



Exploring the Role of Professional Development towards Capacitating Mathematics and Science Teachers for Education for Sustainable Development (ESD)

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ABSTRACT

Recent criticisms of the professional development of teachers with consideration for sustainability have led to disquieting descriptions, such as 'pedagogy of poverty.' The researchers heeded the call for re-orientation of TPD from the reductionist paradigm towards a critical approach where teachers interrogate the assumptions that inform their worldviews and focus on transformative actions towards achieving the Sustainable Development Goals (SDGs). This qualitative inquiry explored the role of the professional development of Mathematics and Science teachers towards Education for Sustainable Development (ESD) through transformative pedagogies. The capacitation of 12 purposively sampled teachers who participated in a TPD workshop based on ESD-driven pedagogies and content was explored through Mezirow's transformative theory. Data was generated using observations, photo-voice, and focus group interviews. The findings revealed that teachers' ESD competencies regarding content and pedagogical expertise were transformed towards more reflexive, creative, and professional development focused on collaborative teaching and learning through teachers. The study recommended that teacher education curricula, especially in Mathematics and Science, must integrate social justice, equality, and sustainability to align with the SDGs and foster transformative pedagogies. Expanded professional development and re-curriculation guided by MRTEQ are essential for embedding ESD across HEIs in South Africa. This study illustrates how transformative pedagogies can empower Mathematics and Science teachers to reimagine curricula through an African lens, centering ESD and fostering democratic, culturally relevant engagement with sustainability. The study contributes to the decolonization of education by integrating Indigenous knowledge into ESD-aligned curricula and advancing post-abyssal, context-sensitive pedagogical frameworks in teacher professional development.

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Publication History

Received:
16th January, 2025
Accepted:
23rd July, 2025.
Published:
28th August, 2025.

To Cite this Article:

Sanjigadu, Sebastian,
and Mzwandile Zulu.
"Exploring the Role of
Professional
Development towards
Capacitating
Mathematics and
Science Teachers for
Education for
Sustainable
Development (ESD)."
*Journal of Education
and Learning
Technology* 6, no. 8
(2025): 674 - 695.
<https://doi.org/10.38159/jelt.20256812>.

Keywords: Teacher Professional Development, Mathematics and Science Teachers, Education For Sustainable Development, Sustainable Development Goals, Transformative Pedagogies.

INTRODUCTION

Education is essential for achieving sustainability, especially in Africa.¹ The definition and understanding of the term 'sustainability' in this study are informed by Sartori et al., who stated that

¹ Hiela Lotz-Sisitka, Sirkka Tshiningayamwe, and S Urenje, "Sustainability Starts with Teachers," *An ESD Professional Development Programme for Secondary Teacher Educators. Introduction and Overview*, 2017; Leon Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas," *Asia Pacific Education Review* 20, no. 2 (2019): 223–37.

"sustainability is a normative concept about how humans should act towards nature, and the responsibility people take for their actions."² Lozano believes that "sustainability is conducive to economic growth based on social justice and the efficient use of natural resources."³ Education for Sustainable Development is directed toward achieving sustainability by allowing people to develop knowledge and skills for lifelong learning to sustainably engage with environmental, social, and economic issues.⁴ In this study, the people were teachers (seen as influential members of society) who engaged in professional development processes, which the researchers subsequently chose to explore.

The United Nations Decade of Education for Sustainable Development (DESD) offered a list of ESD principles, acknowledging that academics and educators in different contexts will understand ESD differently according to their values, needs, and priorities.

- It is based on the principles and values that underlie sustainable development.
- It deals with the well-being of all three realms of sustainability – environment, society, and economy.
- Promotes lifelong learning.
- It is locally relevant and culturally appropriate.
- It is based on local needs, perceptions, and conditions but acknowledges that fulfilling local needs often has international effects and consequences; engages formal, non-formal, and informal education.
- Accommodates the evolving nature of the concept of sustainability.
- Addresses content, considering context, global issues, and local priorities.
- Builds civil capacity for community-based decision-making, social tolerance, environmental stewardship, adaptable workforce, and quality of life.
- Is interdisciplinary. No discipline can claim ESD independently, but all disciplines can contribute to ESD.
- Uses various pedagogical techniques that promote participatory learning and higher-order thinking skills [critical and creative thinking].⁵

The above principles informed this study, specifically the understanding of ESD as it relates to the development of teachers. Research on mathematical and science modelling for sustainability practices is scarce, primarily focusing on the African context. Mathematical modeling (and in this case, Scientific modeling) can be defined as "using mathematics and science to explain and describe events in real life, to test ideas, and to make estimations about real-life events."⁶ In this study, math and science are used to understand and explain issues of sustainability linked to environmental, economic, and social challenges. Modelling an approach to teaching is based on a socially constructive teaching approach,⁷ the tenets of which were taught to the teacher participants in the study. Teachers who the researchers in this study once were were not exposed to initial teacher training where modelling and ESD were taught to them.

Pipere and Mičule argue that teachers' lack of professional development can be attributed to the limited exposure to sustainable development education offered to Higher Education Institutions (HEIs), which indicates the disjuncture between science subjects and ESD.⁸ Ismail notes that "sustainability education within science and mathematics education programmes is often neglected."⁹ Mudaly and

² Simone Sartori, Fernanda Latrônico, and Lucila Campos, "Sustainability and Sustainable Development: A Taxonomy in the Field of Literature," *Ambiente & Sociedade* 17 (2014): 3.

³ Rodrigo Lozano, "Towards Better Embedding Sustainability into Companies' Systems: An Analysis of Voluntary Corporate Initiatives," *Journal of Cleaner Production* 25 (2012): 23.

⁴ UNESCO, "Rethinking Education for the Common Good," 2015, <http://unesdoc.unesco.org/images/0023/002325/232555e.pdf>.

⁵ UNESCO, "Rethinking Education for the Common Good."

⁶ Ayla Arseven, "Mathematical Modelling Approach in Mathematics Education.," *Universal Journal of Educational Research* 3, no. 12 (2015): 973–80.

⁷ Arseven, "Mathematical Modelling Approach in Mathematics Education."

⁸ Anita Pipere and I Mičule, "Mathematical Identity for a Sustainable Future: An Interpretative Phenomenological Analysis," *Journal of Teacher Education for Sustainability* 16, no. 1 (2014): 5–31.

⁹ Raeesa Ismail, "Exploring How Science Teachers Engage in Curriculum Innovating in Environment and Sustainability Education" (University of KwaZulu-Natal, 2017). 17.

Ismail further identified a paucity of addressing sustainability in teacher professional development programmes at South African universities, especially.¹⁰ Teachers who teach mathematics and science subjects need to be exposed to sustainability theories and inclusive curricula to teach these concepts in the classroom.¹¹ Mudaly and Ismail further note that "teacher training programmes that are effective in post-colonial South Africa are programmes that promote societal, environmental and economic transformation."¹² This study argues for different, novel cognitive processes relating to sustainability and local contexts.

Tikly argues that there is a lack of literature and practical examples of how Science and Mathematics teachers can incorporate ESD into the school curriculum.¹³ This is the lacuna that this study seeks to contribute to filling. The main objective of this study is to explore the role of the professional development of Mathematics and Science teachers towards ESD through the utilization of transformative pedagogies. This study focuses on the nature and form of these transformative pedagogies and how they can be adopted. This study seeks to emphasise the need for teachers to undergo some form of training to address ESD in the South African curriculum. This study also explores how mathematics and science teachers conceptualize ESD in the curriculum after undergoing professional development.

LITERATURE REVIEW

Omer argues that "most challenges confronting humankind—such as climate change, water scarcity, inequality, and hunger—can be resolved at the local, national, and global levels."¹⁴ Long-term sustainability is a long-term process that creates a harmonious interaction from human to human and between humans and the natural world, premised on the survival of all future generations.¹⁵

Tikly suggests that ESD must consider local environmental, economic, and societal conditions worldwide.¹⁶ Tailoring ESD to the unique characteristics of each region is not just a necessity but a strategic imperative to effectively address various challenges affecting the environment, economy, and society.¹⁷

The literature demonstrates that mathematics teachers especially avoid mathematical modelling, negating the relevance of using mathematical concepts practically for people's lived experiences, thereby not addressing sustainable development issues in the curriculum.¹⁸ Some studies have found that teachers have a limited understanding of mathematical modeling for real-world contexts,¹⁹ and that teachers lacking training in this field are unlikely to use mathematics in their teaching and introduce students to use it.²⁰ An African initiative based on teacher professional development targeted towards the Mathematics and Science curriculum would mean that Africans can benefit from engaging in a global arena within UNESCO's vision. Still, they engage uniquely within the African context towards sustainability.²¹ Here, teachers, through their professional development, still engage with the SDGs and ESD that the UN and UNESCO advocate for, but from a local South African curriculum

¹⁰ Ronicka Mudaly and Raeesa Ismail, "Teacher Learning through Tapping into Indigenous Knowledge Systems in the Science Classroom," *Alternation* 20, no. 1 (2013): 178–202.

¹¹ Mudaly and Ismail, "Teacher Learning through Tapping into Indigenous Knowledge Systems in the Science Classroom."

¹² Mudaly and Ismail, "Teacher Learning through Tapping into Indigenous Knowledge Systems in the Science Classroom."

¹³ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

¹⁴ Atalia Omer, "Decolonizing Religion and the Practice of Peace: Two Case Studies from the Postcolonial World," *Critical Research on Religion* 8, no. 3 (2020): 273–96.

¹⁵ Omer, "Decolonizing Religion and the Practice of Peace: Two Case Studies from the Postcolonial World."

¹⁶ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

¹⁷ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

¹⁸ Seda Sahin et al., "Prospective Teachers' Criteria for Evaluating Mathematical Modeling Problems.," *International Journal of Research in Education and Science* 5, no. 2 (2019): 730–43; Chandra Kant Raju, "Decolonising Mathematics," *Alternation Journal* 25, no. 2 (2018): 12–43.

¹⁹ Rita Borromeo Ferri, "Mathematical Modeling-The Teacher's Responsibility," *Journal of Mathematics Education at Teachers College*, 2013; R. M. Zbiek, "Supporting Teachers' Development as Modelers and Teachers of Modelers," in *Annual Perspectives in Mathematics Education (APME): Mathematical Modeling and Modeling Mathematics*, ed. R. H. Christian (National Council of Teachers of Mathematics, 2016), 263–72.

²⁰ Serife Sevinc and Richard Lesh, "Training Mathematics Teachers for Realistic Math Problems: A Case of Modeling-Based Teacher Education Courses," *ZDM* 50, no. 1–2 (April 11, 2018): 301–14, <https://doi.org/10.1007/s11858-017-0898-9>.

²¹ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

perspective. The professional development of teachers could be done by drawing on real-life case studies and problem-solving activities that teachers select from their local communities and the school community.

The Sustainable Development Goals (SDGs)

The SDGs are established objectives premised on sustainability. The United Nations identifies the "17 SDGs as representing a global blueprint for addressing some of the most pressing challenges facing our planet and humanity, ranging from poverty eradication to environmental sustainability."²²

According to the UN, the SDGs are "integrated, indivisible, and globally applicable; they consider different national realities, capacities, and levels of development and respect national policies and priorities."²³ Weber believes that the SDGs foreground aspirations for sustainability and are guidelines to address challenges with sustainability.²⁴ In the context of this study, SDG 4 is foregrounded, as its focus is quality education. According to the UN, "SDG 4 is to ensure inclusive and quality education for all and promote lifelong learning."²⁵

Teachers teaching learners about the SDGs is essential for addressing SDG 4, which this study views as quality education and the cornerstone of ESD. Teaching learners about the various interrelated issues about the environment (addressed by SDGs 13, 14, and 15), health (addressed by SDGs 3, 6, and 15), and the economy (addressed by SDGs 1, 2, 8, and 9) will offer them a more meaningful form of education. The SDGs focus not only on development and transformation but also on restoring people's dignity worldwide.²⁶ This has particular significance in the context of South Africa when considering the country's history of exclusionary political and economic policies and practices.²⁷ The SDGs (17) are intrinsically interconnected with ESD, providing a comprehensive framework for addressing pervasive global issues. At the same time, ESD plays a pivotal role in serving as a guide to educate people in society with the requisite skills and knowledge to achieve these goals. Thus, ESD is a vital catalyst, fostering environmental awareness and sustainability and promoting ethical and responsible citizenship, ultimately enabling the SDGs to become a tangible reality in local and global communities.

The process of conceptualizing ESD in the South African teaching and learning landscape affords the possibility of including SDGs within the mathematics and science CAPS curriculum. Agenda 2023 and the SDGs perpetuate universal sustainability values that apply to global citizens.²⁸ Teachers trained to engage with the SDGs are positioned to raise their societies' awareness.

There are three underlying pillars of sustainable development: environmental, social, and economic.²⁹ Klarin argues "that when these three pillars intersect, holistic SD transfers into reality."³⁰ Figure 1 below presents what Klarin calls a nested spheres model of sustainability.

²² United Nations, "Transforming Our World: The 2030 Agenda for Sustainable Development," Pub. L. No. A/RES/70/1. UN General Assembly., Resolution adopted by the General Assembly (2015). 15.

²³ United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development. 13.

²⁴ Heloise Weber, "Politics of 'Leaving No One Behind': Contesting the 2030 Sustainable Development Goals Agenda," *Globalizations* 14, no. 3 (April 16, 2017): 399–414, <https://doi.org/10.1080/14747731.2016.1275404>.

²⁵ United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development. 3.

²⁶ United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development.

²⁷ Statistics South Africa, *Sustainable Development Goals: Country Report 2019* (Statistics South Africa, 2019).

²⁸ United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development.

²⁹ Klarin Tomislav, "The Concept of Sustainable Development: From Its Beginning to the Contemporary Issues," *Zagreb International Review of Economics & Business* 21, no. 1 (2018): 67–94.

³⁰ Tomislav, "The Concept of Sustainable Development: From Its Beginning to the Contemporary Issues." 6.

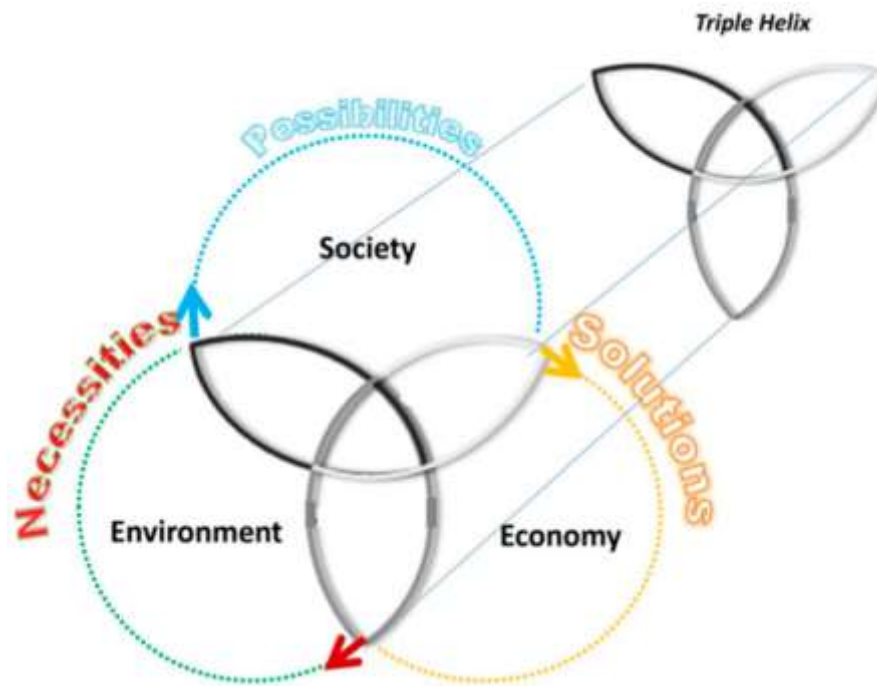


Figure 1: Model of sustainability³¹

According to Klarin, the diagram above emphasizes "key considerations above each pillar of sustainability, i.e., 'Necessities' above 'Environment,' 'Possibilities' above 'Society,' and 'Solutions' above 'Economy.'"³² This study seeks to address what is possible, in Figure 1, called "Possibilities."

Sustainable Development Goal 4 is an overarching SDG that cuts across various components of the 2030 Agenda.³³ Colglazier believes that "the 2030 Agenda proposes 17 SDGs with 169 targets supplemented with numerous indicators."³⁴ African countries established various programs to adopt Agenda 2030 on the continent.³⁵ Some examples are:

- Ghana: Poverty Reduction Strategy (GPRS I and II) and the National Environmental Policy (NEP) were designed.³⁶
- In Tanzania, the National Development Vision (NDV) 2025 was implemented.³⁷
- There was the National Strategy for Solid Waste Management (NSSWM) in Egypt.³⁸

Mohamed presents that "in September 2015, SA signed up for Agenda 2030, which informs their very own National Development Plan (NDP)."³⁹ Mohamed further believes that the NDP's vision states, "a new future is needed for SA, which seeks to eliminate poverty and reduce inequality by 2030."⁴⁰ Cumming et al. note that "the SA National Development Plan is a local endeavor that links to the global call to address the SDGs and Agenda 2030."⁴¹

A good understanding of the SDGs by learners may encourage them (learners) to develop into individuals who engage positively with the SDGs in their lives in areas related to employment,

³¹ Tomislav, "The Concept of Sustainable Development: From Its Beginning to the Contemporary Issues."

³² Tomislav, "The Concept of Sustainable Development: From Its Beginning to the Contemporary Issues."

³³ United Nations, *Transforming Our World: the 2030 Agenda for Sustainable Development*.

³⁴ William Colglazier, "Sustainable Development Agenda: 2030," *Science* 349, no. 6252 (2015): 1048–50.

³⁵ African Union, "Agenda 2063: The Africa We Want. African Union Commission," 2015, <https://au.int/en/agenda2063/overview>.

³⁶ United Nations Economic Commission for Africa, *Progress towards Sustainable Development Report in Africa* (UNECA: Addis Ababa, 2012).

³⁷ United Nations Economic Commission for Africa, *Progress towards Sustainable Development Report in Africa*.

³⁸ African Union Commission, *Agenda 2063: The Africa We Want – Framework Document* (Addis Ababa: African Union Commission, 2015).

³⁹ N. Mohamed, *Sustainability Transitions in South Africa* (Routledge, 2018).2.

⁴⁰ Mohamed, *Sustainability Transitions in South Africa*. 5.

⁴¹ Tracey L. Cumming et al., "Achieving the National Development Agenda and the Sustainable Development Goals (SDGs) through Investment in Ecological Infrastructure: A Case Study of South Africa," *Ecosystem Services* 27 (October 2017): 253–60, <https://doi.org/10.1016/j.ecoser.2017.05.005>.

production, and consumption, and care for life on land and underwater as they relate to the different SDGs. The UN "Quality and inclusive education could contribute to a reduction of inequality within and among countries (SDG 10); promote inclusion, safety, resilience, and sustainability in cities and human settlements (SDG 11); and the promotion of peaceful and inclusive societies that are focused on sustainable development with effective, accountable and inclusive institutions at all levels and access to justice for all (SDG 16)."⁴²

Education for Sustainable Development (ESD)

Understanding ESD is a critical concept that needs to be used to get teachers to understand the practice that shapes contemporary curricula.⁴³ Singh argues that "the values concerning sustainable development that are encompassed in an education system should be explicit in the curriculum."⁴⁴ South Africa's 2019 SDGs report states the goal of guaranteeing that every student understands the competencies to advance SD by 2030.⁴⁵

Ferguson et al. present a study that revealed the following findings: "ESD is vital to equip teachers and teacher educators with the capacity to foster a broader understanding of sustainable development and interdisciplinary, equitable, and inclusive education, emphasizing the transformative potential of ESD to engender a more sustainable future."⁴⁶ Price et al. contend that ESD should establish a clear and direct connection between the SDGs and the curriculum, ensuring its meaningful integration into various subjects taught at all educational levels.⁴⁷

Focus on Mathematics and Science Education

Ningsih and Juandi argue that "one of the ways that ESD can be instilled in learners is through the learning of mathematics and science."⁴⁸ Measuring global warming indicators like CO₂ concentrations relies on intricate mathematical formulae and calculations, yet a discernible connection to the mathematical concepts typically taught in textbooks remains elusive.⁴⁹ This lack of a tangible bridge between real-world environmental issues and conventional mathematics education hinders students' appreciation of the practical relevance of mathematics in addressing pressing global challenges.⁵⁰

Renert believes that "mathematics, especially, is popularly conceived of as a pure body of knowledge, and connections between global warming and the topics found in certain mathematics textbooks, such as fractions or quadratic equations, are not readily apparent."⁵¹ Raju states that the links between mathematics and sustainability issues are limited, if not absent, in many mathematics textbooks.⁵² The research outcomes from Swekwi and Lertlit's study emphasize the necessity for curriculum enhancements to empower learners to translate their skills and experiences into practical application, particularly in the context of ESD in mathematics and science.⁵³ This involves the design of teaching activities and learning activities, providing learners with hands-on experiential learning opportunities to learn from real situations. To effectively implement this, individual teacher and staff

⁴² United Nations, *Transforming Our World: the 2030 Agenda for Sustainable Development*.

⁴³ Chris Reddy, "Environmental Education in Teacher Education: A Viewpoint Exploring Options in South Africa," *Southern African Journal of Environmental Education* 33 (2017): 117–26.

⁴⁴ S K Singh, "The Role of Staff Development in the Professional Development of Teachers: Implications for in-Service Training," *South African Journal of Higher Education* 25, no. 8 (2011): 1626–38.

⁴⁵ Voluntary National Review, "South Africa's Implementation of the 2030 Agenda for Sustainable Development. NDP 2030.," 2019, https://sustainabledevelopment.un.org/content/documents/23402RSA_Voluntary_National_Review_report_July_2019.

⁴⁶ Therese Ferguson et al., "Education for Sustainable Development (ESD) Infusion into Curricula: Influences on Students' Understandings of Sustainable Development and ESD," *Brock Education Journal* 31, no. 2 (2022): 63–84.

⁴⁷ Elizabeth A C Price et al., "Supporting the Role of Universities in Leading Individual and Societal Transformation through Education for Sustainable Development," *Discover Sustainability* 2, no. 1 (2021): 49.

⁴⁸ S Y Ningsih and D Juandi, "Achievement of ESD (Educational for Sustainable Development) through Mathematics Learning," in *Journal of Physics: Conference Series*, vol. 1157 (IOP Publishing, 2019), 042056.

⁴⁹ Murad Jurdak, *Learning and Teaching Real World Problem Solving in School Mathematics* (Cham: Springer International Publishing, 2016), <https://doi.org/10.1007/978-3-319-08204-2>.

⁵⁰ Jurdak, *Learning and Teaching Real World Problem Solving in School Mathematics*.

⁵¹ Moshe Renert, "Mathematics for Life: Sustainable Mathematics Education," *For the Learning of Mathematics* 31, no. 1 (2011): 20–26.

⁵² Raju, "Decolonising Mathematics."

⁵³ Usaporn Swekwi and Supinda Lertlit, "Education for Sustainable Development: The Production of Talented Teachers in Science and Mathematics Project," *Asian Journal of Management Sciences & Education* 10, no. 2 (2021): 16–25.

development plans must be carefully devised, and a supportive cultural and learning environment should be fostered to facilitate the transformation of educational institutions and communities into collaborative learning organizations aligned with the principles of ESD.⁵⁴

Teacher Education Institutions (TEIs) do not emphasize substantially developing students' understanding of SD.⁵⁵ Leal Filho et al. state that "there have been insignificant accomplishments in sustainable development due to a lack of understanding, consciousness, and justice action toward sustainability, especially in Sub-Saharan Africa."⁵⁶ This study holds significance in increasing awareness and promoting a more profound comprehension of sustainable development among mathematics and science teachers.

The Professional Development of Teachers

Professional development programmes are necessary for teachers to understand and incorporate sustainable values into their teaching. Singh highlights the inconsistent development of teachers in SA and believes that teachers who understand SD in the country are limited.⁵⁷ Lotz-Sisitka, therefore, argues that research on teacher professional development is necessary.⁵⁸ Singh provides a model for the professional development of teachers, which is depicted in the figure below.

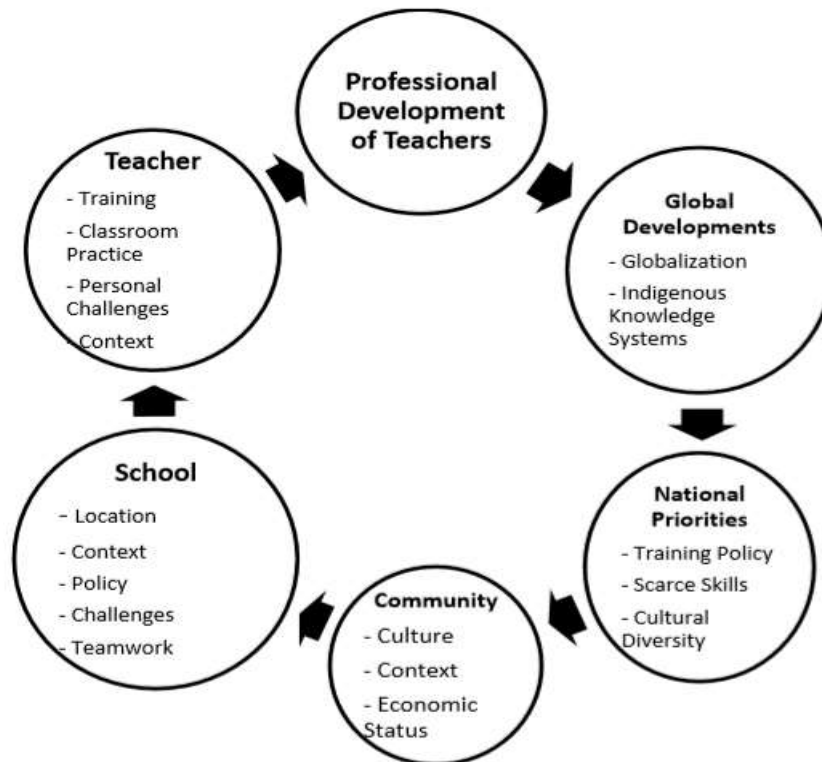


Figure 2: Model of teacher professional development⁵⁹

⁵⁴ Sweeki and Lertlit, "Education for Sustainable Development: The Production of Talented Teachers in Science and Mathematics Project."

⁵⁵ Lotz-Sisitka, Tshiningayamwe, and Urenje, "Sustainability Starts with Teachers."

⁵⁶ W. Leal Filho et al., "Using the Sustainable Development Goals towards a Better Understanding of Sustainability Challenges," *International Journal of Sustainable Development & World Ecology* 26, no. 2 (February 17, 2019): 179–90, <https://doi.org/10.1080/13504509.2018.1505674>.

⁵⁷ Singh, "The Role of Staff Development in the Professional Development of Teachers: Implications for in-Service Training."

⁵⁸ Heila Lotz-Sisitka, "2. Decolonisation as Future Frame for Environmental and Sustainability Education: Embracing the Commons with Absence and Emergence," in *Envisioning Futures for Environmental and Sustainability Education* (Wageningen Academic, 2017), 45–62.

⁵⁹ Singh, "The Role of Staff Development in the Professional Development of Teachers: Implications for in-Service Training."

Teacher professional development is impacted by all components of the model presented above. Global and local contexts drew our attention to the "Global Development" element, focusing on "National Priorities," one of which is the NDP 2030, and the second is the UN Agenda 2030, which focuses on SD. The emphasis on 'community' and collaborative work points to how teachers and schools are a part of communities. Singh argues that "designers of professional development programmes should incorporate aspects of modelling (demonstration) so that teachers gain an understanding of the new practice, and the content of the programme must be specific to that subject rather than generic."⁶⁰

Bentham et al., offer the following ESD principles," 1. Active learning approaches regarding sustainability issues.⁶¹ 2. Learner-centered approaches. 3. Engagement in community and social development activities. 4. Participatory and collaborative learning activities". The principles presented by Bentham et al. informed the researchers' understanding of ESD and formed the foundation for our offering of professional development of teachers through a transformative pedagogy.⁶²

THEORETICAL FRAMEWORK

Mezirow's (2009) Critical Transformative Learning Theory

Mezirow's transformation theory is "a constructivist theory of adult learning, is a comprehensive, idealized, and universal model consisting of the generic structures, elements, and processes of adult learning and development."⁶³ Adopting the theory of transformation can facilitate teacher changes and teacher learning. Mei Kin et al. purport that "teacher change is the process of altering, modifying, or transforming the practices, attitudes, beliefs, and perceptions of teachers."⁶⁴ Change is an individual learning process. Much like most human beings, teachers find it challenging to change their current practices as this entails learning and developmental growth.

There are five primary interacting contexts where learning takes place, according to Mezirow.⁶⁵ Two of these contexts were essential for this study and were selectively adopted. Mezirow states:

1. The meaning perspective or frame of reference in which the learning is embedded.
2. The line of action in which the learning occurs. This has to do with implementing the adult learner's purpose and intentionality and involves exercising their conative powers."⁶⁶

The researchers were interested in exploring how teachers could change their practices and thus explored Mezirow's work to understand the transformative learning experiences of adults (consistent with the adult participants in the study).

Kitchenham believes that "transformative learning is a deep, structural shift in basic premises of thought, feelings, and actions; this definition understands that this type of learning is complex and multifaceted."⁶⁷ This theory assists in understanding what Calleja calls "the shift experienced by individuals who allow themselves to learn from their own experience within a community of practice."⁶⁸ The change from just teaching science or Maths to teaching about sustainable development through the science and Maths curriculum.

⁶⁰ Singh, "The Role of Staff Development in the Professional Development of Teachers: Implications for in-Service Training."

⁶¹ Hayley Bentham, Astrid Sinnes, and Sigrid Gjøtterud, "Exploring the Priorities of Teacher Education Related Policies: An Education for Sustainable Development Perspective.," *Journal for Critical Education Policy Studies (JCEPS)* 12, no. 1 (2014).

⁶² Bentham, Sinnes, and Gjøtterud, "Exploring the Priorities of Teacher Education Related Policies: An Education for Sustainable Development Perspective."

⁶³ J. Mezirow, "An Overview on Transformative Learning," in *Contemporary Theories of Learning: Learning Theorists in Their Own Words*, ed. K. Illeris (London, 2009), 90–105.

⁶⁴ Tai Mei Kin et al., "Principal Change Leadership Competencies and Teacher Attitudes toward Change: The Mediating Effects of Teacher Change Beliefs," *International Journal of Leadership in Education* 21, no. 4 (2018): 427–46.

⁶⁵ Mezirow, "An Overview on Transformative Learning."

⁶⁶ Mezirow, "An Overview on Transformative Learning."

⁶⁷ Andrew Kitchenham, "The Evolution of John Mezirow's Transformative Learning Theory," *Journal of Transformative Education* 6, no. 2 (April 1, 2008): 104–23, <https://doi.org/10.1177/1541344608322678>.

⁶⁸ Colin Calleja, "Jack Mezirow's Conceptualisation of Adult Transformative Learning: A Review," *Journal of Adult and Continuing Education* 20, no. 1 (2014): 117–36.

The influences on Mezirow's early theory of transformative learning included Kuhn's Paradigm, Freire's Conscientization, and Habermas's Domains of Knowledge.⁶⁹ The key ideas of these theorists informed Mezirow's transformative learning theory. This study was based on humans' relationships with each other and the natural world.

Mezirow's theory can be related to emancipatory processes and self-directed development, identified as three distinct types of learning.⁷⁰ These three types of learning are technical learning, practical learning, and emancipatory learning as determined by Habermas,⁷¹ which later would become what Mezirow calls "(a) instrumental, (b) dialogic, and (c) self-reflective."⁷² The understanding of transformation encompasses the three types of learning from Mezirow's perspective. Mezirow's theory has contributed to how educationalists understand learning and, subsequently, has shaped the design of the pedagogies.⁷³ Mezirow emphasizes the importance of the social setting in the social dimension of transformative learning. Mezirow's learning model, or theory of reflectivity, comprises three phases. The first phase is an individual's experience of a disorienting dilemma that arises when they encounter a situation where their expectations do not match their expertise.⁷⁴ Mezirow's model is shown in Figure 3.



Figure 3. Mezirow's Transformative Learning Model⁷⁵

This study selectively adopted Mezirow's phases of learning in this study. In the context of this study, teachers experienced the dilemma of engaging with the unexplored arena of ESD. Teachers experience various dilemmas, and cooperative reflective inquiry can provide a platform for teachers to share their practice experiences and justify their thinking, decisions, and actions regarding their knowledge base through collective sharing.⁷⁶

It begins with a disorienting dilemma that focuses on experiences not in sync with one's expectations.⁷⁷ An example of this could be teaching about sustainable development in the science and

⁶⁹ Mezirow, "An Overview on Transformative Learning."

⁷⁰ Mezirow, "An Overview on Transformative Learning."

⁷¹ Jürgen Habermas, *The Theory of Communicative Action. Reason and the Rationalization of Society* (T. McCarthy, Trans.), vol. 1 (Boston: Beacon, 1984).

⁷² Mezirow, "An Overview on Transformative Learning."

⁷³ Malcolm S. Knowles, *The Modern Practice of Adult Education: From Pedagogy to Andragogy*, 2nd ed. (New York: Cambridge Books, 1980).

⁷⁴ Mezirow, "An Overview on Transformative Learning."

⁷⁵ Mezirow, "An Overview on Transformative Learning."

⁷⁶ Karin Brodie and Hilda Borko, "Introduction," in *Professional Learning Communities in South African Schools and Teacher Education Programmes*, ed. K. Brodie and H. Borko (Pretoria: HSRC Press, 2016), 1–17.

⁷⁷ Mezirow, "An Overview on Transformative Learning."

Maths curriculum. This theory targets changing perspectives that emerge after an in-depth assessment of one's epistemological and ontological assumptions. Intellectual growth occurs when one reflects on one's experience, and this can include a reflection on content, on the process of reflection, and on their premises. Engagement with the UN's SDGs and being exposed to understanding the ESD allows teachers to identify their discontent with teaching the way they have been, and they may begin to realize that they need to transform their pedagogies.

Brodie and Borko believe that "Transformation theory thus provides a theoretical basis for both teacher learning and teacher change, which is the process of altering, modifying, or transforming the practices, attitudes, beliefs, and perceptions of teachers."⁷⁸ Change is an individual learning process. This study's learning was related to integrating the SDGs into the curriculum. Bascopé states that teachers still need training and capacity development to develop sustainable development competencies, which can translate into their classrooms.⁷⁹

METHODOLOGY

For this qualitative study, twelve teachers were purposively selected to participate in a series of professional development workshops that taught them about sustainable development and linked to the mathematics and science curriculum. This group of teachers was all enrolled for the Bachelor of Education honours degree in mathematics and science from one of the South African Higher Education Institutions (HEIs) in the province of KwaZulu-Natal. Six mathematics teachers and six science teachers were selected. The workshop was facilitated at the Wildlife and Environment Society South Africa (WESSA) by four teacher educators of the same HEI in collaboration with the WESSA practitioners. Teachers were divided into two groups for focus group discussions by subject (mathematics and science). For micro-teaching, these groups were further divided into four groups (two mathematics and two science groups) with three participants per group. This paper presents data from all focus groups and observation data from one mathematics micro-teaching group and one science micro-teaching group. The profiles of the participants are presented in Table 1.

Table 1: Participant profiles

Group Number	Pseudonym, Gender, and Race	Subject Specialisation	Length of teaching experience (years)	Micro-teaching topic & grade
One	Lwazi, Male and Black, African	Mathematics	5	Statistics (Gr.11)
One	Hope, Male and Black, African	Mathematics	6	Statistics (Gr.11)
One	Zama, Female and Black, African	Mathematics	3	Statistics (Gr.11)
Two	Cage, Female, and Indian	Life Sciences	27	Atmosphere & Climate Change (Gr 12)
Two	Sam, Female and Black, African	Life Sciences	6	Atmosphere & Climate Change (Gr 12)
Two	Nkosi, Male and Black, African	Life Sciences	7	Atmosphere & Climate Change (Gr 12)

Data collection commenced with an open-ended questionnaire administered through Google Forms, gauging participants' foundational understanding of ESD within their teaching specializations. Following this initial phase, participants actively engaged in an enlightening series of lectures focused

⁷⁸ Brodie and Borko, "Introduction."

⁷⁹ Martín Bascopé, Paolo Perasso, and Kristina Reiss, "Systematic Review of Education for Sustainable Development at an Early Stage: Cornerstones and Pedagogical Approaches for Teacher Professional Development," *Sustainability* 11, no. 3 (2019): 719.

on transformative pedagogies and ESD at large. Concurrently, photo-voice data were meticulously gathered.

Subsequently, a third wave of data collection unfolded, dividing participants into two distinct focus groups aligned with their specializations. Within these groups, participants underwent thorough interrogation regarding their comprehension of transformative pedagogies within their specific subject domains and their awareness of ESD. This phase, termed pre-workshop focus group discussions, served as a platform for in-depth exploration.

Subsequently, participants engaged in various professional development workshops and hands-on tasks (collaborative), which included micro-teaching presentations facilitated by four teacher educators who facilitated workshops. The first session occurred after participants had attended the lectures on transformative pedagogies and the TPD workshops on incorporating ESD into teaching mathematics and science curricula. The second focus group discussion was held after the participants had planned and taught micro-teaching lessons, which the facilitators observed.

The interventions and data collection methods were iterative and sometimes coincided. The initial interview took place before the interventions were administered. Initial interviews were conducted to ascertain the type of knowledge the teachers had about Mathematics/Science and sustainable development. Initial interviews were the baseline data needed for this study. The baseline data collected enabled before and after analysis.

Once the interventions were conducted, which took the form of facilitated workshops, lecturers, and training activities, teachers were asked to teach their micro-teaching lessons in groups, which were observed and formed a part of the data generation plan. Finally, the teachers were interviewed a second time after the intervention to explore the role of professional development towards teacher capacitation for ESD.

For micro-teaching activities, the participants were especially asked to select a topic in the CAPS document and the textbooks and explore how it was presented regarding sustainable development. Observation data were then gathered during micro-teaching presentations. For their selected topic, the participants were asked to develop teaching and learning resources and activities that addressed sustainable development principles and the SDGs. Teacher educators facilitated post-workshop focus group discussions for participants to reflect on their overall experience.



Figure 4: Lecture on Transformative Pedagogies Presented by Facilitator

Figure 5 depicts teachers engaging in a workshop that consisted of an educational hike facilitated by staff from the WESSA, which was one of the partners who assisted in this project. The seminars and training were held at the WESSA facilities in Howick, Kwa-Zulu Natal. This workshop

served as one of the professional development initiatives, the impact of which was explored in this study. The Wildlife and Environment Society of South Africa is a non-government environmental organization (NGO) that participates in the activities of the International Foundation for Environmental Education.⁸⁰



Figure 5: Educational Workshop/Hike Conducted by WESSA

This study addressed the following ethical considerations: treating the participants and information respectfully and honestly. Data from this study will be stored securely for up to five years and disposed of responsibly. The autonomy of participants was ensured by using pseudonyms for participants who voluntarily agreed to participate in this study through written consent. Gatekeeper letters were obtained, and full ethical clearance from the University of Kwa-Zulu Natal with the Protocol reference number HSSREC/00005368/2023 was obtained before conducting this study. The researchers ensure the non-maleficence and confidentiality of participants, which aligns with ethical research practices.

PRESENTATION OF FINDINGS AND DISCUSSION

Baseline data from the initial interview, compared to the micro-teaching observation and post-intervention interview findings, demonstrated that the professional development of participants provided them with insight into how curriculum themes could be contextualized through ESD. They presented ideas about curriculum content and teaching methods for addressing various SDGs during micro-teaching and focus group discussions. Two themes emerged from the data: transformation of participants' instructional and pedagogical approaches and transformation of participants' attitudes, beliefs, and perceptions of the curriculum.

Theme One: Transformation of Participants' Pedagogical Approaches

This theme is illuminated through the analysis of baseline data collected via initial interviews, pre-intervention focus group interviews (FGIs), and post-intervention FGIs, revealing a discernible shift in teaching methodologies and practices. Group 2 (see Table 1), based on the Grade 12 curriculum for the topic 'Atmosphere and Climate Change, participants employed alternative pedagogical approaches, as illustrated in Figure 6, an extract from the observation schedule. They initiated their lesson with a technology-based pedagogy, utilizing a video clip focused on climate change. The clip effectively showcased the impact of factory pollutants on communities and the atmosphere.

Furthermore, the participants demonstrated an innovative use of a local factory as a case study approach to teach atmosphere and climate change. This approach not only exemplified a transformed pedagogy but also highlighted a newfound integration of SDG 13 (Climate Action) — a linkage that had been previously overlooked in their teaching strategies. The case study, centered around a local factory producing harmful pollution and contributing to climate change, provided a tangible and

⁸⁰ Vincent Kakembo, Pheleka Mamfengu, and Graham I. H. Kerley, "Communal Game Farming: A Sustainable Land Use Option?," *Conservation Strategies and Environmental Impacts*, 2013, 155.

contextualized illustration of the environmental impact. This approach fostered a more profound understanding among participants and underscored the significance of their chosen case study within the lesson context. Their approach constituted forms of transformative pedagogies.

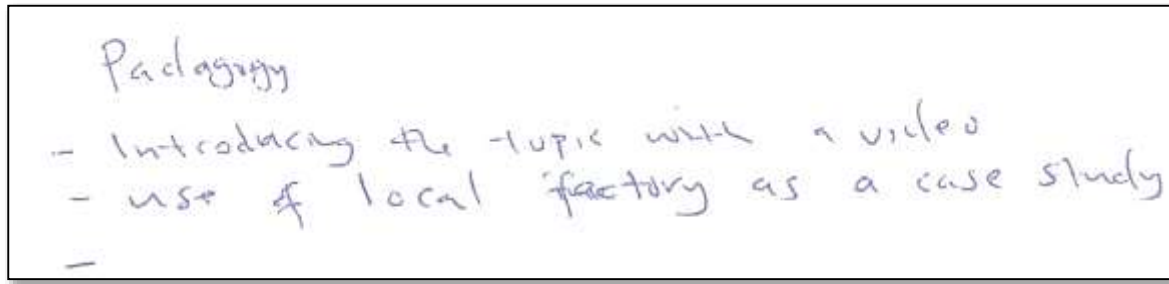


Figure 6: Pedagogies Observed During Micro-Teaching by Group 1

In Figure 7, Group 1 teachers presented a micro-teaching lesson using a model of a sustainable factory, contrasting with the community factory in their previous case study. This model demonstrated their focus on promoting sustainability in their lesson.



Figure 7: Group 1 Presenting their Micro-teaching Lesson

During the focus group discussion, participants were asked: "What is your understanding of Transformative Pedagogies?" In response, Nkosi expressed a desire to use active learning pedagogies to teach by:

...taking learners on a hike to observe trees and animals to learn Life Sciences topics like biotic and abiotic factors, ecosystems, habitat destruction...

Nkosi referred to taking the learners out of the classroom and exploring the natural environment to learn various topics. This was in keeping with Bentham et al.'s ideas of active learning approaches regarding sustainability to teach sustainable living.⁸¹

During the post-intervention focus group discussion, participants were asked: "How could you link some of the activities you completed to your own teaching?" Cage explained:

...before this workshop, my teaching was more about memorization and transmission, but now it's more about impact. I am going to be more focused on involvement with the learners and the

⁸¹ Bentham, Sinnes, and Gjøtterud, "Exploring the Priorities of Teacher Education Related Policies: An Education for Sustainable Development Perspective."

community itself and then incorporating sustainable development and practical examples of climate change issues by demonstrating land and air pollution in the community and how to mitigate this.

Figure 8 depicts an extract from the observation schedule from the lesson delivered by Group 2, which demonstrated evidence of transformative pedagogies that focus on addressing the SDGs relevant to South African learners' context. Transformation in this context is based on showing learners the sources of air pollution in the community and also discussing ways they could mitigate this with learners. This implies intentionally aligning educational strategies with the goals and challenges relevant to the local academic environment.

<p>4. Evidence of focus on the SA context/transformative pedagogies (Relevance to South African learners' contexts? Reflects de-colonial, indigenous ideologies?)</p>	<p>- used local carbon emission stats. aircrafts on King Shaka airport - Local relevant data was used. Focus on local context.</p>
<p>5. Evidence of focus on addressing the Sustainable Development Goals. (Names of the SDGs presented; clear integration within the Science or Mathematics topic shown; detail on how</p>	<p>- SDG 4, 12, 3 - Linked to Carbon Emissions from aircraft - Health concerns from the pollution of the air.</p>
<p>- project-based learning. Looked at pollution and cars for learners activity. More clarity of transformative pedagogy. This is present.</p> <p>- Used project-based learning by expanding their content and classroom discusses to the community. Collecting cars from the community.</p>	

Figure 8: Extract from OS of Group 2

The Statistics lesson presented by Group 2 used the carbon emission data from aircraft at the King Shaka International Airport located in Durban, 13 km away from Lwazi's school in the La Mercy neighbourhood, which was used as an example. The group illustrated how project-based learning transformed their lesson to address various SDGs (4, 12, and 3).

During the Group 2 post-intervention focus group discussion, in response to "What types of strategies did you use when addressing ESD in the school mathematics curriculum?" Lwazi stated:

...I designed a project-based learning for my learners in Statistics lessons by asking them to collect data on the number of cars that pass by our school gate per day and give them an average estimation of carbon emissions produced by one car... then use that data to design questions that are relevant to the Mathematics curriculum first, while also raising awareness about it with SDGs. I would have not done this before.

The participant's narrative showcases transformative pedagogies through project-based learning in Statistics lessons. By integrating real-world data on carbon emissions, the participant addresses mathematics concepts and promotes awareness of SDGs. The responses of the Mathematics and Science teachers during the post-intervention focus group discussions, as well as the researchers' observations during the participants' micro-teaching lessons, indicated that they had experienced instructional and pedagogical transformation. This study thus contributes to the knowledge of how

education can be developed to enable teachers to integrate the SDGs into their teaching of Science and Mathematics curricula.

Madlingozi argues that "teachers exercise their agency and their freedom from imposed knowledge by taking ownership of their learning."⁸² Through exposure to transformational professional development processes, teachers may develop the agency to identify the exclusionary lenses of curricula and the types of knowledge that have been pushed to the margin of curricula. Arday et al., in their book titled 'reimagining inclusive pedagogy and decolonising the curriculum within the Academy,' state that knowledge related to sustainable development continues to be excluded from our curricula.⁸³ Michel, writing about the South African context, states that "a good approach to educating students about sustainability is by infusion throughout the curriculum."⁸⁴ Michel further states, "While there is mounting evidence that sustainability should be taught to students beyond the disciplinary confines of natural science and geography, little is known about the prevalence of this topic throughout an entire curriculum."⁸⁵

Teacher agency can be achieved when teachers understand the possibilities of transcending familiar epistemological boundaries.⁸⁶ The review informed this process of literature, collective engagement, and individual agency through a process of commitment. In this study, ESD in the current educational context is an alternative epistemology, which Tikly argues is not explicit in the CAPS curriculum.⁸⁷

Theme Two: Transformation of Participants' Attitudes, Beliefs, and Perceptions about the Curriculum

A change was observed in how the teachers perceived the curriculum after the professional development interventions. Group 1 expressed a transformed belief about the Grade 12 topic they selected. The following extract from the observation notes documents this.

Focus Criteria	Micro-lesson Observations
4. Evidence of focus on the SA context/transformational pedagogies (Relevance to South African Learners' contexts? Reflects de-colonial, Indigenous ideologies?)	The ranking of countries according to their CO ₂ emissions shows that South Africa is 13 th globally and 1 st in Africa for carbon emissions. This shows the topic's significance in relation to the South African context.
5. Evidence of focus on addressing the Sustainable Development Goals. (Names of the SDGs presented; clear integration within the Science or Mathematics topic shown;	The focus is on SDG 13: Climate Action. SDG 13 is directly linked to the topic as per the Life Sciences curriculum.

Figure 9: Extract from Observation Schedule from Group 2 Lesson

Group 1 showed some evidence of focusing on the SA context by accessing secondary data on the country's carbon emissions and including this information in their micro-teaching lesson. This real-life example is highly relevant to both the topic and the lives of the Grade 12 learners who will be taught this way if this is practically applied in the classroom.

⁸² Tshepo Madlingozi, "Social Justice in a Time of Neo-Apartheid Constitutionalism: Critiquing the Anti-Black Economy of Recognition, Incorporation and Distribution," *Stellenbosch Law Review* 28, no. 1 (2017): 123–47.

⁸³ Jason Arday, Dina Zoe Belluigi, and Dave Thomas, "Attempting to Break the Chain: Reimagining Inclusive Pedagogy and Decolonising the Curriculum within the Academy," *Educational Philosophy and Theory* 53, no. 3 (2021): 298–313.

⁸⁴ Jessica Ostrow Michel, "Mapping out Students' Opportunity to Learn about Sustainability across the Higher Education Curriculum," *Innovative Higher Education* 45, no. 5 (2020): 355–71.

⁸⁵ Michel, "Mapping out Students' Opportunity to Learn about Sustainability across the Higher Education Curriculum."

⁸⁶ Ronicka Mudaly and Sebastian Sanjigadu, "Epistemic Journeying across Abyssal Lines of Thinking: Towards Reclaiming Southern Voices," *Education as Change* 26, no. 1 (2022): 1–29.

⁸⁷ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

Group 1 also showed evidence of focusing on SDG 13 specifically, through constant reference to climate action, looking at ways to address this and reduce carbon emissions.

The group included empirical data on carbon emissions from South Africa and related this to global conditions. They could also link this to SDG 12 (Climate Action), which they indicated they would not have thought about previously, as shown below.

In response to the question, "What strategies did you use when addressing ESD in the school Science or Mathematics curriculum?" Sam stated:

We learned about looking at the SDGs and linking them to specific topics in the Life Science curriculum. I did not previously do this in my own teaching, but for the lesson we presented, we managed to link to SDG 12 seamlessly.

Sam's response infers Tikly's contention that ESD is lacking in the CAPS curriculum.⁸⁸ It also implies what Mudaly and Ismael observed: teachers need to be innovative in their teaching and supported through professional development to teach sustainable development principles effectively, as they had not been offered this during their initial teacher training.⁸⁹

Additionally, in response to the same question regarding strategies, Zama and Hope concurred that adopting a project-based approach to learning and teaching is an instrumental strategy that can be used to address ESD within the Mathematics curriculum. They stated:

Since mathematics mostly deals with numbers and symbols, I think a good strategy is to take the concept and use symbols, numbers, or rules to make meaning of the concepts in a question from a mathematical perspective and contextualize it...like, exposing learners to mathematical modelling, and allow them to engage in project-based learning...(Zama).

...when discussing mathematical modelling and contextualizing the problems to real-world scenarios and issues relevant to learners or their communities, it is best to incorporate these SDGs... (Hope).

This linkage of adopting mathematical modelling to contextualize real-world problems emphasizes a novel awareness among the participants of the importance of addressing sustainability goals within the school Mathematics curricula. One notable strategy from the study was relating the SDGs to specific topics in the Life Science curriculum, which the participants had not previously considered. Additionally, participants embraced a project-based approach to teaching, as evidenced by Mathematics teachers commenting on the significance of mathematical modelling and contextualizing problems to real-world scenarios. This transformation in participants' teaching methods demonstrates the power of reflective practice in shifting teachers away from their earlier perceptions of the curriculum. According to Horton-Deutsch and Sherwood, reflective practice in the South African context involves more than merely contemplating the events in a lesson; it goes beyond mere thought and adds depth and significance to the reflection process. They contend that this approach allows teachers to cultivate a comprehensive understanding of how they contribute to the promotion of quality teaching and learning.⁹⁰ In this study, teachers could transform their thinking through reflective practice and move away from their previous perceptions of the curriculum, as shown in their responses above.

DISCUSSION

In this study, Mezirow's transformative theory provided the theoretical basis for teacher transformation. The teachers who participated in this study expressed a transformed understanding of instructional and pedagogical approaches and a transformation of their attitudes, beliefs, and perceptions about the curriculum. Teacher participants developed new actions and adopted new roles.⁹¹ The findings revealed

⁸⁸ Tikly, "Education for Sustainable Development in Africa: A Critique of Regional Agendas."

⁸⁹ Ronicka Mudaly and Raeesa Ismail, "Professional Development in Environmental and Sustainability Education: Voices, Practices and Reflections of Science Teachers," *Southern African Journal of Environmental Education* 32 (2016): 66–86.

⁹⁰ Sara Horton-Deutsch and Gwen Sherwood, *Reflective Practice: Transforming Education and Improving Outcomes*, 2nd ed. (Sigma Theta Tau International, 2017).

⁹¹ Mezirow, "An Overview on Transformative Learning."

that teachers' perspectives about the curriculum were transformed towards encompassing ESD competencies regarding content and pedagogy. In this study, teacher professional development was reoriented from the reductionist paradigm of a market-driven economic ideology towards a critical paradigm where teachers gained awareness of the assumptions that informed their worldviews and focused on transformative thoughts and actions to achieve SDGs. The catalyst to achieving this was the opportunity for teachers to commit to transformative learning approaches.

Padayachee et al. believe that "social justice, equality, and human dignity are directly linked to the SDGs."⁹² According to the UN, "the SDGs encompassing objectives such as eradicating poverty, advancing good health and well-being, fostering greater gender equality and women's empowerment, ensuring access to clean water, and establishing enduring partnerships are integral to the humanistic pursuit."⁹³ It is thus essential to incorporate these goals, especially in the Mathematics and Science curricula. This became evident in the study by observing participants' micro-teaching lessons, where they included various SDGs and sustainable development principles in their presentations. They spoke about human impact, environmental awareness, and sustainability (see Figures 7 and 8). Teachers were trained about the SDGs, the various types of transformative pedagogies, and possible topics. Still, they were not probed on developing lessons and linking the SDGs to the different issues in each topic. This lesson development process was based on teacher agency and cognitive development.

Additionally, teachers engaged in productive dialogue and used their agency as teachers to consider options to develop relevant curriculum content that could address sustainable development from a uniquely African perspective. Teachers worked in groups and expanded their lessons to involve the local community (as depicted in Figure 7) in keeping with the African notion of Ubuntu, which, according to Molefe, translates to 'I am because you are' meaning the belief in a shared universal connection that unites all of humanity.⁹⁴

Teachers engaged in relevant professional development as they included SDGs and sustainable development principles in their teaching of the mainstream Science and Mathematics CAPS curricula. The focus on SDGs paradoxically favours what Singh refers to as "more affluent, technologically advanced, and better-resourced global North contexts as opposed to global South contexts",⁹⁵ which Mudaly and Sanjigadu state is "more based on the connectedness of human to human, human to nature and human to the cosmos and allows for re-aligning ontological positioning."⁹⁶ However, Agenda 2030 for SD has been embraced globally, regardless of geopolitical positioning. Raju believes colonization does not address SD, especially in adopting SDGs as a curriculum focus in Mathematics and Science subjects.⁹⁷ This approach explores possibilities for what de Sousa Santos refers to as 'post-abysal thinking'.⁹⁸

RECOMMENDATIONS

Social Justice, equality, and human dignity are directly linked to the SDGs. End poverty, promoting good health and well-being, increasing gender equality and women's empowerment, providing access to clean water, and creating meaningful, lasting partnerships are central to humanistic endeavor and should be included in the science and mathematics teacher training and professional development curricula, especially.

The findings of this study revealed the significant time and effort required for maths and science teachers, especially in reimagining and transforming how they teach. This study further motivates and expands professional development programmes in Math and Science for teachers of various subjects.

⁹² Kershree Padayachee, Mapula Matimolane, and Rita Ganas, "Addressing Curriculum Decolonisation and Education for Sustainable Development through Epistemically Diverse Curricula," *South African Journal of Higher Education* 32, no. 6 (2018): 288–304.

⁹³ United Nations, *Transforming Our World: the 2030 Agenda for Sustainable Development*.

⁹⁴ Motsamai Molefe, "Ubuntu and Development: An African Conception of Development," *Africa Today* 66, no. 1 (2019): 96, <https://doi.org/10.2979/africatoday.66.1.05>.

⁹⁵ Shalini Singh, "From Global North-South Divide to Sustainability: Shifting Policy Frameworks for International Development and Education," *International and Multidisciplinary Journal of Social Sciences* 9, no. 1 (2020): 76–102.

⁹⁶ Mudaly and Sanjigadu, "Epistemic Journeying across Abyssal Lines of Thinking: Towards Reclaiming Southern Voices."

⁹⁷ Raju, "Decolonising Mathematics."

⁹⁸ B. de Sousa Santos, *Beyond Abyssal Thinking: From Global Lines to Ecologies of Knowledges. Review* (Fernand Braudel Center, 2007).

This study has implications for the Minimum Requirements for Teacher Education Qualifications (MRTEQ), a national policy in South Africa, through the re-curricular and integration of ESD, as MRTEQ establishes the foundational framework for teacher education. The MRTEQ policy is essential for guiding the development of teacher education programs across the country, and the implications of integrating ESD into this document should be considered. This study also has implications for HEIs and their teacher education programmes, whereby the notion of transformative pedagogical approaches to ESD in the Mathematics and Science teacher programmes need to be explored and engaged with.

CONCLUSION

In this study, teachers engaged in intercultural dialogue. They developed their agencies to think about possibilities for creating relevant units of work (from the Mathematics and Science curricula) that could address SD from a uniquely African perspective. Teachers could rediscover and recover their own culture and re-imagine and enact an alternative curriculum that centres on ESD. The transformative approach used in this study allowed for repainting the curriculum canvas and recasting curriculum actors to participate democratically in a sustainable, more-than-human world. It can be argued that the focus on SDGs (paradoxically) favours the more affluent, technologically advanced, and better-resourced global North. The 2030 Agenda for SD has been embraced globally, regardless of its geopolitical position. Adopting SDGs as a curriculum focus was suitable for exploring possibilities post-abyssal thinking. Individuals (teachers) were able to re-enter the present with a renewed sense of self, able to see the wholeness of past, present, and future, and ask what this means and what can I do? and therefore identified different ESD principles as a basis for a transformed Mathematics and science curriculum. In an attempt to explore the role of the professional development of Mathematics and Science teachers towards Education for ESD through the utilization of transformative pedagogies, Mathematics and Science teachers were able to transform their pedagogical approaches and align their attitudes, beliefs, and perceptions about the curriculum, towards ESD-oriented Math and Science curriculum. This study has illustrated how transformative pedagogies can empower Mathematics and Science teachers to reimagine curricula through an African lens, centering ESD and fostering democratic, culturally relevant engagement with sustainability.

Suggestions for Research in the Future

There is a need for scholarship that focuses on leveraging Indigenous knowledge (IK) (based on the African IK context) within the curriculum to address SD is necessary to address challenges related to sustainability. There is a need to retrieve the silenced and marginalized knowledge through engaging in the "sociology of absences," which is a procedure showing that agents on the South side of the abyssal line are actively engaging in resistance against dominant ways of knowing.⁹⁹ Future research should be directed to explore how the curriculum can address SD.

Acknowledgments

The researchers wish to thank Professors Ronicka and Vimolan Mudaly for their academic insights, facilitation, technical assistance, and ideas that made the research possible.

Conflict of Interest

None.

Funding

The researchers acknowledge the DSI-NRF Centre of Excellence in Mathematical and Statistical Sciences (CoE-MaSS), South Africa, for funding this research.

⁹⁹ B. de Sousa Santos, *The End of the Cognitive Empire: The Coming of Age of Epistemologies of the South* (Duke University Press, 2018), 152.

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