



Sustainable Education Affordances in Natural Sciences to Promote Quality Learning

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ABSTRACT

This study explores the affordances for sustainable education (SE) in Natural Sciences (NS) teaching within South African schools, focusing on how teachers utilize available resources and curricula to promote quality learning outcomes aligned with Sustainable Development Goal 4 (SDG4). Adopting an interpretivist paradigm and an exploratory case study design, the research engaged five experienced NS teachers from socioeconomically disadvantaged schools in Bloemfontein. Data was collected through semi-structured interviews, document analysis, and situation analysis, ensuring credibility, transferability, dependability, and confirmability. Findings reveal that despite teachers in under-resourced South African schools demonstrating resilience and innovation in advancing SE through NS, systemic inequities, lack of support, and environmental misalignment hinder meaningful progress. The findings reveal a stark contrast between the potential affordances for SE inherent in the NS curriculum and the challenging on-the-ground realities faced by dedicated teachers. Through the employment of the affordance theory, the research accentuates the potential of existing teaching environments to promote SE when adequately supported. Recommendations include targeted interventions to bridge resource gaps, collaborative stakeholder engagement, and a reorientation of teacher training to emphasize sustainability. This study contributes to the discourse on SE by providing insights into the practical realities of NS teaching in under-resourced contexts and advocating for systemic reforms to achieve equitable, quality education. *We should not merely reform—We should revolutionize education.*

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INTRODUCTION

As the year 2030 approaches, marking a critical milestone for global education targets, there is a growing discourse on the need for inclusive, equitable, and quality education, particularly in the context of sustainable education (SE) affordances within Natural Sciences (NS) to enhance meaningful and transformative learning experiences. This comes as evidence suggests that in South Africa (SA), as many as multiple interventions are in place and there are signs of progress; however, significant aspects such as teacher training continue to suffer, manifesting the idea that the country is far from achieving quality

education for all.¹ A thorough being a signatory of the Sustainable Development Goals (SDG) by the United Nations General Assembly and disseminating the National Developmental Plan 2030 (NDP) acknowledged the essentiality of the development of SE.² Hence, the significance of SE is celebrated and seen by countries around the world, including SA to be a promoter of responsible citizenship through fostering higher-order thinking skills, for self and others. This is evidently reflected in the national policy and guideline documents such as Minimum Requirements for Teacher Education Qualifications of 2008 (MRTEQ) and Curriculum and Assessment Policy Statement of 2011(CAPS), amongst others.³ The NS CAPS purports to prepare “learners for active participation in a democratic society that values human rights and promotes responsibility toward the environment [...] also prepare learners for economic activity and self-expression.”⁴ In the same accord, MRTEQ stipulates a set of minimum competencies that newly qualified teachers should be in possession of to mediate learning suitable to the country’s needs.⁵ This gives an understanding that SA has committed structures to the achievement of equitable, quality education with lifelong learning opportunities. However, implementing this vision, particularly in science education, due to its relationality to socio-scientific issues, has been in a dormant state due to several challenges.⁶⁷

Various studies have been conducted on the teaching of NS for sustainability in education. This is reflected by the well-documented struggles faced by teachers in relation to the translation of the national policy and guideline documents’ assertions into the much-desired quality pedagogical practices.⁸ Authors Frisk and Larson observe that the competence and commitment of teachers greatly impact the efficacy of incorporating SE into the school curriculum and practices.⁹ In support of this, authors Nieveen and Kuiper state that teachers’ professionalism ensures effective curriculum implementation, predicated on their expertise, and that curriculum renewal can only be successful and sustainable if teachers assume responsibility for it.¹⁰ Conversely, it is highlighted in the literature that there is a need for a focus redirection towards teacher training on “competent learning” as NS curriculum misalignment was identified by authors.¹¹ Furthermore, researchers amplify that many SA teachers experience disempowerment and a lack of support in their teaching due to insufficient preparation for implementing the new CAPS curriculum.¹²

Given the above-discussed studies having made ground in the teacher development for quality education in NS, none of the studies have made the teaching of NS for sustainability through well-researched pedagogical practices a focal point. Hence, we annotate the problem to be the lack of coherence and integration of SE in all educational phases, as well as the absence of supporting resources and teacher

¹ Hennades T Tabe, “Teacher Quality as a Defining Factor of Student Academic Performance in Schools: The Case of a District in South Africa,” *African Perspectives of Research in Teaching and Learning* 7, no. 3 (2023): 487–502; Statistics South Africa, *Census in Brief* (Pretoria: Statistics South Africa, 2003).

² *Our Future : Make It Work : National Development Plan, 2030* (National Planning Commission, 2012).

³ Department of Higher Education and Training, *Higher Education Statistics Report* (Pretoria: DHET, 2022); DBE (Department of Basic Education), *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12* (Pretoria: Government Printers, 2011).

⁴ DBE (Department of Basic Education), *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12*.

⁵ Department of Higher Education and Training, *Higher Education Statistics Report*.

⁶ Tabe, “Teacher Quality as a Defining Factor of Student Academic Performance in Schools: The Case of a District in South Africa.”

⁷ Moeketsi Tlali, “Towards Developing a Science-Language Learning Programme for the Equality of Sustainable Learning Opportunities for Young Children,” *Educational Research for Social Change* 12, no. 1 (April 2023): 41–51, http://ersc.nmmu.ac.za/articles/ERSC_April_2023_Vol_12_No_1_Tlali_pp_41-50.pdf.

⁸ Jan-Ole Brandt et al., “Developing ESD-Specific Professional Action Competence for Teachers: Knowledge, Skills, and Attitudes in Implementing ESD at the School Level,” *Environmental Education Research* 28, no. 12 (2022): 1691–1729.

⁹ Erin Frisk and Kelli L Larson, “Educating for Sustainability: Competencies & Practices for Transformative Action,” *Journal of Sustainability Education* 2, no. 1 (2011): 1–20.

¹⁰ Nienke Nieveen and Wilmad Kuiper, “Balancing Curriculum Freedom and Regulation in the Netherlands,” *European Educational Research Journal* 11, no. 3 (2012): 357–68.

¹¹ Department of Higher Education and Training, *Higher Education Statistics Report*; Tebogo E Nkanyani and Awelani V Mudau, “Natural Sciences Teachers’ Experiences on Teaching Planet Earth and beyond Knowledge Strand,” *Journal of Turkish Science Education* 16, no. 4 (2019): 478–88.

¹² Anriët Deventer and Raita Steyn, “Teachers’ Attitudes towards the Amendments in the Design Curriculum: A Critical Overview of the Approach and Findings of the Study,” *Information Technology Education and Society* 27 (July 16,2022):53–69.

development.¹³ The continued neglect of SE in NS may result in a generation ill-equipped to address socio-scientific challenges, ultimately compromising their ability to contribute to a sustainable and equitable future.¹⁴ Consequently, the goal to achieve quality and equitable education is only being attended to in a perfunctory manner that includes teachers' inability to utilize the curricula and policies effectively, as well as limited access to resources.¹⁵ Thus, this study comes with an inimitable argument, calling for the use of SE-aligned pedagogical practices through already provided avenues and the detachment from the cosmetic arguments seeking to add on to challenges. And further, proposes to address teachers' challenges in utilizing curriculum and policies to facilitate the effective integration of SE in the teaching of NS.

This study aims to understand how the teaching of NS can be geared towards sustainable education. The study focused on the SE affordances provided by the NS and the teachers' efforts to utilize them towards quality education.

LITERATURE REVIEW

Sustainable Education Affordances

Sustainable education affordances are the opportunities and benefits that educational systems provide as a means to promote sustainability across various disciplines, in this case, NS education.¹⁶ As global challenges like climate change, biodiversity loss, and resource depletion intensify, there is an urgent need to equip learners with the skills and knowledge required for sustainable living and stewardship. These affordances become critical in the nurturing of a deeper understanding of sustainability and equipping involved parties with the necessary competencies to address complex environmental challenges.¹⁷ Researchers emphasize the critical need to identify key teaching opportunities in NS to promote sustainable education.¹⁸ This accentuates the importance of developing teachers' abilities to facilitate curriculum-aligned lessons that enable learners to transfer classroom knowledge to real-world contexts. Authors have explored the complex nature of science teachers' beliefs and their impact on instructional practices within a climate change-centred curriculum.¹⁹ Their study highlights a gap in addressing political controversies surrounding climate change in science classrooms and proposes strategies for effective teaching in this area. This research reinforced the significance of teachers' perspectives and instructional practices, as well as their ability to interpret curriculum content to foster sustainability in education.

International and Local Landscape

Continental studies further emphasize the integration of sustainable NS education, highlighting its substantial influence on environmental, social, and economic dimensions.²⁰ These findings stress the need for equitable distribution of opportunities that enhance sustainable NS education, including teacher development, resource allocation, and an explicit sustainability-focused curriculum. Some authors support this perspective through a comparative analysis of science curriculum guidelines in Taiwan and Colombia,

¹³ Mohd Syahidan Zainal Abidin, Mahani Mokhtar, and Mahyuddin Arsaf, "School Leaders' Challenges in Education for Sustainable Development: A Scoping Review," *International Journal of Academic Research in Progressive Education and Development* 12, no. 1 (January 13, 2023), <https://doi.org/10.6007/IJARPED/v12-i1/15922>.

¹⁴ Marianne Logan and Amy Cutter-Mackenzie, "Incorporating Sustainability as a Socio-Scientific Reality into Science Teacher Education," in *Educating Science Teachers for Sustainability* (Springer, 2015), 297–321.

¹⁵ Elize C Du Plessis and Mantekana Jacobine Letshwene, "A Reflection on Identified Challenges Facing South African Teachers," *The Independent Journal of Teaching and Learning* 15, no. 2 (2020): 69–91.

¹⁶ Chien-Chang Lin, Anna Y Q Huang, and Owen H T Lu, "Artificial Intelligence in Intelligent Tutoring Systems toward Sustainable Education: A Systematic Review," *Smart Learning Environments* 10, no. 1 (2023): 41.

¹⁷ Darmawan Harefa, "Strengthening Mathematics And Natural Sciences Education Based On The Local Wisdom Of South Nias: Integration Of Traditional Concepts In Modern Education," *Haga : Jurnal Pengabdian Kepada Masyarakat* 3, no. 2 (November 7, 2024): 63–79, <https://doi.org/10.57094/haga.v3i2.2347>.

¹⁸ Kailiang Chen, Juanjuan Chen, and Chung Wang, "The Effects of Two Empathy Strategies in Design Thinking on Pre-Service Teachers' Creativity," *Knowledge Management & E-Learning: An International Journal*, September 18, 2023, 468–86, <https://doi.org/10.34105/j.kmel.2023.15.027>.

¹⁹ Molly Trendell Nation and Allan Feldman, "Environmental Education in the Secondary Science Classroom: How Teachers' Beliefs Influence Their Instruction of Climate Change," *Journal of Science Teacher Education* 32, no. 5 (2021): 481–99.

²⁰ Francisco O Machín Armas et al., "Sostenibilidad, Ingeniería y Enseñanza de Las Ciencias Básicas. Marco Teórico Conceptual," *Revista Iberoamericana de Educación* 73 (2017): 179–202.

emphasizing a quality education approach.²¹ Their findings align with UNESCO's recommendations for effective teaching and learning strategies that advance sustainable development in both learner and teacher education institutions.²²

In the South African context, NS education has been recognized as a crucial subject for fostering sustainable education and cultivating active, scientifically literate citizens.²³ The Department of Basic Education reinforces this through policy objectives aimed at developing learners who can effectively utilize science and technology in environmentally responsible ways.²⁴ Additionally, the South African curriculum seeks to ensure that learners acquire and apply knowledge and skills in ways that are meaningful to their lives, balancing local contextual knowledge with global imperatives²⁵. This approach acknowledges the value of incorporating diverse perspectives, experiences, and epistemologies into teaching, learning, and research.²⁶

Despite these structural affordances outlined in policy documents, the literature indicates persistent challenges in the teaching of NS. Concerns have been raised regarding the implementation of multiple guidelines and policies without sufficient teacher consultation, leading to a diminished role for educators in executing these frameworks.²⁷ Additional challenges include high teacher-to-learner ratios, insufficient teacher professional development and inadequately resourced schools unable to deliver quality education.²⁸ These challenges highlight the need for a holistic and transformative approach to NS teaching for sustainable development. Such an approach should incorporate the promotion of scientific thinking from early education stages, experiential and service learning, social responsibility, self-regulated learning, and continuous professional development strategies for educators.

THEORETICAL FRAMEWORK

This study is couched on the affordance theory. The initial conceptualization of this theory stems from James J. Gibson with the intent to depict the rapport between the environment and its organism, stressing the latent actions that an environment affords to the organism.²⁹ In the context of this study, the affordances are embodied by the opportunities provided by teaching methods, curricula, and resources to promote specific learning outcomes. The employment of this framework offers an appropriate framework to examine teaching practices and the learning environment's ability to foster knowledge, skills, and attitudes conducive to sustainability.

The affordance theory seeks to provide a theoretical foundation for understanding how the affordances present in the learning environment can support the realization of SE in NS teaching. It can

²¹ José Molina et al., "SDG's Quality Education Approach: Comparative Analysis of Natural Sciences Curriculum Guidelines between Taiwan and Colombia," *Sustainability* 13, no. 6 (2021): 3352.

²² Deirdre Hogan and Joanne O'Flaherty, "Exploring the Nature and Culture of Science as an Academic Discipline: Implications for the Integration of Education for Sustainable Development," *International Journal of Sustainability in Higher Education* 23, no. 8 (December 19, 2022): 120–47, <https://doi.org/10.1108/IJSHE-06-2021-0236>.

²³ Daniella Taranto and Michael T Buchanan, "Sustaining Lifelong Learning: A Self-Regulated Learning (SRL) Approach," *Discourse and Communication for Sustainable Education* 11, no. 1 (2020): 5–15; TBM Chowdhury, Jack Holbrook, and Miia Rannikmäe, "Socioscientific Issues within Science Education and Their Role in Promoting the Desired Citizenry," *Science Education International* 31, no. 2 (June 4, 2020): 203–8, <https://doi.org/10.33828/sei.v31.i2.10>.

²⁴ DBE (Department of Basic Education), *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12*.

²⁵ Dimakatso Gaseitsekgoi and Glen Legodu, "Exploring Life Sciences Pre-Service Teachers' Competences in Education for Sustainable Development," *Journal of Inquiry Based Activities* 15, Special Issue (August 28, 2025): 172–185, <https://www.ated.info.tr/index.php/ated/article/view/249>.

²⁶ Rubby Dhunpath and Reshma Subbaye, "Student Success and Curriculum Reform in Post-Apartheid South Africa," *International Journal of Chinese Education* 7, no. 1 (January 1, 2018): 85–106, <https://doi.org/10.1163/22125868-12340091>.

²⁷ Elize Du Plessis and Mantekana Jacobine Letshwene, "A Reflection on Identified Challenges Facing South African Teachers," *The Independent Journal of Teaching and Learning* 15, no. 2 (November 7, 2024): 69–91, <https://doi.org/10.17159/cv8gfx71>.

²⁸ Roy Venketsamy, "Exploring the Teacher-Learner Ratio and Its Effect on Invitational Teaching and Learning: A South African Study," *Journal for the Education of Gifted Young Scientists* 11, no. 1 (March 16, 2023): 33–43, <https://doi.org/10.17478/jegys.1237615>; Nombuso Mlotshwa and Maria Tsakeni, "Challenges Experienced by Teachers When Integrating Indigenous Knowledge Systems in Natural Sciences Practical Work," *African Journal of Research in Mathematics, Science and Technology Education* 28, no. 2 (2024): 300–313; Toyer Nakidien, Marcina Singh, and Yusuf Sayed, "Teachers and Teacher Education: Limitations and Possibilities of Attaining SDG 4 in South Africa," *Education Sciences* 11, no. 2 (2021): 66.

²⁹ James J. Gibson, *The Ecological Approach to Visual Perception* (Psychology Press, 2014), <https://doi.org/10.4324/9781315740218>; Anthony Chemero, "An Outline of a Theory of Affordances," in *How Shall Affordances Be Refined? Four Perspectives* (Routledge, 2018), 181–95, <https://doi.org/10.4324/9780203726655-5>.

therefore be derived that the adoption of the affordance theory offers this study a promising framework for examining the integration of SE within the teaching of NS. This is because the theory allows the exploration of the various affordances present in the teaching and learning environment and leverages them to promote SDG4. In adopting a situational perspective and focusing on the interactions between learners, teachers, and the environment, the creation of meaningful learning experiences that empower learners to contribute to sustainability comes alive.

Employing affordance theory in the context of NS curriculum scrutiny and related teaching practices application emphasizes the importance of considering available resources as vehicles for SE.³⁰ This amplifies the idea that through engaging an affordance-based theory, teachers can move beyond just identifying curriculum characteristics and features and instead focus on how these resources can best be used to shape theories, values, and improvement practices.³¹ Hence, the employment of the affordance theory in this study aligns with SE principles. As espoused by Branden, SE affords all learners the necessary support to succeed while advancing lifelong competencies that enable them to contribute meaningfully to society.³² This is done using resources that are immediately available to that environment. However, many education systems struggle to bridge achievement gaps, harness students' full potential, and equip them with the skills needed for employment and active participation in a rapidly evolving world. This in a sense, relates to a systemic shortfall as in this case, a one-sided environment (classroom, policies, or guideline documents) might afford the organism (teachers, and/or learners) with latent actions, however, due to structural ineffectiveness the other side of the environment (quality training, resource provision, or non-inclusive education) fails the organism.

METHODOLOGY

This paper based its focal lens on an interpretivist paradigm. Accordingly, this paradigm is denoted by researchers to stress the interpretations and subjective meanings of individuals and their social contexts.³³ The paradigm displays its relevance to this paper through the attempt to make sense of the world in the context of NS teaching for SE. Therefore, it is via a qualitative research approach, as viewed by Kemparaj et.al., that this study explored the methods and resources, if there are any, utilized by intermediate-phase NS teachers to ensure education sustainability.³⁴ This study adopted an exploratory case study research design to investigate the methods and resources utilized by intermediate-phase NS teachers. The employment of this design was to create preliminary knowledge of the recognition and therefore, the implementation of SE in NS classrooms phenomenon with the emphasis on discovering an introduction to the structure, dynamics, and context of empirical evidence.³⁵

Participants for this study were identified through judgment sampling.³⁶ This study involved five NS teachers from Bloemfontein, South Africa. These participants were all seasoned in teaching NS. All participants agreed to be part of the study, including the inclusion of their interview data. The participants were selected through purposive sampling based on their experiences in facilitating NS. The participants teach at quintile schools in a socioeconomically disadvantaged neighbourhood characterized by high unemployment, semi-segregation, and a neighbourhood that has distressingly high school drop-out rates. (Appendix: Table 1) represents the participants' profiles.

³⁰ Prema Gaikwad, "Sustainable Learning," *Spicer Adventist University Research Articles Journal* 1, no. 1 (February 1, 2022): 18–25, <https://doi.org/10.56934/sauraj.v1i1.63>.

³¹ George Kalmpourtzis and Margarida Romero, "An Affordance-Based Framework for the Design and Analysis of Learning Activities in Playful Educational Robotics Contexts," *Interactive Learning Environments*, December 23, 2022, 1–14, <https://doi.org/10.1080/10494820.2022.2158478>.

³² Kris Van den Branden, "Sustainable Education: Basic Principles and Strategic Recommendations," *School Effectiveness and School Improvement* 23, no. 3 (September 2012): 285–304, <https://doi.org/10.1080/09243453.2012.678865>.

³³ Nasrin Pervin and Mahani Mokhtar, "The Interpretivist Research Paradigm: A Subjective Notion of a Social Context," *International Journal of Academic Research in Progressive Education and Development* 11, no. 2 (April 25, 2022), <https://doi.org/10.6007/IJARPEd/v11-i2/12938>.

³⁴ Umesh Kemparaj and Sangeeta Chavan, "Qualitative Research: A Brief Description," *Indian Journal of Medical Sciences* 67, no. 3 (2013): 89, <https://doi.org/10.4103/0019-5359.121127>.

³⁵ Hans Lehmann, "Research Method: Grounded Theory for Descriptive and Exploratory Case Studies," in *The Dynamics of International Information Systems: Anatomy of a Grounded Theory Investigation* (Springer, 2010), 53–65.

³⁶ Kevin O'Gorman and Robert MacIntosh, "Mapping Research Methods," *Research Methods for Business and Management: A Guide to Writing Your Dissertation*, 2015, 50–74.

The Faculty of Education Ethics Committee at one of the SA institutions of higher learning in the Free State province approved the research, and the Special Interest Group committee ensured compliance with ethical guidelines. Permission from the Free State Department of Education was obtained, and head teachers were informed of the study's purpose for transparency and cooperation. For effective data collection, this study employed the trifecta of interviews, document analysis, and situation analysis as tools. To understand how teachers' viewpoints on curriculum and teacher development in Bloemfontein primary schools affect the recognition of and implementation of SE in NS classrooms, the researchers conducted semi-structured individual interviews with teachers. They further employed a combination of target situation analysis to understand the teaching needs and challenges in this area comprehensively. Target situation analysis for this study involved identifying the desired outcomes, goals, and opportunities for teaching NS for sustainability.³⁷ This included determining the specific communication skills and competencies learners need to develop academically. Furthermore, a systematic exploration of policy documents, lesson plans, learner and teacher textbooks, and other pertinent written sources assisted in the collection, arrangement, and analysis of data. This was done to understand the relationship between the intended objectives of the NS-related documents, teacher recognition and implementation of SE in NS. The curriculum documents, course syllabi (scheme of work and lesson plans drawn from the syllabi), and the CAPS were utilized. A summary of the data-collecting tools used for each objective can be found in Appendix 2.

The analysis of data in this study was conducted through the employment of Clarke and Braun's six-phase inductive thematic analysis method.³⁸ With this approach, the aim was to uncover and describe patterns emerging from the raw data to address the research question.³⁹

PRESENTATION OF FINDINGS

The findings of the study shed light on multifaceted views of the context at hand, documents under review and organisms of the system as perceived by the theory framing the study.⁴⁰ The findings delve into how teachers can make the most of the identified opportunities to enhance the teaching of NS with SE in mind. Additionally, strategies for effectively utilizing teaching opportunities are presented and concluded by addressing feedback methods identified through data analysis. A method of highlighting correlations in the data and conveying the standard message derived from the collected information is then employed as a structured approach. A further incorporation of direct quotations from the participants serves as supporting evidence for the assertions made based on the data.

NST Sustainability Affordances

An exploration of the affordances the NS curriculum provides and policies for teaching sustainable development. Seeking to understand the opportunities in the curriculum and the policy for the extent to which learning is facilitated in inclusive, future-oriented and sustainable ways. The analysis focuses on the explicit integration of critical topics (matter and material, climate change, water quality and conservation, and environmental management) into the curriculum and policy. These topics are vital as they influence economic, social, and environmental aspects of life, both in the present and the future.

Findings from the document analysis communicate that the curriculum plays a pivotal role in equipping learners with the knowledge, skills, and values necessary for responsible citizenship, meaningful societal participation, and personal fulfilment. This stresses the need for education to transcend rote memorization, instead promoting the practical application of knowledge in real-world contexts. Through the emphasis on critical thinking and problem-solving competencies, the curriculum advances both individual and societal development. A fundamental component of this framework is its focus on contextualized knowledge, ensuring that learning is relevant to local realities. As articulated in

³⁷ Hanna Tovkanets, "APPLICATION OF THE SITUATION ANALYSIS METHOD IN A PRIMARY SCHOOL," *Scientific Bulletin of Uzhhorod University. Series: «Pedagogy. Social Work»*, no. 2(51) (October 25, 2022): 175–79, <https://doi.org/10.24144/2524-0609.2022.51.175-179>.

³⁸ Virginia Braun and Victoria Clarke, "Thematic Analysis: A Practical Guide," 2021.

³⁹ Saraswati Dawadi, "Thematic Analysis Approach: A Step by Step Guide for ELT Research Practitioners," *Journal of NELTA* 25, no. 1–2 (December 31, 2020): 62–71, <https://doi.org/10.3126/nelta.v25i1-2.49731>.

⁴⁰ Braun and Clarke, "Thematic Analysis: A Practical Guide."

the curriculum framework, education should "equip learners, irrespective of their socio-economic background, race, gender, physical or intellectual ability, with the knowledge, skills, and values necessary for self-fulfilment and meaningful participation in society as citizens of a free country."⁴¹ This approach not only enhances engagement by anchoring learning in familiar environments but also fosters ecological awareness, sustainability, and the preservation of indigenous knowledge systems. Moreover, the curriculum integrates global perspectives, preparing learners to navigate and address contemporary global challenges.

Table 1: NS Sustainability Affordances: Semi-structured Interviews

Data Set	Format, Context & / units of observation	Themes	Categories	Excerpts from raw data
Semi-structured Interviews	Question and answer (see appendix)	Practical knowledge Meaningful learning	Applied knowledge, Caring for environment	<i>"I would like to say that our school does not have a laboratory and science ... Natural Sciences ...is all about the resources for experiments and all those things... what helps is only the science kit."</i> <i>"...So, all the things, if I have to tell you, all the things that I am doing, I am taking them out of my pocket. Starting from the project, starting from practical things. What is it that the government has done for us? Because when I arrived at the school, I was shocked that the kids didn't even use those things practically."</i> <i>"...when I arrived at the school, I was shocked that the kids didn't even use those things practically. They were just theorizing natural sciences. I had to go and buy the stuff. I had to ask my parents to assist me with the stuff for the practical."</i>

Table 1 findings highlight significant challenges in teaching NS towards SE, primarily due to inadequate infrastructure, financial constraints, and limited resource utilization. The absence of science laboratories, as noted by participants, restricts hands-on learning, and leaves teachers at a disadvantage of relying on minimal resources like donated science kits. Additionally, participants' frustration highlights the financial burden on teachers, who often fund practical activities out of pocket due to insufficient government support. Furthermore, the lack of student engagement with available resources suggests gaps in training, accessibility, or curriculum alignment. While CAPS aims to equip learners with knowledge and skills for meaningful participation in society, its implicit integration of SE principles remains a challenge without explicit implementation strategies and adequate resource provision. Addressing these barriers through improved funding, infrastructure development, and teacher support would enhance practical science learning and foster greater educational equity.

⁴¹ DBE (Department of Basic Education), *Curriculum and Assessment Policy Statement (CAPS): Mathematics Grade 10–12*.

Teachers' Efforts for Sustainable Education**Table 2: Findings on Teachers' Efforts**

Data Set	Format, Context & / units of observation	Themes	Categories	Excerpts from raw data
Document Analysis	NST Curriculum (Teachers' efforts for sustainability)	Teachers' Efforts for Sustainable NST Education School Infrastructure and Learning Environment	Resource Management Inclusivity and Diversity School Infrastructure Deficiencies in NST Resources	CAPS General Aim: "Inclusivity should become a central part of the organisation, planning and teaching at each school. To address barriers to learning and how to plan for diversity." CAPS Teaching Natural Sciences and Technology: Science and Technology as activities that sustain enjoyment and curiosity about the world and natural phenomena
Situational Analysis	School Premises and Surroundings			The school has a well-maintained infrastructure, providing a conducive learning environment for students to engage in sustainable education. Nevertheless, a deficiency is observed in the absence of NST-related charts and tools within the classrooms, consequently limiting the opportunities for hands-on practical learning experiences for learners.
Semi-structured Interviews				<i>"...when I wanted the refill of the resources in the science kit, we are using the resources in the science kit and some of them are finished... so we have to... refill them. So, to motivate that thing, I go to my supervisor and write a letter to say that learners are running short of what? Of the resources."</i> <i>"...the problem is that the resources are the ones that ...that causes me not to activate my achievement sustainable education, the lack of resources and then, lack of support from the district officials."</i> <i>"When it comes to this thing of learning to do, we have the practicals. We must do the practical examples, whenever you teach learners...we have to go to the laboratory or to go to the class, you must demonstrate...implementation...practicality is learning to know."</i> <i>"...you must teach learners about the careers, you incorporate or you integrate that thing in natural science and technology...career!"</i>

			“...the method that we use for sustainability. First, we plan our lessons, and then whenever learners do not perform, we must have the subject improvement plan as an intervention strategy.... Identify errors first and then implement new intervention strategies.” “We must teach learners about in-service learning, how important our resources are, so that we can sustain them.” “I was going to the University of the Free State like you are coming from the University of the Free State to waste my time, especially when I was thinking when I think of going there on a Saturday. Then the next thing, nothing was there, nothing happened. So, those are the things that are boring. Really frustrating and wasting time, I can say that. You come up with something that has got nothing to do with teaching and learning.” “We received that skill, we were certificated, and they gave us the laptops, of which, when you leave the school, you leave the laptops” “And then, it was meant for science and maths and English, but when we came back, we distributed all the information to the other grades. So that's why I said, they worked, and they worked with the little that they have, so successfully, to achieve the goals that were maybe meant for two, but it happened that they did it for the rest.”
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The findings in Table 2 reveal significant challenges in the teaching of NS, particularly in under-resourced schools. Key issues include inequitable resource distribution, ineffective teacher development programs, and a disconnect between policy intentions and classroom realities. Teachers often lack the necessary materials and support to deliver quality education, despite demonstrating innovation and agency in their teaching practices, and this has affected their trust in the system and connection to teaching for a better future. Additionally, systemic inefficiencies, such as delayed resource allocation and insufficient follow-through on training initiatives, further hinder progress.

Optimization of Opportunities for Sustainability

Table 3: Findings of Optimization of Opportunities

Data Set	Format, Context & / units of observation	Themes	Categories	Excerpts from raw data
Semi-structured Interviews	Questions and answers	Learning and Understanding Scientific Concepts	Learning Through Application	“Learners understand the scientific concept through application, and this helps learners to remain focused on their learning through meaning learners are

		Practical Application of Knowledge Impact on Learners and Society	Content Knowledge Professional Practices	<i>able to understand all the scientific concepts.”</i> <i>“Projects such as germination of seeds. Learners know how to grow a seed until it becomes a full plant. They know what to do for a plant seed to grow.”</i> <i>“They must practice what has been taught to them and then bring to reality, change the economy of the country, change the socio-economic aspects of the community.”</i> <i>“I’ve got learners whom I taught Natural Sciences. Some of them are doctors, some of them are Geologists...others are nothing.... the professionals are practising what I taught them, like natural science and technology... “</i> <i>“We must teach learners through in-service learning how important our resources are, so that we can sustain them.”</i> <i>“...first time we're dealing with life and living. We took them to this place, Botanical Garden, so that they can get to experience and get new information from other people about life, about plants, basically, it's dealing with plants, photosynthesis, how it works.”</i> <i>“We were also thinking of taking them to the planetarium this year. Okay, yes. But due to the funds, that's a challenge..... we took them to the Kimberly big hole.”</i>
Situational analysis	Social and economic aspects			Project-based learning: The school possesses land resources that can be effectively employed for horticultural activities. Furthermore, educators and learners have cultivated trees in the vicinity of the school premises, primarily to promote environmental consciousness and commemorate Arbor Day. Unemployment and School Drop-Out Rate in the Community: In the vicinity of the school, immediately before its entrance, an assemblage of males spanning various age groups can be observed in a state of aimless lingering. This phenomenon is attributed to the impact of the older, jobless demographic on learners' decisions to discontinue their education, thereby encouraging the

			prevailing socio-economic stagnation within the community.
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The findings presented in Table 3 highlight the critical role of SE affordances in NS in fostering meaningful learning outcomes and addressing socio-economic challenges. Through project-based learning and the practical application of scientific concepts, such as seed germination and horticultural activities, learners not only deepen their understanding of scientific principles but also develop a sense of environmental stewardship and resource sustainability. The data from participants and the situation surrounding the environment advocate for assertion. Teachers stress that hands-on experiences bridge theoretical knowledge with real-world contexts, enhancing learners' engagement and retention of scientific concepts. This becomes relevant in the case of education, as these practices are in alignment with professional teaching standards and have long-term societal impacts, as evidenced by former learners who have pursued careers, directly applying the knowledge and skills acquired during their education. However, the situational analysis reveals significant barriers, including high unemployment rates and school dropouts, which perpetuate socio-economic stagnation in the community. Despite these challenges, the school's initiatives demonstrate a commitment to fostering sustainable practices and community development. Nevertheless, financial constraints limit the expansion of such programs.

DISCUSSION

The purpose of this study was to understand how the teaching of NS can be geared towards SE from the lens of the affordance theory. The above-presented findings reveal the profound resilience of teachers in under-resourced schools, who, despite systemic inequities and a lack of support, employ innovative strategies to advance SE, exposing the urgent need for systemic reform, cross-sector collaboration, and transformative pedagogies to bridge the gap between curriculum aspirations and on-the-ground realities. This places learners and their aspirations for quality education at a deficit, in accordance with Liebig's law of the minimum, in a sense of growth being limited by the scarcest component.⁴² These significant deficits in line with affordances, either physical, cognitive or social, present a noteworthy paradox in terms of the SDG (4) country report as it hails improvement in the sector.⁴³ However, teachers in SA primary schools encounter a lack of multiple-faceted support. It is due to this lack of support, amongst other challenges, that the attainment of the much-desired SDG4 emerges to be blurry, as these improvements are counteracted. This direct perception from the teachers became relevant to the researcher during the interviews, where all the participants cited their discontent with the system, and some called for intervention from institutions, such as universities, to initiate teacher development programs that seek to equip them with skills and resources. The provision of support and assistance to teachers and under-resourced schools is fundamental for the attainment of the desired teaching and learning outcomes and the future of the country.⁴⁴ From this finding against the backdrop of the affordance theory, it is revealed that in as much although there's potential for existing physical and social teaching environments and their affordances to promote SE, the growth of both agents, the teacher and learner, is curbed by their unsustainable environment. This, in turn, disrupts the reciprocal agent–environment and environment–agent mutualism loop, as the quality of teaching and learning is compromised. Consequently, learners find themselves unable to transfer the knowledge acquired in the classroom to real-life problem-solving contexts.

The illumination of the complex interplay between curriculum affordances, teacher agency, and systemic challenges in advancing SE through NS in under-resourced SA schools is pertinent.⁴⁵ These systemic inefficiencies not only hinder the effective implementation of the CAPS but also exacerbate educational inequities, particularly in schools where teachers are forced to fund practical activities out of

⁴² Alexander N. Gorban et al., "Law of the Minimum Paradoxes," *Bulletin of Mathematical Biology* 73, no. 9 (September 19, 2011): 2013–44, <https://doi.org/10.1007/s11538-010-9597-1>.

⁴³ Statistics South Africa, "Census 2022: Housing and Household Amenities (," *Report No. 03-01-11* (Pretoria: Stats SA, 2023).

⁴⁴ Katherine L. Boice et al., "Supporting Teachers on Their STEAM Journey: A Collaborative STEAM Teacher Training Program," *Education Sciences* 11, no. 3 (March 5, 2021): 105, <https://doi.org/10.3390/educsci11030105>.

⁴⁵ Nakidien, Singh, and Sayed, "Teachers and Teacher Education: Limitations and Possibilities of Attaining SDG 4 in South Africa."

pocket. This financial burden can reduce their motivation and limit the scope of hands-on learning, at the end of the day, significantly impeding the delivery of quality NS education, particularly in marginalized communities, as this can lead to teacher burnout combined with rebellious drive against established systems.⁴⁶ This teacher demoralization and distrust of the system on the rise reveals the absence of both systems thinking and self-awareness competency, which are one of the key competencies needed for personal and societal transformation for sustainability.⁴⁷ The nature of these competencies being mutually interdependent with each other may lead to the already attained minimum teacher requirements being tampered with, which may affect the plight of transforming education.

The relevance of inverse traditional teaching and learning strategies, such as field trip learning, horticultural activities, and seed germination projects, reveals personal attempts being made by teachers to keep up with the global best practices in sustainable education that enhance learners' understanding of scientific principles but also cultivate a sense of environmental responsibility and resource sustainability.⁴⁸ However, the findings reveal a stark contrast between the curriculum's aspirational goals and the on-the-ground realities faced by teachers. This disconnect accentuates the need for a more holistic and transformative approach to NS teaching, one that integrates experiential learning, social responsibility, and continuous professional development for teachers. Drawing from the definition of SE, there is prominence placed on the knowledge, skills, values, and attitudes of learners for a sustainable future. This prominence emphasizes a key aspect of SE on its dependence on the learner's environment, both physical (e.g., school infrastructure, resources) and socio-cultural (e.g., community values, economic conditions) which shapes their ability to internalize and act on sustainability principles. Therefore, if a learner's environment is not in support of sustainability, for example, the lack of recycling facilities, high consumerism, or economic pressures prioritizing short-term survival over long-term sustainability, as shown in the results, a cognitive and behavioral dissonance arises. It is these crumbs of misalignment that have led to the undermining of values and attitudes where sustainability is taught in theory but contradicted by the learner's daily reality.

RECOMMENDATIONS

This study therefore recommends that the prioritization of the SA education system is centered and pivoted towards not just reforming but, revolutionizing education to be able to adapt to these moving times. To set this revolution for a go-ahead it becomes imperative to consider the teaching of NS as a catalyst for SE, as all the NS learning strands can be directly linked to the socioscientific issue relatable to the learners. This study proposes a set of bold, systemic, and actionable recommendations that challenge the status quo and call for a redefinition of how SE is integrated into under-resourced schools. There is a need to optimize the interchange between the teaching environment and the agents to enhance SE through NS. To better leverage the inherent affordances within the physical, cognitive, and social teaching environments, systemic reforms are crucial to providing equitable access and support, thereby enabling teachers to effectively utilize these affordances for SE. Targeted professional development should focus on equipping teachers to perceive and act upon existing and potential affordances for SE, fostering innovative pedagogies that bridge the gap between curriculum aspirations and the realities of under-resourced schools. Furthermore, fostering cross-sector collaborations and promoting experiential learning strategies will create richer and more relevant affordances for learners to engage with SE principles, ultimately disrupting the negative feedback loop created by unsustainable environments and cultivating a reciprocal agent-environment mutualism conducive to quality education for a sustainable future.

CONCLUSION

In accordance with Agenda 2030, the imperative for SE in SA is critical. This accentuates the urgent necessity to utilize NS education for SE, especially in under-resourced settings, where numerous key domains require focus. Emphasizing continuous training and professional advancement for educators is

⁴⁶ Du Plessis and Letshwene, "A Reflection on Identified Challenges Facing South African Teachers," 2020.

⁴⁷ Nora'ayu Ahmad Uzir et al., "Analytics of Time Management Strategies in a Flipped Classroom," *Journal of Computer Assisted Learning* 36, no. 1 (2020): 70–88.

⁴⁸ UNESCO, *Global Education Monitoring Report* (UNESCO, 2020).

crucial. Providing educators with pedagogical strategies that effectively incorporate sustainability principles into NS education, despite resource constraints, significantly improves student engagement and the assimilation of sustainability concepts. A context-sensitive curriculum review may be essential. Modifying the NS curriculum to clearly emphasize and utilize opportunities for interdisciplinary thinking and problem-solving about sustainability equips learners to apply scientific knowledge to tangible environmental and social issues. Robust infrastructure, encompassing access to essential resources and chances for leveraging the local environment as an educational resource, is a vital necessity. Investing in the development of favourable learning environments and fostering resourcefulness guarantees that students obtain practical experiences that connect theory with practice. Outreach programs, including community-based projects and partnerships with local sustainability efforts, ignite student interest in SE and its relation to NS disciplines. Public-private collaborations can provide practical exposure and promote the use of scientific principles in sustainable practices. Active participation from parents, caregivers, and community members fosters a conducive environment for reinforcing sustainable principles. Promoting parental involvement in school environmental efforts and decision-making augments student engagement and achievement in SE. Policymakers should prioritize SE activities in the NS curriculum by investing specific funding and resources for teacher training and contextually relevant materials. Guaranteeing fair access, especially for under-resourced regions, is essential for mitigating inequities in social equity outcomes. Comprehensive monitoring and evaluation systems can assess the incorporation of SE into NS education, pinpoint obstacles, and guide evidence-based decision-making. Continuous progress depends on data-driven insights and adaptable techniques that address the specific requirements of varied educational settings. Advocating for inclusivity in SE within NS fosters varied viewpoints and guarantees comprehensive student engagement in tackling sustainability issues. Collaborating with international partners and conforming to worldwide educational standards for SE promotes best practices and cross-cultural interchange, hence augmenting the country's role in global sustainability initiatives. An effectively integrated NS-based SE system significantly advances sustainable development objectives, enabling the country to cultivate environmentally aware and responsible individuals. Executing these recommendations could reconcile curriculum objectives with practical realities, foster a populace capable of tackling sustainability issues, stimulate innovation in eco-friendly solutions, and promote a more just and environmentally sustainable future for all citizens.

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