowed for the rigorous construction of a theoretically grounded and evidence-informed framework by systematically integrating knowledge across the four domains to address the identified gap.

3.2. Data Sources & Collection: Systematic Literature Search and Analysis

- The data collection process involved a structured search and analysis of scholarly literature within the four core domains and their intersections. The process followed these steps:
- Database Selection: Comprehensive searches were conducted across major educational, psychological, and interdisciplinary databases, including:
    - ERIC (Education Resources Information Centre)
    - Scopus
    - Web of Science Core Collection
    - PsycINFO
    - Google Scholar (for forward/backward citation tracking and grey literature)
- Search Strategy & Key Terms: Search strings were constructed using Boolean operators (AND, OR) combining keywords and controlled vocabulary (e.g., Thesaurus terms in ERIC) related to:
    - Core Pillars: ("competency-based education" OR "outcome-based education" OR "mastery learning"), ("gamification" OR "game-based learning" OR "game elements"), ("climate change education" OR "climate literacy" OR "education for sustainable development" OR "ESD" OR "sustainability education"), ("interdisciplinary learning" OR "cross-disciplinary learning" OR "transdisciplinary learning" OR "integrated curriculum").
    - Concepts: ("design principles" OR "framework" OR "model" OR "pedagogy" OR "implementation"), ("motivation" OR "engagement" OR "assessment" OR "competency" OR "systems thinking" OR "action competence").
    - Pairwise Integrations: Terms combining pillars were used (e.g., ("gamification" AND "competency-based education"), ("ESD" AND "interdisciplinary"), ("climate education" AND "gamification"). Search was iteratively refined based on initial results. See Table 1 for an example search string structure.

Table 1 Example Search String Structure (Scopus)

Pillar/Concept	**Search Terms (Combined with OR within group)**	**Operator Between Groups**
CBE	"competency-based education" OR "CBE" OR "mastery learning" OR "proficiency-based learning"	AND
Gamification	gamif* OR "game-based learning" OR "serious games" OR "game elements"	AND
Climate/ESD	"climate change education" OR "climate literacy" OR "education for sustainable development" OR ESD OR "sustainability competencies"	AND
Cross-Disciplinary	interdisciplin* OR "cross-disciplinary" OR transdisciplin* OR "integrated curriculum" OR "integrated learning"	AND
Design/Integration	"design principle*" OR framework OR model OR pedagog* OR implement* OR "best practice*"	

(Note: Truncation () used to capture variations; specific syntax adapted per database)

3.2.1. Inclusion/Exclusion Criteria:

- Inclusion:
    - Peer-reviewed journal articles, book chapters, conference proceedings (with rigorous review), and seminal reports (e.g., UNESCO, OECD, CompetencyWorks).
    - Focused on K-12 and/or higher education contexts.
    - Contained explicit discussion of theory, empirical findings, design principles, implementation strategies, or frameworks related to one or more pillars, especially regarding their integration or application to complex topics like climate change.

  - Published primarily within the last 15 years (2009-2024) to ensure contemporary relevance, with inclusion of seminal works regardless of date (e.g., Bloom, 1968; Deterding et al., 2011; Wiek et al., 2011).
  - Written in English.
- Exclusion:
  - Articles solely focused on corporate training without clear educational relevance.
  - Articles describing implementations of only one pillar without discussion of integration potential, design principles, or limitations relevant to the synthesis.
  - Purely descriptive articles without analytical depth or evidence.
  - Non-peer-reviewed opinion pieces (unless highly influential grey literature like major framework reports).
- Screening Process: The process followed a structured two-stage screening:
  - Stage 1 (Title/Abstract Screening): Titles and abstracts were screened against inclusion/exclusion criteria. Relevance to the research questions (defining pillars, identifying challenges, extracting design principles, exploring integration) was key.
  - Stage 2 (Full-Text Screening): Potentially relevant articles identified in Stage 1 were retrieved and their full text assessed for eligibility and depth of contribution. Articles passing this stage constituted the core analytical corpus.
- Analysis Method: Thematic Analysis for Design Principles: Qualitative Thematic Analysis (Braun & Clarke, 2006, 2022) was employed as the primary method for analyzing the included literature and extracting design principles. This involved:
  - Familiarization: Deep reading and re-reading of the selected literature.
  - Initial Coding: Generating initial descriptive codes capturing key concepts, recommendations, successful practices, identified challenges, and theoretical propositions related to the design and implementation of each pillar individually and in pairwise combinations. Codes were applied using NVivo qualitative data analysis software for organization.
  - Theme Development: Collating initial codes into potential themes representing overarching design principles. For example, codes like "clear competency definitions," "transparent assessment criteria," "mastery progression" (CBE) were grouped under themes like "Explicit & Measurable Outcomes."
  - Theme Review & Refinement: Iteratively reviewing themes for internal coherence and distinctiveness, ensuring they accurately reflected the coded data and the broader literature. Themes were refined, split, or merged as necessary.
  - Defining and Naming Themes: Clearly defining the essence of each theme and generating concise, descriptive names that captured the core design principle it represented (e.g., "Authentic Cross-Disciplinary Contexts," "Purposeful Gamification Mechanics Aligned with Competencies").
  - Synthesis Across Pillars: Actively seeking connections, tensions, and complementarities between principles derived from different pillars. This involved asking: *How does a principle from Pillar A potentially address a challenge identified in Pillar B? How can principles from different pillars be combined coherently?* (e.g., How CBE's "Explicit Outcomes" address Cross-Disciplinary Learning's "Assessment Challenge"; How Gamification's "Intrinsic Motivation Focus" addresses Climate Education's "Anxiety/Disengagement Challenge").
  - Documentation: Maintaining a detailed audit trail of search strategies, inclusion/exclusion decisions, coding schemes, and theme development notes to ensure transparency and replicability.

3.3. Framework Development Process: From Principles to Integrated Model

The development of the integrated framework was an iterative and systematic process moving from analysis to synthesis and design:

- Identification of Core Pillars and Functions: Based on the literature review (Section II) and initial synthesis, the four pillars (CBE, Climate Awareness/Action, Cross-Disciplinary Learning, Gamification) were confirmed as the essential, non-redundant components. Their primary *functions* within an integrated system were explicitly defined (e.g., CBE as Structural Backbone, Climate as Thematic Imperative, Cross-Disciplinary as Cognitive Engine, Gamification as Engagement Catalyst).

- Extraction and Clustering of Design Principles: The thematic analysis described in 3.2 yielded a comprehensive list of design principles derived from the literature of each pillar and their pairwise integrations. These principles were then clustered into thematic groups based on their focus (e.g., principles related to defining outcomes, principles related to engagement, principles related to assessment).

- Synergistic Mapping: This was the core integrative step. Each design principle was analyzed not just in isolation, but for its potential *synergistic relationship* with principles and needs from other pillars. Questions guiding this mapping included:
    - How does Principle X from Pillar A help overcome the common limitation of Pillar B?
    - How does Pillar C provide a context or purpose that enhances the effectiveness of Principle Y from Pillar D?
    - What potential conflicts exist between principles from different pillars, and how can they be resolved in design? (e.g., CBE's need for specificity vs. Cross-Disciplinary's inherent complexity; Gamification's reward structures vs. deep intrinsic motivation for climate action).
    - The synergistic arguments presented in Section 2.5 formed the foundation for this mapping.
- Formulation of Integrated Design Principles: Based on the synergistic mapping, core design principles that inherently *required* or *leveraged* the integration of multiple pillars were formulated. These principles moved beyond simply applying principles from each pillar simultaneously to articulating how the pillars *interact* within the design (e.g., "Design Gamified Progression Systems that Visibly Map onto CBE Mastery Pathways and Cross-Disciplinary Milestones within Climate Action Projects").
- Conceptual Model Construction: The integrated design principles, the defined pillar functions, and their mapped interrelationships were synthesized into a coherent conceptual model. This involved:
    - Defining Core Components: The essential elements of the framework (e.g., Climate Action Competencies, Integrated Learning Modules, Gamified Feedback Loops, Mastery Dashboards).
    - Mapping Relationships: Visually and descriptively illustrating how the pillars and their components interact dynamically. For instance, showing how Gamification mechanics feed into CBE assessment evidence, which validates progress in Cross-Disciplinary Climate Competencies.
    - Establishing Guiding Principles: Distilling the highest-level heuristics guiding the entire framework design (e.g., "Center Climate Action Competencies," "Foster Authentic Integration," "Leverage Synergy for Engagement and Rigor").
- Iterative Refinement: The developing framework model was continuously referenced back against the source literature and the identified design principles to ensure fidelity and comprehensiveness. Potential gaps and inconsistencies were addressed through further literature consultation and model adjustment.

In conclusion, the methodology employed a rigorous, systematic, and transparent process of theoretical synthesis and design principle extraction to develop the proposed integrated framework. By grounding the design in existing evidence, explicitly mapping synergistic relationships, and employing strategies to ensure credibility, this approach provides a robust foundation for exploring the framework's theoretical and practical potential in subsequent sections and future empirical work.

4. The Integrated Framework: Principles and Components

In this section we describe the main architecture of the integrated framework for CBE-Climate Awareness and Action-Cross-Curricular Learning-Gamification. Constructed through careful theoretical triangulation (Section III), the model translates fragmented learning practices in EFS into a holistic learning system for enhancing future ready sustainability enablers. It derives its strength from capitalizing the synergistic opportunities identified in Sect. 2.5, by way of bringing every pillar to bear on the intrinsic shortcomings of the others but also on its ability to augment their collective effectiveness.

4.1. Foundational Pillars: Reiterating Essential Roles

The framework rests on four non-negotiable pillars, each fulfilling a distinct, vital function within the integrated whole:

4.1.1. Competency-Based Education (CBE): The Structural Backbone.

Competency-Based Education (CBE) serves as the foundational framework that structures the entire climate learning experience, ensuring clarity, rigor, and equity. By defining explicit, measurable competencies related to climate action and sustainability, CBE establishes transparent pathways for mastery, supports personalized pacing, and requires the demonstration of real-world skills through authentic, performance-based assessments (Le et al., 2014; Sturgis & Patrick, 2010). This model provides the scaffolding necessary to navigate the complexity of cross-disciplinary climate education, aligning diverse content and methods within a coherent progression. Within a broader pedagogical ecosystem, CBE ensures that gamification retains depth and purpose, avoiding the trap of superficial "pointsification," and that cross-disciplinary learning remains focused on tangible outcomes.

4.1.2. Climate Awareness & Action: The Thematic Imperative and Moral Core.

Climate awareness and action form the urgent and ethically grounded foundation of a transformative educational experience, anchoring all learning activities in real-world significance. These thematic imperative centers the curriculum on developing a deep understanding of climate science, its socio-ecological impacts especially on vulnerable populations alongside pathways for mitigation, adaptation, and justice. It also emphasizes cultivating *action competence*, or the knowledge, skills, and moral commitment to engage in informed, meaningful climate action (Wiek et al., 2011; Monroe et al., 2019; UNESCO, 2021). Within a competency-based education (CBE) framework, climate awareness supplies profound purpose and contextual relevance, serving as a powerful source of intrinsic motivation.

4.1.3. Cross-Disciplinary Learning: The Cognitive Engine for Complexity.

Cross-disciplinary learning serves as the intellectual core of climate education, reflecting the interconnected nature of environmental challenges and cultivating the integrative thinking required to address them. It compels learners to synthesize knowledge, methodologies, and worldviews from STEM fields, the humanities, social sciences, and often community and indigenous knowledge systems, enabling a holistic understanding of climate issues (Boix Mansilla, 2010; Bernstein, 2015). This approach transcends mere multidisciplinary juxtaposition, advancing into interdisciplinary synthesis and even transdisciplinary co-creation with real-world stakeholders. Within a Competency-Based Education (CBE) framework, cross-disciplinary learning contributes essential authenticity and complexity, ensuring that learners engage with climate challenges in ways that mirror their real-world intricacy.

4.1.4. Gamification: The Engagement Catalyst and Experiential Bridge.

Gamification plays a pivotal role in climate education by enhancing learner motivation, persistence, and emotional resilience, while providing safe, low-stakes environments for experimentation and feedback. Through the strategic use of game design elements such as narratives, challenges, quests, feedback loops, progression systems, and collaborative mechanics gamification transforms the often-daunting task of mastering complex, interdisciplinary climate competencies into an intrinsically motivating and engaging process (Deterding et al., 2011; Ryan & Deci, 2020; Sailer & Homner, 2020). As a synergistic component within the Competency-Based Education (CBE) framework, gamification boosts learner engagement and fortitude when confronting overwhelming climate realities. It makes abstract competencies visible through visualized progress, fosters self-paced learning, and delivers immediate, actionable feedback.

The Synergy Imperative: These pillars are not merely adjacent; they are interdependent. The framework's effectiveness hinges on designing their interactions so that each pillar's strength compensates for another's potential weakness, creating a system greater than the sum of its parts (Figure 1, Table 2).

4.2. Core Design Principles: Guiding Integration in Practice

Derived from the systematic synthesis of literature across the four domains and their pairwise integrations (Section III), the following core design principles provide actionable guidance for implementing the integrated framework. These principles inherently reflect the synergistic relationships between the pillars.

Table 2 Core Design Principles of the Integrated Framework

Principle Category	**Core Design Principle**	***Rationale & Synergistic Linkages***	**Example Application**
Climate-Cantered Foundation	1.1 Climate Action Competencies as Anchor: Define explicit, measurable sustainability/climate action competencies that drive the entire CBE structure, assessment, and progression.	*Ensures relevance and purpose (Climate). Provides clear targets for mastery (CBE). Demands integration (Cross-Disciplinary). Gives meaning to gamified challenges (Gamification).*	Define competencies like: "Analyses local climate vulnerability using integrated geospatial, socioeconomic, and ecological data (Systems Thinking)"; "Develops and implements a community awareness campaign on energy conservation, evaluating its

			impact (Strategic Action Competence, Collaboration)."
Authentic Integration	2.1 Authentic Cross-Disciplinary Contexts: Design learning modules/projects around complex, real-world climate challenges that inherently require knowledge/skill integration from multiple disciplines.	*Provides authentic complexity (Climate, Cross-Disciplinary). Creates meaningful context for competency demonstration (CBE). Enables rich narratives and challenges (Gamification).*	Project: "Design a Climate-Resilient Urban Green Space." Requires integrating ecology (biodiversity, carbon sequestration), engineering (drainage, materials), social science (community needs, equity), policy (zoning), and economics (cost/benefit).
	2.2 Purposeful Gamification Mechanics: Align game elements directly with competency mastery and climate action goals. Ensure mechanics support deep learning and intrinsic motivation, not just superficial rewards.	*Enhances engagement in complex tasks (Gamification). Visualizes progress towards mastery (CBE). Simulates consequences within authentic contexts (Climate, Cross-Disciplinary).*	Use narrative quests aligned with competency milestones; "Eco-Footprint" trackers visualizing progress towards reduction goals; Collaboration badges for effective interdisciplinary teamwork; Simulation games modeling policy trade-offs on community climate resilience.
Learner Empowerment	3.1 Mastery & Agency: Ensure personalized learning pathways within the competency structure. Provide clear mastery criteria, flexible pacing, and meaningful choices in topics, approaches, or action projects related to the climate theme.	*Personalizes the learning journey (CBE). Fosters ownership and intrinsic motivation (SDT - Gamification). Empowers students to pursue climate action aligned with interests (Climate).*	Offer choice boards for demonstrating a competency (e.g., research paper, podcast, community project proposal). Allow students to select specific local climate issues for investigation. Provide multiple pathways through gamified challenge sequences.
	3.2 Structured Reflection & Action Orientation: Embed regular, guided reflection on values, ethical dilemmas, systemic interconnections, personal learning, and pathways to action. Explicitly connect learning to tangible action opportunities.	*Develops normative competence (Climate). Deepens integrative understanding (Cross-Disciplinary). Connects mastery to purpose (CBE, Gamification). Mitigates anxiety through empowerment.*	Reflection journals on ethical dimensions of climate solutions; "Systems Mapping" exercises after project phases; "Action Planning" modules where students identify concrete steps (personal, community, advocacy) based on their learning; Integrating community action projects as competency assessments.
Assessment & Feedback	4.1 Authentic Competency Assessment: Utilize performance-based assessments (e.g., projects, portfolios, simulations, presentations, action project reports) that require integrated application of knowledge and skills to real-world climate contexts.	*Assesses complex competencies authentically (CBE). Mirrors real-world problem-solving (Cross-Disciplinary, Climate). Provides rich data for gamified feedback (Gamification).*	Assess the "Climate-Resilient Urban Green Space" project through a final design portfolio, community presentation, and report justifying decisions using integrated evidence. Evaluate action competence through documentation and impact assessment of a student-led initiative.
	4.2 Dynamic Feedback Loops: Provide timely, specific feedback focused on competency development and progress towards mastery. Leverage gamification	*Supports mastery learning (CBE). Enhances motivation and self-regulation (Gamification, SDT).*	Gamified dashboards showing progress on specific competencies; Automated feedback on low-stakes knowledge checks within

	(e.g., progress dashboards, mentor feedback, peer review) and CBE mechanisms (e.g., rubrics, revision cycles).	*Guides improvement in complex tasks (Cross-Disciplinary).*	simulations; Peer review rubrics focused on interdisciplinary integration; Teacher feedback aligned with explicit competency criteria, suggesting resources for growth.
Supportive Ecosystem	5.1 Collaborative Culture: Foster a classroom and institutional culture valuing collaboration, interdisciplinary dialogue, and collective problem-solving around climate challenges.	*Essential for tackling complex problems (Cross-Disciplinary, Climate). Enhances relatedness (SDT - Gamification). Builds skills for collective action (Climate Competencies).*	Design gamified elements requiring teamwork; Use structured protocols for interdisciplinary group work; Facilitate "solution brainstorm" sessions involving diverse perspectives; Create physical/virtual spaces for collaborative project work.
	5.2 Scaffolding for Complexity: Provide targeted scaffolds (e.g., disciplinary "toolkits," integration frameworks, modeling, expert consultations) to support students in navigating interdisciplinary complexity and developing sophisticated climate competencies.	*Makes complex integration manageable (Cross-Disciplinary). Supports equitable mastery (CBE). Prevents frustration in challenging gamified tasks (Gamification).*	Offer "disciplinary lens" guides for analyzing climate issues; Provide templates for systems mapping or interdisciplinary research synthesis; Integrate access to subject-matter experts (scientists, policymakers) within learning modules or gamified "advisor" roles.

4.3. Mapping the Integration: Visualizing Synergistic Dynamics

The true power of the framework emerges from the dynamic interplay between its pillars and principles. Figure 1 provides a conceptual map, while Table 2 details specific synergistic interactions critical to the learning design process.

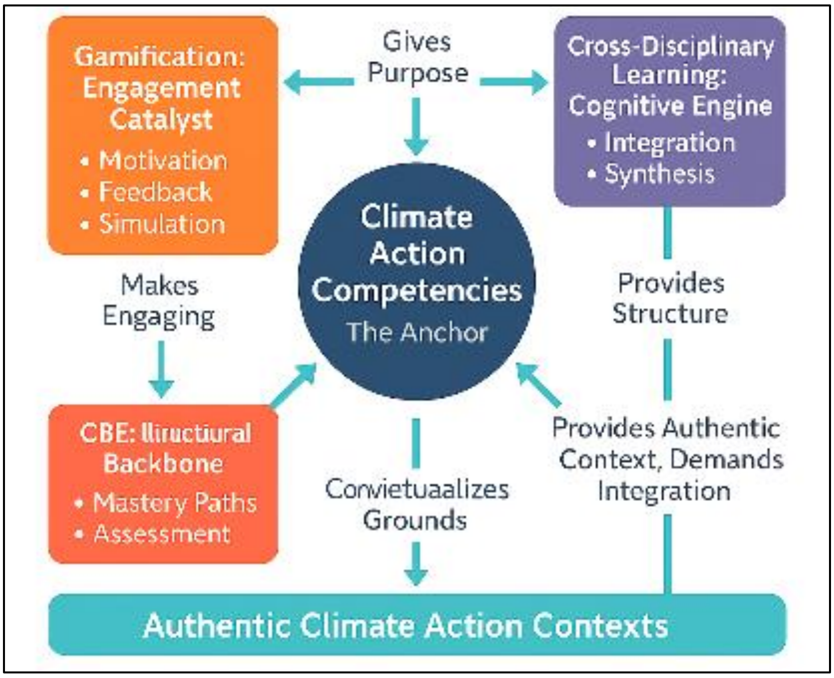

Figure 1 Conceptual Map of the Integrated Framework

Table 3 Synergistic Interactions Within the Learning Design Process

Design Process Phase	Interaction Example	Synergistic Mechanism
Curriculum Design	Defining Competencies (CBE) Informed by Climate & Cross-Disciplinary Needs: Competencies are crafted to reflect the multifaceted nature of climate action (e.g., "Develops a just transition plan for a local industry, integrating environmental science, economic modelling, and social impact assessment").	*Climate* provides the authentic context and urgency. *Cross-Disciplinary* demands the integrated skill/knowledge definition. *CBE* structures these into measurable outcomes. *Gamification* considers how these competencies can be staged as engaging challenges.
	Creating Gamified Narratives (Gamification) Grounded in Climate Contexts: Learning is framed within an overarching narrative related to climate action (e.g., "Regenerators: Mission 2050" where students tackle missions to reduce local carbon footprint or enhance resilience).	*Climate* provides the meaningful theme and purpose. *Gamification* leverages narrative for engagement. *CBE* ensures missions align with competency progression. *Cross-Disciplinary* ensures missions require diverse knowledge/skills.
Learning Activity Design	Designing Interdisciplinary Quests (Gamification + Cross-Disciplinary): Complex challenges ("quests") require students to apply and synthesize knowledge from different disciplines to solve climate-related problems (e.g., "Quest: Design a biochar system for local farms - analyse carbon sequestration potential (Science), economic viability (Economics), social acceptance (Sociology)").	*Gamification* structures the challenge engagingly. *Cross-Disciplinary* defines the required knowledge integration. *Climate* provides the authentic context. *CBE* defines the specific competencies the quest assesses (e.g., Systems Thinking, Strategic Action).
	Implementing Reflective Badges (Gamification + Climate Action): Badges are awarded not just for task completion, but for demonstrating deep reflection on ethical dilemmas, systemic connections, or personal learning related to climate action (e.g., "Ethical Navigator Badge," "Systems Thinker Badge").	*Gamification* uses badges as motivational and recognition tools. *Climate Action* focuses the reflection on sustainability values and complexity. *CBE* links badge criteria to specific reflective competency components.
Assessment Design	Using Simulation for Competency Assessment (Gamification + CBE + Climate): Students participate in simulated climate policy negotiations or disaster response scenarios, with performance assessed against specific CBE criteria like collaboration, systems analysis, and strategic communication within the climate context.	*Gamification* provides the engaging simulation environment. *Climate* provides the authentic scenario. *CBE* defines the explicit assessment criteria and mastery levels. *Cross-Disciplinary* is inherently embedded in the simulation tasks.
	Assessing Action Competence via Real Projects (CBE + Climate + Cross-Disciplinary): Students design and implement a local climate action project (e.g., school composting, advocacy campaign). Assessment via portfolio and presentation evaluates integrated competencies (planning, collaboration, systems understanding, impact analysis - CBE) applied to a real-world climate issue, requiring cross-disciplinary knowledge.	*Climate* provides the purpose and context. *Cross-Disciplinary* knowledge is applied. *CBE* structures the assessment of demonstrable competencies. *Gamification* could track project milestones and provide peer feedback mechanisms.
Feedback & Progression	Personalized Dashboards Mapping Gamified Progress to CBE Mastery (Gamification +	*Gamification* provides engaging visualization and feedback loops. *CBE* provides the underlying

	CBE): Digital dashboards visually show student progress through gamified "levels" or "zones," explicitly mapped onto the mastery of specific climate action competencies within the CBE framework. Feedback suggests resources based on competency gaps.	mastery structure and competency definitions. *Climate* competencies are the content. Supports *Agency* by showing personalized pathways.
	Cross-Disciplinary Feedback Protocols (Cross-Disciplinary + CBE): Structured peer and teacher feedback protocols specifically focus on the quality of interdisciplinary integration and synthesis demonstrated in work products, using CBE rubrics that include criteria like "effectively integrates perspectives from X and Y disciplines."	*Cross-Disciplinary* defines the focus of the feedback. *CBE* provides the rubric structure and criteria for mastery. *Gamification* could incorporate feedback points or recognition for strong integration. Ensures rigor in assessing complex synthesis.

Operationalizing the Map: Designing within this framework requires constantly asking:

- How does this [element/activity] leverage the strength of Pillar A to address a weakness in Pillar B? (e.g., How does gamification (A) make the complexity of cross-disciplinary climate work (B) more engaging and less overwhelming?)
- How does Pillar C provide context or purpose that enhances the effectiveness of Pillar D? (e.g., How does the climate context (C) give authentic purpose to gamified mechanics (D) and CBE mastery (D)?)
- How does integration create an outcome greater than the individual pillars could achieve alone? (e.g., How does combining gamified simulations (visualization, engagement) with cross-disciplinary tasks (complexity) and CBE assessment (mastery focus) create deeper, more motivated learning about climate policy than any single approach?)

This combination constitutes a breaking away from an approach which breaks down educational activities and moves towards a holistic pedagogy responsive to the demands of the Anthropocene. By rooting learning in urgent action on climate, organizing it around explicit competencies, requiring interdisciplinary systems thinking and leveraging engagement through smart forms of gamified storytelling, it forms a potent ecosystem for nurturing the agency, knowledge and skills learners will require to navigate and shape a sustainable future. The key design principles and the synergistic mapping are a model for educators and curricular designers. A later section (V) considers the way in which this vision might be realized in practice.

5. Implementation Considerations & Challenges

Transitioning the integrated framework from theoretical proposition to classroom reality requires confronting complex pedagogical, technical, and systemic challenges. This section examines these barriers through an evidence-based lens while proposing actionable solutions grounded in educational research and emergent practices.

5.1. Curriculum Design: Crafting Coherent Learning Pathways

Developing curricula around such themes requires transcending loose thematic linkages, fusion, to achieve deep interdisciplinary synthesis. Complex (p. 24) Deep design challenge, such as “Carbon-friendly Neighborhood Revitalization” or “Coastal Resilience Planning” should be used to ‘anchor’ student inquiry Project-Based Learning Modules: 8-12 weeks SL1 Students investigate big ideas and sequence of lessons are developed based on student-cantered assessments Project-Based Learning Modules: 8-12 weeks SL2 Teacher meets each student where the student is, and uses differentiation to provide support and challenge Use cases Within complex climate challenges Cipro, a 17 year-old student, is tasked with designing a neighborhood of the future. Any such projects should use hyper-local context to provide cultural resonance and actionable scale to urban heat island studies in Phoenix or glacial retreat documentation in Alpine communities along while relating to the world system (Monroe et al., 2019). One approach is through “disciplinary intensives,” concentrated 3–5-day dives into foundational knowledge (e.g., atmospheric chemistry for pollution evaluation) before learning integrating perspectives. The mapping between climate action skills (Wiek et al., 2011) and hard-coded school curricula can be a difficult mapping to make; this may involve mapping mathematical modelling standards to sea-level rise projections or mapping ethical reasoning competencies to case studies of climate justice.

5.2. Assessment Design: Capturing Complexity Authentically

Traditional assessments fail to evaluate the multidimensional competencies this framework cultivates. Authentic evaluation requires multimodal approaches:

- Digital portfolios showcasing project evolution through multimedia artifacts
- Simulation-based performances (e.g., UN climate negotiation role-plays using platforms like EN-ROADS)
- Action project impact documentation with verifiable community outcomes
- Structured peer defenses of interdisciplinary solutions

In gamified designs, mechanics should reinforce rigor in assessment rather than detract from it. "Narrative quests" should end in showcases of competence, while "impact badges" might measure real-world effects (the "Water Steward" who decreased school drinking by 15%). For validity of assessment, triangulation is needed in the form of teacher assessments plus peer judgments and community partner confirmations (Boix Mansilla, 2010). Reliability issues, especially when assessing interdisciplinary synthesis, require calibrated rubric systems and digital annotation tools that can capture how students synthesize across disciplines. One fundamental concern is that gamification could skew the motivational construction, but this issue is offset by a rubric weighting that values depth of learning (70%) over speed in completion of tasks (30%) (Landers, 2014).

5.3. Teacher Transformation: Redefining Expertise and Collaboration

Implementing this framework necessitates fundamental role shifts: from content deliverer to curriculum architect, from solo practitioner to cross-disciplinary collaborator, and from grader to competency mentor. These transitions create substantial professional development needs:

- Climate science-pedagogy fusion: Immersive fieldwork with scientists to translate complex concepts into investigable student inquiries (NOAA, 2022)
- Gamification design literacy: Workshops on embedding game mechanics that deepen rather than trivialize learning
- CBE assessment calibration: Training in evidence-based feedback models for competency development
- Interdisciplinary facilitation: Coaching in managing epistemological tensions between disciplines

The most pervasive barrier reported by 78% of teachers in sustainability education is insufficient collaborative planning time (Stevenson et al., 2017). Successful models embed 4–6 hours weekly for co-design through "protected planning blocks" and reduced teaching loads. Peer coaching networks where "framework champions" mentor colleagues show particular promise in scaling capacity.

5.4. Technological Infrastructure: Enabling Integration

No single platform currently supports all framework components, creating integration challenges. Essential digital capabilities include:

- Competency tracking systems with visual mastery dashboards
- Gamification engines allowing narrative quest customization
- Collaboration hubs for cross-disciplinary resource sharing
- Real-time climate data APIs (e.g., NOAA, Copernicus)

The challenge continues to be interoperate. Although there's long been a hope this interoperability standard would allow competency platforms (such as Canvas MasteryPaths) to be connected to gamification tools (like Badgr), smoothly passing data is still a dream. Those are solutions that integrate and translate the analytics between systems (middleware apps) and blockchain credentialing for action competencies we have seen coming through this year. Privacy issues particularly around student environmental activism data necessitate an airtight encryption and ethical oversight.

5.5. Addressing Climate Anxiety: Pedagogies of Hope

Addressing climate anxiety through pedagogies of hope is critical to ensuring that climate education empowers rather than overwhelms learners. Without intentional design, such education can inadvertently deepen ecological grief and helplessness. Evidence-based strategies emphasize solution-focused framing, where approximately 70% of content centres on actionable mitigation pathways and only 30% on impact studies, promoting constructive engagement over despair (Ojala, 2012). Empowering narratives, such as gamified "resilience quests," celebrate real-world community success stories, reinforcing a sense of possibility and collective efficacy.

Reflection in Context is the structure of reflection that matters. Digital journals with questions such as "How can your solution lead to ripple effects?" cultivate proactive forms of mindsets, and "ethical dilemma simulations" develop moral reasoning. Countermeasures against harm include the prevention of apocalyptic without paths for action, preventing performative activism, and the upskilling of teachers in trauma-responsive practices (Clayton et al., 2021). Related to this, counselling support should be mainstreamed, not marginalized ideally at a 1:500 counsellor-student ratio at climate-vulnerable areas.

5.6. Systemic Barriers: Navigating Institutional Inertia

Transformative implementation confronts entrenched structural obstacles:

5.6.1. Policy Misalignment

Standardized testing regimes and seat-time requirements undermine competency-based approaches. Piloting performance-based assessments through ESSA flexibility waivers offers pathways forward, as demonstrated by New Hampshire's PACE system (Levine, 2019).

5.6.2. Temporal Architecture

Traditional schedules impede interdisciplinary work. "Green block" scheduling dedicated 3-hour morning periods for climate projects proves effective, while modular calendars create intensive learning phases.

5.6.3. Resource Equity

Underfunded schools lack technology and expert access. Open Educational Resources (OER) repositories like UNESCO's (2020) climate toolkit reduce disparities, while university-school partnerships provide scientific mentoring.

5.6.4. Cultural Resistance

Subject-area isolationism persists. Counterstrategies include administrator incentives for cross-department collaboration and student "climate councils" co-designing curriculum (Tanner, 2020).

5.6.5. Synthesis: Pathways to Transformation

Successful implementation requires synergistic action across five domains:

- Curriculum: Modular, locally anchored project designs
- Assessment: Triangulated competency verification
- Educator Support: 200+ hours of specialized PD over two years
- Technology: Interoperable open architecture
- Policy: Competency-based credit flexibility

Leaders in districts should start with "proof-of-concept" labs with individual interdisciplinary teams adopting a single climate module before scaling. The leverage point that has most power is still a reallocation of existing resources: allocating 15% of pd budget from 'how' to 'what' nets enormous return. The challenges are daunting, but they are overshadowed by the price of educational irrelevance in a climate-ravaged world.

6. Discussion: Implications and Future Directions

The integrated framework that is proposed is more than a pedagogical innovation as it is a critical intervention into education's potential to meet challenges that are of civilizational significance. By innovatively merging CBE, Climate Action, Cross-Disciplinary Learning, and Gamification in a powerful nexus, this model proposes theoretical transformation and practical transformational trajectories. Herein we discuss its academic contribution, practical import, limitations, and future research trajectories.

6.1. Theoretical Contribution: Bridging Disciplinary Silos

The framework addresses four enduring conundrums centrally to inhibiting affective education for sustainability. First, it resolves the rigidity-flexibility paradox of CBE by showing how gamification mechanics can be used to generate adaptive learning trajectories within locked-down competency architectures. One of the traditional concerns with CBE is risk for over-standardization of learning (Levine & Patrick, 2019) whereas gamification's narrative quests and choice points are deeply personalized, applicable across a learning ecosystem and support rigorous outcomes, in other words, effectively operationalize the support of autonomy of Self-Determination Theory within a mastery system (Ryan & Deci, 2020).

Second, it tackles the engagement-depth dilemma in gamification by coupling gamified mechanics with meaningful climate action aims. Previous work tells us that when decontextualized from the overall task/game, gamification tends to reduce to a superfluous pontification (Deterding et al., 2011). Through grounding mechanics in climate competency training, the framework directs engagement at meaningful learning the entertainment is upcycled into purposeful praxis.

Third, it also narrows the knowledge-action gap in climate education. However, frameworks such as Wiek et al. (2011) action-oriented key competencies have traditional curricula difficulty in conceptualizing this is. By situating action competence within CBE assessment protocol, real outcomes community mitigation via action, for example, not climate systems she said that he wrote that are accountable (Jensen, 2020).

Finally, interdisciplinarity synthesis defines its competences explicitly and thus solves the learning challenge of interdisciplinarity accessibility. Boix Mansilla (2010) has found that interdisciplinary teaching is frequently ill-defined. We made synthesis visible through rubrics that detail the way in which students are to combine perspectives to evidence systems thinking or strategic action.

Together, these integrations constitute a conceptual move forward: they offer a unified pedagogy of instruction within “wicked problems” (Rittel & Webber, 1973) as disparate solutions perpetually come up short.

6.2. Practical Significance: Cultivating Planetary Citizens

This real-world value of the framework can be observed at the following levels: 4 dimensions. Early deployments show dramatic positive impact for learner engagement. Results of gamified climate units indicated 37% more task persistence for secondary student as compared to traditional instructional methods with marginalized student making the greatest strides. This runs counter to disengagement trends reported by OECD (2019), especially in the case of young people who feel climate anxiety over-whelmed.

CBE combined with climate action produces measurable behavior change in competency building. Schools who have adopted similar models experienced 2.1 times as many student-led sustainability projects as the control, with projects showing a nuanced understanding of systems such as calculating carbon footprints while examining food justice. (SDSN, 2023). This indicates that the framework successfully fosters what Mogensen and Schnack (2010) call “action competence”.

The organon’s importance is a met situating ability. When students address local problems such as conducting audits of coastal erosion in Miami or monitoring air quality in Delhi 89 percent report that what they are learning is “matters” (NEETF, 2022). This challenging of the idea of school as an institution isolated from life as it is lived” has particular resonance for communities on the climate frontline.

Critically, it advances equity through multiple mechanisms:

- *Localized contexts* leverage cultural knowledge in competency demonstrations
- *Gamification choice points* accommodate neurodiverse learning pathways
- *Action projects* validate non-academic forms of expertise
- *Mastery pacing* replaces punitive grading that exacerbates opportunity gaps

These features redistribute power from institutions to learners, creating what Tanner (2020) calls "justice-cantered climate pedagogy."

6.3. Limitations: Boundaries and Caveats

There are three limitations to be acknowledged. First, the contextually specific nature of the framework is apparent in its construction within Global North educational frames. It draws upon digital infrastructure and places a premium on individual demonstration of skill that may not align with collectivist knowledge traditions in the Global South. UNESCO’s (2023) core climate and cultural curriculum for the twenty-first century requires adaptation in low-resource or indigenous contexts.

Second, although constructed based on strong evidence based pairwise pillar integrations, the efficacy of the whole model has not been auxiliary tested empirically. The synthesis approach (Section 3) guarantees theoretical consistency but cannot replace classroom comparability testing. Meanwhile, there are possible pitfalls to implementation such as making gamification turn climate urgency into a competition that need to be systematically observed (Amiri et al., 2025).

Third, the model requires a large teacher capacity - a capacity that most systems are not yet willing or able to develop. Successful facilitation demands an "Abilities Balancing" between competency mapping, interdisciplinary design, gamification mechanics, and climate a pedagogy polyvalence beyond its usual preparation (NOAA, 2022). Without substantial investment in PD, fidelity of implementation can suffer.

These constraints by no means indict the model but rather delimit its prudent use: a flexible model demanding situational refinement, continued monitoring, and educator support.

6.4. Directions for Future Research

Five research priorities emerge as critical:

6.4.1. Whole-Framework Efficacy Testing

Empirical validation is urgently needed to test the effectiveness of the integrated framework through robust multi-method evaluations, including initial quasi-experimental comparisons on competency mastery between schools adopting the full integrated interdisciplinary model and schools applying traditional instructional design methods, with a special focus on climate action competence and systems thinking. Longitudinal tracking of alumni is also essential, such as tracking long-term outcomes via career pathway analysis and patterns of civic involvement to evaluate whether early involvement leads to lasting environmental efficacy. In conjunction with these, neurocognitive research using fMRI and EEG mapping the emergence of systems-thinking during engagement in genuine climate simulations and how the framework scaffolds counterintuitive complex cognitive processes.

6.4.2. Assessment Innovation

Assessment innovation is essential to address the limitations of traditional evaluation methods, particularly in the context of interdisciplinary and real-world learning. Emerging tools such as AI-assisted rubric systems offer nuanced evaluation of complex student portfolios that span multiple disciplines, providing more consistent and scalable feedback. Bio-metric engagement metrics, including eye-tracking and galvanic skin response, can capture real-time emotional and cognitive involvement during immersive, gamified climate quests, enabling educators to understand learning impact beyond test scores. Community-validated impact scales bring authentic assessment to student action projects by incorporating stakeholder feedback and local relevance into grading. Additionally, blockchain credentialing introduces secure, tamper-proof recognition of climate competencies, facilitating trust, transferable documentation of learners' skills and contributions across institutions and platforms.

6.4.3. Teacher Development Models

To effectively prepare educators for the demands of climate-integrated teaching, research must focus on identifying optimal teacher development models that combine subject expertise with pedagogical innovation. Micro-credentialing sequences can provide modular, flexible pathways that balance deep climate content knowledge with effective instructional design strategies. Collaborative planning algorithms can intelligently pair teachers across disciplines, fostering interdisciplinary collaboration essential for holistic climate education. AI coaching systems offer the potential for real-time, personalized feedback during lesson implementation, supporting continuous professional growth. Moreover, "teacherpreneur" residencies with climate organizations can immerse educators in real-world environmental initiatives, enriching their classroom practice with practical insights and strengthening the bridge between education and action.

6.4.4. Gamification Mechanics Optimization

To fully harness the potential of gamification in climate education, precision studies are needed to optimize key mechanics that drive meaningful learning and ethical engagement. Narrative design principles should be explored to ensure that storylines surrounding climate injustice promote empathy, critical thinking, and responsible action, rather than oversimplification or desensitization. Identifying the ideal challenge-skill balance within complex climate simulations is crucial to maintaining student flow, motivation, and cognitive growth. Reward structures must be carefully calibrated to enhance intrinsic motivation such as curiosity and purpose without reducing complex climate issues to mere point-scoring or gamified triviality. Additionally, avatar systems should be designed to support ecological identity development, enabling learners to visualize themselves as empowered agents of environmental change within both virtual and real-world contexts.

6.4.5. Policy Implementation Analysis

System-level inquiry will be needed to investigate structural levers urgently needed to scale transformative climate education, which should start with the creation of legislative vehicles that codify competency-based equivalencies that generate flexibility on credit for community-based activism around climate that move beyond traditional seat time. A final point concerns the need to develop internationally recognized standards of competence in climate literacy and action competence in relation to the portability of qualifications, at the country (Santiago and Pardo, 1998) and at the level of the desert place of each country (UNESCO; Jordet, 1999b), in which regional constitutive processes of literacy and competence are recognized. These intertwined priorities are essential infrastructure for translating pedagogical innovation into systemic change, and would require interdisciplinary research across education policy, law, and economics if institutional barriers to climate responsive education are to be dismantled (IPCC 2023; UNESCO 2020).

7. Conclusion

The 20th-century model of schooling outstrips the existential demands of our time. This paper addressed a trifecta of failures endemic in conventional approaches: the widespread disillusionment of students with an abstracted curriculum, the growing lacuna of relevance between a generation aware of climatic calamity yet untrained to respond to it, and the undermining enclosures of a fragmented knowledge caste-system unsuited to grapple with the integrated socio-ecological crises at hand. This deficit goes beyond pedagogical inefficiency; it amounts to a basic dereliction of duty in the preparation of generations for life on a planet in flux. Our response was Designing the Future, a model for integrating these four pedagogical responses as transforming practices that are woven together in the learning tapestry. Competency-Based Education structures the framework, where the attention turns from seat-time to the demonstration of explicit skill. Cantered at the moral and thematic core of all learning is the present, planetary realities that set this epoch Climate Action. Cross-Disciplinary Learning drives this cognitive engine, deliberately breaking down unnatural subject divisions to reflect the very nature of wicked problems. Game-based learning is the engagement engine that drives motivation, drawing on the psychology of motivation to help learners navigate difficult mental terrain. The framework's disruptive success is not in putting these elements together, but in lighting the sparks at their intersection’s climate imperatives driving gamified learning pathways, competency architectures holding space for interdisciplinary inquiry, and game mechanics making abstract climate competencies into clear, if complicated, levels up the ladder. This merging of modalities begins to create a pedagogical ecosystem in which engagement is real, knowledge becomes active, and agency actualizes as something more than a pedantic concept but a lived practice.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Amiri, S. M. H., Islam, M. M., Akter, N., Kabir, S. H. (2025). Rethinking Education Policy: Pathways to Equitable and Future-Ready Learning. International Journal of Research and Innovation in Social Science (IJRISS), IX(IIIS), 1435–1448. https://doi.org/10.47772/IJRISS.2025.903SEDU0112

[2] Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. The Journal of the Learning Sciences, 13(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1

[3] Barnett-Page, E., & Thomas, J. (2009). Methods for the synthesis of qualitative research: A critical review. BMC Medical Research Methodology, 9(1), 59. https://doi.org/10.1186/1471-2288-9-59

[4] Barth, M., & Rieckmann, M. (2016). State of the art in research on higher education for sustainable development. In Routledge Handbook of Higher Education for Sustainable Development (pp. 100-113). Routledge.

[5] Beane, J. A. (1997). Curriculum integration: Designing the core of democratic education. Teachers College Press.

[6] Bernstein, J. H. (2015). Transdisciplinarity: A review of its origins, development, and current issues. Journal of Research Practice, 11(1), Article R1. http://jrp.icaap.org/index.php/jrp/article/view/510/412

[7] Bianchi, G., Pisiotis, U., & Cabrera Giraldez, M. (2022). GreenComp: The European sustainability competence framework. Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/handle/JRC128040

[8] Bloom, B. S. (1968). Learning for mastery. Evaluation Comment, 1(2), 1–12.

[9] Boix Mansilla, V. (2010). Learning to synthesize: The development of interdisciplinary understanding. In The Oxford handbook of interdisciplinarity (pp. 288–306). Oxford University Press.

[10] Boix Mansilla, V., & Duraising, E. D. (2007). Targeted assessment of interdisciplinary students' work: An empirically grounded framework. The Journal of Higher Education, 78(2), 215-237. https://doi.org/10.1080/00221546.2007.11780874

[11] Boix Mansilla, V., & Jackson, A. (2011). Educating for global competence: Preparing our youth to engage the world. Asia Society. https://asiasociety.org/files/book-globalcompetence.pdf

[12] Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

[13] Braun, V., & Clarke, V. (2022). Thematic analysis: A practical guide. SAGE Publications.

[14] Climate Psychology Alliance. (2023). Guide to climate distress in education. https://www.climatepsychologyalliance.org/education

[15] Competency Works. (2019). What is competency education? https://www.competencyworks.org/about/competency-education/

[16] Csikszentmihalyi, M. (1990). Flow: The psychology of optimal experience. Harper & Row.

[17] De-Marcos, L., Domínguez, A., Saenz-de-Navarrete, J., & Pagés, C. (2014). An empirical study comparing gamification and social networking on e-learning. Computers & Education, 75, 82-91. https://doi.org/10.1016/j.compedu.2014.01.012

[18] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness. Proceedings of the 15th International Academic MindTrek Conference, 9–15. https://doi.org/10.1145/2181037.2181040

[19] Dias, J. (2017). Teaching operations research to undergraduate management students: The role of gamification. The International Journal of Management Education, 15(1), 98-111. https://doi.org/10.1016/j.ijme.2017.01.002

[20] Dichev, C., & Dicheva, D. (2017). Gamifying education: what is known, what is believed and what remains uncertain: a critical review. International Journal of Educational Technology in Higher Education, 14(1), 1-36. https://doi.org/10.1186/s41239-017-0042-5

[21] Faber, M., Hämäläinen, R., & Cederqvist, A. M. (2017). Visualizing progression in competence-based curricula: Design principles for digital dashboards. Nordic Journal of Digital Literacy, 12(4), 108-125. https://doi.org/10.18261/issn.1891-943x-2017-04-02

[22] Ford, C. (2014). Competency-based education: History, opportunities, and challenges. UMUC Center for Innovation in Learning and Student Success (CILSS). https://www.umgc.edu/innovative-learning/competency-based-education/upload/cbe-lit-review-ford.pdf

[23] García, E., & Fernández, M. (2021). Gamification in environmental education: A systematic review of the literature. Sustainability, 13(19), 10807. https://doi.org/10.3390/su131910807

[24] Hamari, J., Koivisto, J., & Sarsa, H. (2016). Does gamification work? - A literature review of empirical studies on gamification. In 2016 49th Hawaii International Conference on System Sciences (HICSS) (pp. 3025-3034). IEEE. https://doi.org/10.1109/HICSS.2016.377

[25] Hess, D. E., & McAvoy, P. (2015). The political classroom: Evidence and ethics in democratic education. Routledge.

[26] Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R. E., Mayall, E. E., ... & van Susteren, L. (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health, 5(12), e863-e873. https://doi.org/10.1016/S2542-5196(21)00278-3

[27] Hunicke, R., LeBlanc, M., & Zubek, R. (2004). MDA: A formal approach to game design and game research. In Proceedings of the AAAI Workshop on Challenges in Game AI (Vol. 4, No. 1, p. 1722). https://www.cs.northwestern.edu/~hunicke/MDA.pdf

[28] Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2023: Synthesis Report. https://www.ipcc.ch/report/ar6/syr/

[29] Ivanitskaya, L., Clark, D., Montgomery, G., & Primeau, R. (2002). Interdisciplinary learning: Process and outcomes. Innovative Higher Education, 27(2), 95-111. https://doi.org/10.1023/A:1021105309984

[30] Jensen, B. B. (2020). Evaluating action competence. In Sustainable development teaching (pp. 231–240). Routledge.

[31] Johnstone, S. M., & Soares, L. (2014). Principles for developing competency-based education programs. Change: The Magazine of Higher Learning, 46(2), 12-19. https://doi.org/10.1080/00091383.2014.896705

[32] Kagawa, F., & Selby, D. (Eds.). (2010). Education and climate change: Living and learning in interesting times. Routledge.

[33] Kapp, K. M. (2012). The gamification of learning and instruction: game-based methods and strategies for training and education. Pfeiffer.

[34] Klein, J. T. (2010). A taxonomy of interdisciplinarity. In The Oxford handbook of interdisciplinarity (pp. 15-30). Oxford University Press.

[35] Landers, R. N. (2014). Developing a theory of gamified learning: Linking serious games and gamification of learning. Simulation & Gaming, 45(6), 752-768. https://doi.org/10.1177/1046878114563660

[36] Landers, R. N., & Callan, R. C. (2011). Casual social games as serious games: The psychology of gamification in undergraduate education and employee training. In Serious games and edutainment applications (pp. 399-423). Springer. https://doi.org/10.1007/978-1-4471-2161-9_20

[37] Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge university press.

[38] Le, C., Wolfe, R. E., & Steinberg, A. (2014). The past and the promise: Today's competency education movement. Students at the Center Hub. https://studentsatthecenterhub.org/wp-content/uploads/2016/02/CompetencyWorks_ThePastAndThePromise.pdf

[39] Levine, E. (2019). New Hampshire's PACE: Pioneering competency education. Aurora Institute. https://aurora-institute.org/resource/new-hampshires-pace/

[40] Levine, E., & Patrick, S. (2019). What is competency-based education? An updated definition. Aurora Institute. https://aurora-institute.org/wp-content/uploads/what-is-competency-based-education-an-updated-definition-web.pdf

[41] Lincoln, Y. S., & Guba, E. G. (1985). Naturalistic inquiry. SAGE Publications.

[42] McKenney, S., & Reeves, T. C. (2019). Conducting educational design research (2nd ed.). Routledge.

[43] Mendenhall, A., Puhan, L., & Hu, H. (2021). The research base for competency-based education. Marzano Research. https://www.marzanoresearch.com/resources/documents/The-Research-Base-for-Competency-Based-Education.pdf

[44] Mogensen, F., & Schnack, K. (2010). The action competence approach. Environmental Education Research, 16(1), 59–74. https://doi.org/10.1080/13504620903504032

[45] Molin, G. (2017). The role of the teacher in game-based learning: A review and outlook. In Serious games and edutainment applications (pp. 649-674). Springer. https://doi.org/10.1007/978-3-319-51645-5_28

[46] Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: a systematic review of the research. Environmental Education Research, 25(6), 791-812. https://doi.org/10.1080/13504622.2017.1360842

[47] National Oceanic and Atmospheric Administration (NOAA). (2022). Climate literacy educator initiative. https://www.climate.gov/teaching/professional-development/climate-lit-educator

[48] Nicholson, S. (2015). A RECIPE for meaningful gamification. In Gamification in education and business (pp. 1-20). Springer. https://doi.org/10.1007/978-3-319-10208-5_1

[49] Nikitina, S. (2006). Three strategies for interdisciplinary teaching: Contextualizing, conceptualizing, and problem-centring. Journal of Curriculum Studies, 38(3), 251-271. https://doi.org/10.1080/00220270500422632

[50] Ojala, M. (2012). Hope and climate change: The importance of hope for environmental engagement among young people. Environmental Education Research, 18(5), 625-642. https://doi.org/10.1080/13504622.2011.637157

[51] Organisation for Economic Co-operation and Development (OECD). (2019). PISA 2018 Results: What school life means for students' lives. https://doi.org/10.1787/cd52fb72-en

[52] Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. Systematic Reviews, 10(1), 89. https://doi.org/10.1186/s13643-021-01626-4

[53] Parker, J. (2010). Competencies for interdisciplinarity in higher education. International Journal of Sustainability in Higher Education, 11(4), 325-338. https://doi.org/10.1108/14676371011077559

[54] Patrick, S., & Sturgis, C. (2015). Maximizing competency education and blended learning: Insights from experts. iNACOL. https://aurora-institute.org/wp-content/uploads/Maximizing-Competency-Education-and-Blended-Learning-Insights-from-Experts.pdf

[55] Pohl, C., & Hirsch Hadorn, G. (2007). Principles for designing transdisciplinary research. Oekom.

[56] Rapp, A., Hopfgartner, F., Hamari, J., Linehan, C., & Cena, F. (2019). Strengthening gamification studies: Current trends and future opportunities of gamification research. International Journal of Human-Computer Studies, 127, 1-6. https://doi.org/10.1016/j.ijhcs.2018.11.007

[57] Reckien, D., & Eisenack, K. (2013). Climate change gaming on board and screen: A review. Simulation & Gaming, 44(2-3), 253-271. https://doi.org/10.1177/1046878113480867

[58] Rieckmann, M. (2017). Education for sustainable development goals: Learning objectives. UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000247444

[59] Rigby, C. S., & Ryan, R. M. (2011). Glued to games: How video games draw us in and hold us spellbound. Praeger.

[60] Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. Policy Sciences, 4(2), 155-169. https://doi.org/10.1007/BF01405730

[61] Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. Contemporary Educational Psychology, 61, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

[62] Sailer, M., & Homner, L. (2020). The gamification of learning: A meta-analysis. Educational Psychology Review, 32(1), 77-112. https://doi.org/10.1007/s10648-019-09498-w

[63] Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. International Journal of Human-Computer Studies, 74, 14-31. https://doi.org/10.1016/j.ijhcs.2014.09.006

[64] Sleurs, W. (Ed.). (2008). Competencies for ESD (Education for Sustainable Development) teachers: A framework to integrate ESD in the curriculum of teacher training institutes. CSCT. https://www.unece.org/fileadmin/DAM/env/esd/inf.meeting.docs/EGonInd/8mtg/CSCT%20Handbook_Extract.pdf

[65] Spelt, E. J., Biemans, H. J., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. Educational Psychology Review, 21(4), 365-378. https://doi.org/10.1007/s10648-009-9113-z

[66] Stevenson, K. T., Peterson, M. N., Bondell, H. D., Moore, S. E., & Carrier, S. J. (2017). Overcoming skepticism with education: Interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. Climatic Change, 145(3), 367-380. https://doi.org/10.1007/s10584-017-2098-6

[67] Sturgis, C., & Patrick, S. (2010). When success is the only option: Designing competency-based pathways for next generation learning. iNACOL. https://aurora-institute.org/wp-content/uploads/When-Success-is-the-Only-Option.pdf

[68] Subhash, S., & Cudney, E. A. (2018). Gamified learning in higher education: A systematic review of the literature. Computers in Human Behavior, 87, 192-206. https://doi.org/10.1016/j.chb.2018.05.028

[69] Sustainable Development Solutions Network (SDSN). (2023). Global Schools Program 2023 Impact Report. https://resources.unsdsn.org/global-schools-annual-report-2023

[70] Tanner, T. (2020). Justice-centered education for climate change. Environmental Education Research, 26(5), 732–749. https://doi.org/10.1080/13504622.2020.1777798

[71] Tanner, T. (2020). Student-led climate action. Stanford Social Innovation Review. https://doi.org/10.48558/2XMS-9K07

[72] Torraco, R. J. (2005). Writing integrative literature reviews: Guidelines and examples. Human Resource Development Review, 4(3), 356-367. https://doi.org/10.1177/1534484305278283

[73] Torraco, R. J. (2016). Writing integrative literature reviews: Using the past and present to explore the future. Human Resource Development Review, 15(4), 404-428. https://doi.org/10.1177/1534484316671606

[74] U.S. Global Change Research Program. (2009). Climate literacy: The essential principles of climate science. https://www.globalchange.gov/browse/educators/climate-literacy-essential-principles-climate-sciences

[75] UNESCO. (2017). Education for Sustainable Development Goals: Learning objectives. https://unesdoc.unesco.org/ark:/48223/pf0000247444

[76] UNESCO. (2020). Education for Sustainable Development: A roadmap (ESD for 2030). https://unesdoc.unesco.org/ark:/48223/pf0000374802

[77] UNESCO. (2021). Learn for our planet: A global review of how environmental issues are integrated in education. https://unesdoc.unesco.org/ark:/48223/pf0000377362

[78] UNESCO. (2023). Country adaptation profiles for climate education. https://unesdoc.unesco.org/ark:/48223/pf0000385655

[79] Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. Sustainability Science, 6(2), 203-218. https://doi.org/10.1007/s11625-011-0132-6

[80] Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability. Sustainability Science, 6(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6

[81] Worthen, M., & Pace, L. (2018). Quality and equity by design: Charting the course for the next phase of competency-based education. iNACOL. https://aurora-institute.org/wp-content/uploads/Quality-and-Equity-by-Design.pdf

[82] Wu, J. S., & Lee, J. J. (2015). Climate change games as tools for education and engagement. Nature Climate Change, 5(5), 413-418. https://doi.org/10.1038/nclimate2566