

DEVELOPING A FRAMEWORK FOR THE INTEGRATION OF EDUCATION FOR SUSTAINABLE DEVELOPMENT INTO SCIENCE TEACHING AND LEARNING

Monde Kazeni, & Eunice Nyamupangedengu

Division of Technology and Science, University of the Witwatersrand (South Africa)

Abstract

Global efforts to embed Education for Sustainable Development (ESD) into curricula, particularly science education, are gaining traction. Yet research highlights that teachers often lack a clear understanding of sustainability objectives, competencies, and pedagogies. This gap is largely due to the absence of frameworks guiding the integration of ESD into science lessons, to align with the 2030 Agenda for Sustainable Development. To address this, the study developed a practical, comprehensive, and cohesive framework incorporating ESD principles. Using a qualitative conceptual design, the study developed a framework which outlines SDG-specific learning objectives, sustainability competencies, and transformative pedagogies to develop the competences in learners. The framework is expected to strengthen teachers' grasp of ESD and empower them to integrate it in their teaching to cultivate a generation of students equipped to tackle sustainability challenges.

Keywords: *Education, science, ESD, sustainability, framework.*

1. Introduction

The global community faces urgent challenges such as climate change, hunger, conflict, and inequality (UNESCO, 2015), prompting UNESCO to introduce the 2030 Agenda for Sustainable Development, which is built around 17 Sustainable Development Goals (SDGs) (UNESCO, 2015). Education for Sustainable Development (ESD) is central to achieving this agenda, as it equips learners with the knowledge, skills, and values necessary to advance global sustainability (UNESCO, 2017). Yet many teachers struggle to integrate the SDGs into their lessons due to limited understanding and the absence of clear pedagogical frameworks (de Souza, 2025). To address this gap, the study proposes a framework that outlines SDG-specific objectives, transformative teaching approaches, and targeted competencies to support science educators in embedding sustainability into their practice.

2. Literature review

2.1. Education for sustainable development in science education

Science education provides fertile ground for embedding ESD due to its emphasis on inquiry, evidence-based reasoning, systems thinking, and ethical reflection (Vilmala et al., 2022). However, studies reveal that sustainability principles are often included unintentionally, superficially, with some key competencies absent, and teachers lacking sufficient knowledge of ESD (Kazeni & Nyamupangedengu, 2025; Rieckmann, 2018; Khadim et al., 2022). Moreover, many teachers lack training, institutional support, and clarity on how to translate ESD principles into classroom practice (UNESCO, 2021). Policy commitments frequently fail to materialize due to resource constraints and systemic barriers (de Souza, 2025). These findings underscore the need for structured guidelines to support adequate and intentional ESD integration.

2.2. Approaches for integrating sustainable development (ESD) into education

Existing approaches to integrating Education for Sustainable Development (ESD), which include transformative pedagogy, curriculum integration, whole-school strategies, and community engagement, show promise but face challenges such as resource limitations, curriculum overload, and uneven implementation (Azmi et al., 2024; Roach, 2023). Moreover, a systematic review conducted by Habibaturrohman et al. (2023) highlights strategies for integrating ESD into STEM education, such as

embedding SDG concepts into lesson, hands-on projects, real-world problem-solving, community partnerships, and teacher training. However, these remain fragmented due to resource constraints (Azmi et al., 2024), institutional inertia, siloed curricula, and limited teacher confidence. As UNESCO (2021) stresses that sustainability begins with teachers, this study proposes a comprehensive framework combining UNESCO's ESD model with UCL's integration guidelines. By offering structured, practical guidance, the framework aims to build teacher capacity to embed sustainability principles into science education without major curricular changes, thereby cultivating learners who are equipped to promote sustainability.

2.3. Theoretical foundations of the developed ESD integration framework

Effective integration of Education for Sustainable Development (ESD) into curricula requires teachers to have a clear understanding of sustainability competencies, ESD principles, and integration pedagogies, which are key components of the UNESCO ESD framework (UNESCO, 2017). Guided by UNESCO's ESD framework (2017) and the integration steps outlined in the University College London (UCL) toolkits (Roach, 2023), this study developed a framework for embedding ESD into science lessons. The UNESCO ESD framework is described in detail in Section 4 below. The UCL toolkits propose five steps for integrating ESD into teaching: reflecting on current practice, identifying relevant topics, adopting active and critical pedagogies, aligning assessment with sustainability learning, and building supportive networks (Roach, 2023).

3. Methodology

The study employed a qualitative conceptual design, a systematic interpretive research process for constructing theoretical frameworks by analysing existing literature, policies, and expert perspectives (Creswell et al., 2018). Data was collected through a systematic literature review, document analysis, and semi-structured interviews. The documents analyzed included UNESCO's 2030 Agenda for Sustainable Development, Education for Sustainable Development (ESD) guidelines (UNESCO, 2017; Byers et al., 2024), and South African science curricula (Natural Sciences, Life Sciences, and Physical Sciences [Department of Basic Education, 2011]). These documents were examined to identify (i) sustainability learning objectives, (ii) competencies critical for advancing sustainability, and (iii) transformative pedagogical approaches effective in cultivating sustainability competencies.

In addition, seven science lecturers from a South African university participated in semi-structured interviews to determine whether they integrate ESD into their lessons and to identify gaps and opportunities for improved integration. Data from these sources were then used to develop a framework for embedding ESD into science lessons.

4. Results: The developed framework

Scholars argue that cohesive frameworks are essential for guiding teachers in embedding ESD into science lessons (Shumba & Kampamba, 2013). Combining the UCL-ESD integration steps ESD principles, and insights from lecturer interviews led to the development of a framework for integrating ESD into science lessons. This practical framework is designed to help teachers apply ESD principles without deviating significantly from their usual pedagogical practices. Its purpose is twofold: (1) to provide teachers with accessible sustainability learning objectives, sustainability competences, and transformative pedagogies, and (2) to offer a stepwise integration of ESD principles for fostering sustainability competencies.

ESD principles are organized into three components: (1) SDG-specific learning objectives, (2) cross-cutting sustainability competencies, and (3) transformative pedagogies, consistent with the UNESCO ESD framework (2017).

4.1. SDG-specific learning objectives

SDG-specific objectives are framed within cognitive, socio-emotional, and behavioural domains.

- *Cognitive domain*: Focuses on knowledge and critical thinking skills needed to understand the SDGs and their challenges. These learning objectives include content from the three pillars of sustainability (environmental, social, and economic), established at the Rio Earth Summit (Lanchberry, 1996).
 - i. *Environmental pillar*: includes ecosystem protection, resource management, and climate action, linked to SDGs 6, 7, 13, 14, and 15.
 - ii. *Social pillar*: comprises attributes such as equity, justice, human rights, and community well-being, linked to SDGs 1, 2, 3, 4, 5, 10, and 16.

- iii. *Economic pillar*: involves growth, innovation, and responsible consumption aligned with sustainability, linked to SDGs 8, 9, 11, and 12. Teachers can select objectives based on grade, topic, and context.

These pillars are interconnected and mutually reinforcing, forming the foundation of the 17 SDGs (Purvis et al., 2019).

- *Socio-emotional domain*: Involves skills such as self-reflection, empathy, emotional intelligence, values, and attitudes that raise awareness of sustainability issues. Activities foster collaboration, negotiation, and communication.
- *Behavioural domain*: Encompasses action competencies that encourage learners to promote and model behaviours supporting the SDGs (UNESCO, 2017). This domain is seldom integrated into science teaching (Kazeni & Nyamupangedengu, 2025).

Science teachers must understand the SDG-specific learning objectives across these three domains to effectively and intentionally incorporate them into lessons.

4.2. Cross-cutting key ESD competencies

Cross-cutting competencies enable individuals to engage responsibly with complex global issues. They are transversal, multifaceted, and context-independent, empowering learners to address sustainability challenges. Table 1 outlines these key competencies (UNESCO, 2017).

Table 1. cross-cutting key ESD competencies.

Cross-cutting Key Competency		Description
1	<i>Systems thinking</i>	The ability to recognize and understand relationships; to analyse complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
2	<i>Anticipatory /Futures thinking</i>	The ability to understand and evaluate multiple futures; possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
3	<i>Normative / Value thinking</i>	The ability to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4	<i>Strategic thinking</i>	The ability to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5	<i>Collaboration</i>	The ability to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
6	<i>Critical thinking</i>	The ability to question norms, practices and opinions; to reflect on own one's values, perceptions and actions; and to take a position in the sustainability discourse.
7	<i>Self-awareness</i>	The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
8	<i>Integrated problem-solving</i>	The ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences.

4.3. Transformative pedagogies

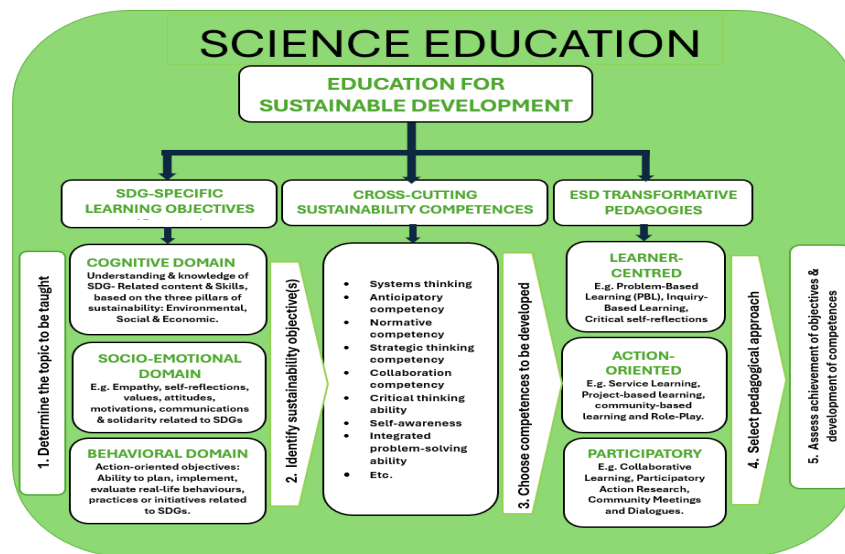
Transformative ESD pedagogies are grouped into three categories: learner-centred, action-oriented, and participatory (UNESCO, 2017). *Learner-centred* approaches encourage critical reflection, with educators acting as facilitators, using methods such as inquiry-based learning, experiential learning, self-reflection, game-based learning, Socratic dialogue, portfolio assessment, and collaborative learning. *Action-oriented* pedagogies engage students in real-world activities followed by reflection, linking abstract concepts to lived experiences. Strategies include project-based learning, internships, community-based learning, fieldwork, service learning, sustainability labs, and workshops. *Participatory* pedagogies empower learners to challenge assumptions, shift perspectives, and reimagine worldviews through active dialogue and engagement. Techniques include Problem-Based Learning, Participatory Action Research, scenario building, theatre, role play, simulations, and participatory decision-making.

Based on the steps outlined in the UCL toolkits (Roach, 2023), the developed framework suggests the following process for integrating ESD into science lessons.

1. Determine the science topic or concept to be taught.
2. Identify relevant SDG-specific learning objectives from cognitive, socio-emotional, or behavioural domains.
3. Select cross-cutting sustainability competencies to be developed alongside the topic.
4. Choose transformative pedagogies to deliver the content, achieve objectives, and foster competencies.
5. Assess students on their understanding of both the topic and sustainability competencies.

A combination of the described learning objectives, sustainability competencies, transformative pedagogies, and the ESD integration steps from the UCL toolkits has resulted in the following framework for integrating Education for Sustainable Development (ESD) into science lessons.

Figure1. Diagrammatic representation of the developed ESD integration framework.



By using this framework, teachers can integrate SDG-specific objectives and sustainability competencies into science lessons in a consistent and systematic manner without deviating from the curriculum or requiring additional instructional time.

5. Discussion of result

Since ESD integration primarily occurs in classroom practice, frameworks must clearly articulate SDG-specific objectives, identify relevant content, and recommend pedagogical strategies aligned with sustainability competencies (UNESCO, 2017). Research highlights that teachers often lack adequate knowledge of ESD principles and when they embed them, they usually do so unintentionally (Khadim et al., 2022; Rieckmann, 2018). Structured frameworks can therefore provide clarity and empower educators to integrate ESD consistently across science curricula. The framework developed in this study addresses this need by outlining both the principles to be incorporated and the steps for integration.

Aligned with UNESCO's 2030 Agenda and national education policies, the framework is designed to enhance teacher preparedness, build confidence, and encourage intentional integration without requiring major changes to existing practices. Nonetheless, challenges remain, particularly the need for teachers to master transformative pedagogies and understand sustainability competencies in depth.

6. Conclusion

The developed framework offers:

- A structured approach to integrating ESD into science teaching.
- Teachers' accessibility to sustainability objectives, competencies, and pedagogies.
- A stepwise guidance for embedding sustainability objectives and competencies into lessons.
- A method for integrating ESD into lessons without deviating from the curriculum and usual teaching practices.

If widely adopted, this framework has the potential to significantly advance sustainability education. Future research should focus on empirical testing and validation across diverse contexts.

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