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Changes in Agricultural Teachers' Competencies to Apply Sustainable Practices in Their Teaching After Education for Sustainable Development Intervention

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ABSTRACT
The infusion of Education for Sustainable Development (ESD) into secondary school agricultural education positively influenced teachers' understanding, pedagogical practices, and action competencies, confirming the potential of professional development interventions. In this study, thirty in-service agricultural science teachers in the Free State province of South Africa participated in an ESD-infused intervention. All teachers completed pre- and post-intervention instruments, while a sub-sample took part in focus groups (n = 8) and classroom observations (n = 5). The intervention was designed to enhance teachers' awareness of sustainability concepts and strengthen their pedagogical reasoning in line with ESD principles. Findings indicate that teachers' conceptual understanding of sustainable agriculture broadened to encompass ecological stewardship, social responsibility, and economic awareness. However, classroom observations revealed that some teachers struggled to translate this expanded knowledge into practical classroom activities, particularly hands-on agricultural tasks, highlighting a gap in pedagogical skills. These results align with the Pentagon model of Pedagogical Content Knowledge (PCK), which emphasises the integration of content knowledge, pedagogical strategies, learner understanding, curriculum knowledge, and assessment to enable sustainability-focused learning. The study recommends that the Department of Basic Education strengthen sustainability awareness and ESD integration through dedicated curriculum initiatives, support professional development that emphasises project- and community-based learning, and adopt inter- and multidisciplinary approaches. These strategies will better equip teachers to apply sustainable agricultural practices in their classrooms and communities, contributing to broader societal transformation.

KEYWORDS
Education for sustainable development; teacher competencies; agriculture science; and pedagogical content knowledge

INTRODUCTION

Agricultural education is widely recognised as a key driver in equipping societies with the knowledge, skills, and values needed to address pressing challenges such as food insecurity, climate change, and environmental degradation. Globally, scholars argue that the twenty-first century requires education systems to prepare learners not only for economic productivity but also for active citizenship in sustainable societies (Tilbury, 2011; UNESCO, 2017; Wals, 2015). In contexts such as South Africa, agriculture remains both a source of livelihood and a cornerstone of rural development, yet the sector faces persistent threats from climate variability, land degradation, and the disengagement of rural youth from farming (Leal Filho et al., 2018). These challenges highlight the urgent need to reorient agricultural education toward sustainability, ensuring that learners are not only consumers of agricultural knowledge but also agents capable of transforming their communities.

Education for Sustainable Development (ESD) has become central to this reorientation, as it integrates ecological stewardship, social equity, and economic resilience into teaching and learning (Barth & Rieckmann, 2012; Blose, 2025; UNESCO, 2017). ESD emphasises competencies such as systems thinking, anticipatory competence, normative reasoning, and action-oriented practice, which enable learners and teachers to make informed decisions and engage in responsible action. Scholars stress that these competencies are critical for bridging the gap between abstract awareness and practical sustainability implementation in schools and communities (Biasutti et al., 2018; Rieckmann, 2012).

In-service agricultural teachers occupy a particularly strategic position in this transformation. Unlike pre-service teachers still in training, in-service teachers already mediate knowledge in classrooms and local agricultural communities, making their competencies and pedagogical reasoning central to learners' engagement with sustainability issues (Leal Filho et al., 2018). However, evidence from both African and international contexts indicates that many in-service teachers hold fragmented or surface-level understandings of sustainability, often equating it solely with environmental protection while neglecting social and economic dimensions (Sterling, 2010; Tilbury, 2011). This limitation is exacerbated by gaps in pedagogical content knowledge (PCK), as agricultural education has frequently prioritised theoretical content while underemphasising experiential and problem-based learning approaches (Park & Oliver, 2008). As a result, teachers often possess declarative knowledge of sustainability but struggle to transform this knowledge into pedagogical strategies and assessments that engage learners meaningfully.

Recent studies highlight the transformative potential of professional development interventions that deliberately integrate ESD principles into teachers' professional growth (Barth & Rieckmann, 2012; Biasutti et al., 2018). Such interventions provide opportunities for teachers to broaden their understandings of sustainability, experiment with learner-centred pedagogies, and strengthen action competence. In agricultural education, competencies such as systems thinking and anticipatory competence are especially critical, as agricultural decisions

carry ecological, social, and economic consequences that extend across generations (Rieckmann, 2012; Wals, 2015). When in-service teachers develop the ability to situate sustainability as an interconnected and future-oriented concept, they become better equipped to design learning experiences that link theory with practice, empower learners, and contribute to sustainable agricultural development.

While international research has generated substantial insights into teacher professional development for sustainability, evidence from Sub-Saharan Africa remains limited. Scholars have observed that much of the global ESD discourse has been dominated by experiences in Europe, Asia, and North America, with African contexts often underrepresented in empirical studies (Leal Filho et al., 2018; Mochizuki & Fadeeva, 2010). Where African studies exist, they tend to emphasise environmental awareness or curriculum policy, while the lived experiences of in-service teachers in integrating sustainability into classroom practice remain underexplored (Shumba & Kampamba, 2019). This gap is particularly significant because teachers in African contexts often work under conditions of resource scarcity, rigid curricula, and systemic inequities that shape the feasibility of pedagogical innovation (Lotz-Sisitka, 2017). Understanding how in-service teachers negotiate these challenges while engaging with ESD competencies is therefore essential for developing strategies that are contextually relevant and sustainable.

Within South Africa, agricultural education has historically been shaped by tensions between production-oriented goals and broader developmental imperatives. Policies such as the Curriculum and Assessment Policy Statement (CAPS) emphasise agriculture's role in food security, employment, and rural development, yet classroom implementation often falls short of preparing learners for sustainability challenges (Department of Basic Education, 2011). Teachers themselves frequently report difficulties in integrating cross-cutting issues such as sustainability into existing curricula, citing lack of training, inadequate resources, and competing policy demands (Leal Filho et al., 2018; Lotz-Sisitka, 2017). Professional development interventions that explicitly engage teachers with ESD frameworks can therefore play a critical role in bridging this gap between curriculum aspirations and classroom realities.

This study responds to that need by examining how in-service agricultural teachers' competencies changed after an ESD-infused intervention. Using the Pentagon model of pedagogical content knowledge (Park & Oliver, 2008) as an analytical framework, the study explores shifts in teachers' conceptual understandings, pedagogical reasoning, and classroom practices. It highlights movement from fragmented and one-dimensional conceptions of sustainability toward integrated, future-oriented, and action-oriented perspectives that align with international discourses on sustainability education.

The significance of the research lies in its dual contribution. Practically, it demonstrates how structured interventions can enhance in-service agricultural teachers' ability to integrate sustainability into everyday teaching, with potential ripple effects for learners and communities. Scholarly, it contributes to the limited body of empirical research on ESD in Sub-Saharan Africa,

offering insights into how professional interventions can reshape teacher competencies in under-resourced and high-need contexts (Lotz-Sisitka, 2017; Shumba & Kampamba, 2019). In this way, the study addresses both a national priority in South Africa and a global knowledge gap in sustainability education.

Guided by this framing, the study addresses the following research questions. First, what were in-service agricultural teachers' initial conceptions of sustainability and Education for Sustainable Development prior to the intervention? Second, how did participation in the ESD-infused program influence their competencies to apply sustainable practices in teaching? Third, in what ways did their post-intervention reflections demonstrate changes in pedagogical reasoning and classroom practice, particularly with reference to systems thinking, anticipatory competence, and action competence? Finally, what implications do these shifts hold for supporting in-service agricultural teachers as agents of sustainability in both their schools and broader agricultural communities?

LIERATURE REVIEW

Agricultural Science Teachers' Knowledge and Support of Sustainable Development

The integration of sustainable development (SD) and Education for Sustainable Development (ESD) has become central to both global and local education agendas. In 2015, the United Nations adopted the 17 Sustainable Development Goals (SDGs) as a blueprint for promoting sustainable living. SDG 4 highlights the role of education in equipping learners with the knowledge and skills to foster sustainable development, while SDG 2 emphasises food security and sustainable agriculture (Barakat et al., 2016). ESD operationalises these goals by addressing the environmental, social, and economic dimensions of sustainability and embedding them in education systems (OECD, 2008; UNESCO, 2017). In South Africa, in-service agricultural science teachers are critical to achieving these objectives because their pedagogical practices directly shape learners' ability to think critically, solve problems, and engage with agricultural sustainability challenges. Despite policy commitments, research suggests that many in-service teachers face challenges in implementing ESD-oriented pedagogies. Their understandings of sustainable development are often fragmented, focusing narrowly on environmental protection while overlooking the interdependence of social and economic dimensions (Leal Filho et al., 2018; Sterling, 2010; Tilbury, 2011). This limited conceptualisation reduces teachers' capacity to adopt learner-centred and participatory pedagogies that cultivate systems thinking, collaboration, and problem-solving (Wals, 2015). In the South African context, the Curriculum and Assessment Policy Statement (CAPS) incorporate sustainability content, but its treatment of ESD is inconsistent and frequently superficial, leaving teachers with limited guidance on how to integrate sustainability into agricultural science classrooms (Department of Basic Education, 2011; Lotz-Sisitka, 2017). Strengthening the competencies of in-service agricultural teachers has therefore emerged as a key priority. Teachers require not only content knowledge about sustainability but also pedagogical content knowledge (PCK) that enables them to connect

sustainability concepts with practical agricultural tasks and real-life learner experiences (Baas & Tsotetsi, 2023; Mbhanyisi et al., 2025; Park & Oliver, 2008; Rieckmann, 2012). Without targeted professional development, many teachers default to lecture-based instruction, limiting learners' opportunities to engage actively with sustainability challenges (Shumba & Kampamba, 2019). This is especially problematic in agricultural education, where issues such as soil degradation, water scarcity, biodiversity loss, and climate variability require systemic, action-oriented, and future-focused learning approaches (Barth & Rieckmann, 2012; Wals, 2015).

Collaborative approaches offer promising avenues for overcoming these challenges. Partnerships between teachers, agricultural extension officers, farmers, and community gardeners create opportunities for shared expertise, practical demonstrations, and contextually relevant teaching (Dyg, 2014). Such collaborations strengthen teachers' confidence in applying ESD principles and help bridge the gap between theoretical sustainability concepts and real-world agricultural practices. Examples include school gardens, farmer–teacher partnerships, and project-based learning where learners experiment with drought-resilient crops or sustainable livestock practices. These partnerships not only enhance classroom practice but also contribute to wider community sustainability goals.

Capacity-building initiatives must also go beyond raising awareness of sustainability to explicitly embedding ESD competencies into agricultural curricula. Research highlights the importance of integrating systems thinking, anticipatory competence, and normative reasoning into teacher development to prepare learners for complex socio-ecological challenges (Rieckmann, 2012; Rundgren & Yamada, 2023). UNESCO (2017, 2018) emphasises that effective ESD integration requires alignment across content, pedagogy, context, and leadership. However, implementation in South Africa often depends heavily on individual teachers' discretion, resulting in uneven application and limited systemic change (Lotz-Sisitka, 2017; UNESCO, 2017). Persistent barriers further constrain in-service teachers' ability to integrate ESD into agricultural science. These include insufficient professional development opportunities, lack of consensus among stakeholders on sustainability priorities, limited coverage of ESD content in training, and shortages of teachers with specialised expertise in sustainability (Anapey, 2024; Goller & Markert, 2024). Despite generally positive attitudes toward sustainability, many teachers lack the depth of conceptual knowledge and pedagogical strategies required for effective integration (Shumba & Kampamba, 2019). Addressing these barriers requires sustained investment in teacher professional development, with deliberate strategies for linking theory to practice, promoting collaboration, and equipping teachers with practical pedagogical tools.

Integrating ESD into agricultural science education is therefore not simply a policy aspiration but a pedagogical necessity. Empowering agricultural science teachers with the competencies to enact sustainability in their classrooms holds the potential to transform agricultural education, equipping learners with the knowledge, skills, and values needed to navigate complex environmental and socio-economic challenges. Through deliberate and

systemic capacity-building, teachers can become key agents of sustainability and contribute directly to broader societal transformation.

Conceptual Framework

Education for Sustainable Development (ESD) equips teachers with the knowledge, skills, values, and attitudes required to address complex environmental, social, and economic challenges (UNESCO, 2018). In South Africa's agricultural sector, learners face pressing issues such as climate change, land degradation, water scarcity, and food insecurity (Nhamo et al., 2021). In-service agricultural teachers are central to addressing these challenges because their pedagogical practices shape learners' ability to critically analyse agricultural issues, develop practical skills, and implement sustainable farming practices. Professional development interventions that embed ESD principles can therefore play a transformative role in enhancing teacher capacity for sustainability-oriented futures (Wilhelm et al., 2019). Building on the UNESCO ESD 2030 Competency Framework, this study adopts a set of competencies as evaluative benchmarks for teacher capacity. These competencies ensure that sustainability knowledge is translated into meaningful classroom practice and community engagement. As outlined in Table 1, they include systems thinking, anticipatory competence, normative competence, strategic competence, collaboration and participation, critical reflection, and action and implementation (Barth & Rieckmann, 2012; UNESCO, 2017; Wals, 2015).

Table 1.

ESD Competencies for Teacher Capacity Building

Teacher Characteristics	**Key Indicators**
Systems Thinking	Recognising interconnections among environmental, social, and economic systems
Anticipatory Competence	Envisioning future scenarios and designing strategies for sustainable outcomes
Normative Competence	Applying ethical principles and sustainability values
Strategic Competence	Translating sustainability knowledge into practical classroom actions and projects
Collaboration & Participation	Engaging learners, colleagues, and community stakeholders in sustainability initiatives
Critical Thinking & Reflection	Analyzing complex sustainability challenges and reflecting on teaching practices
Action & Implementation	Designing learning activities that promote practical, sustainable practices

Research demonstrates positive outcomes from embedding ESD competencies in teacher professional development. For instance, Mkomwa et al. (2022) documented the value of conservation-based teaching approaches, while Mula and Tilbury (2023) found that

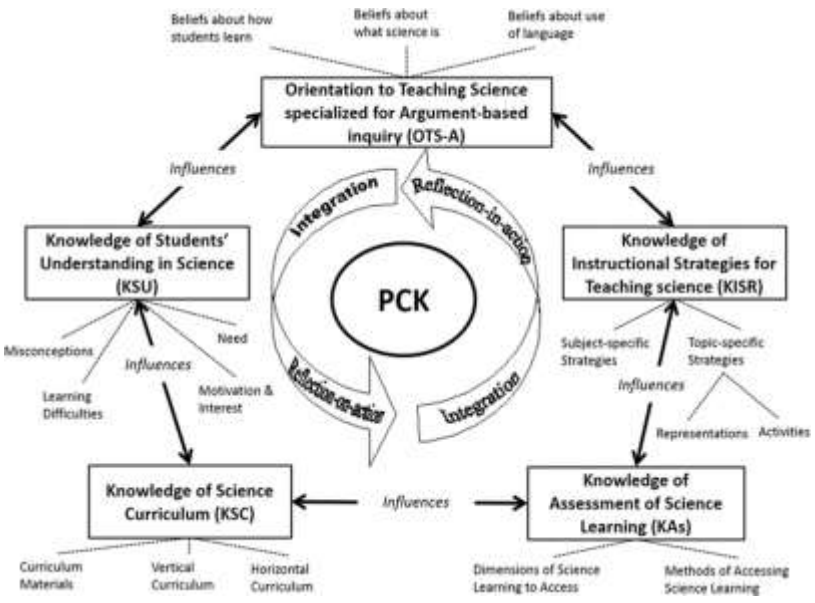
sustainability integration improved in-service teacher programmes. Kamali and Javahery (2025) emphasised reflective practice, participatory methods, and local adaptation as critical to effectiveness. Yet challenges remain, including limited policy support, resource constraints, and insufficient training (Islam, 2024). In South Africa, although the Curriculum and Assessment Policy Statement (CAPS) recognises sustainability, integration is often superficial and dependent on individual teachers' discretion, resulting in inconsistent practice (Department of Basic Education, 2011; Lotz-Sisitka, 2017).

Pedagogical Content Knowledge (PCK)

Pedagogical Content Knowledge (PCK), conceptualised by Shulman (1986), refers to the integration of subject content, pedagogical strategies, and contextual understanding to improve learner outcomes. Within agricultural science, PCK is essential for breaking down complex sustainability topics into accessible learning, employing learner-centred approaches, and designing assessments that foster practical competencies in areas such as soil and water management, crop production, and livestock practices (Lekhu, 2023; Rehman et al., 2023; Yameogo et al., 2024). PCK thus provides the bridge between abstract sustainability concepts and real-world agricultural applications.

Figure 1.

Pentagon model of PCK for teaching science (Park & Oliver, 2008) Integrated Conceptual Framework



Park and Oliver's (2008) Pentagon model of PCK (see Figure 1) provides a structured lens for examining teacher practice. It highlights content knowledge, instructional strategies, learner understanding, assessment, and curriculum knowledge as interrelated domains. Applying this model to agricultural education reveals how teachers can integrate sustainability concepts into

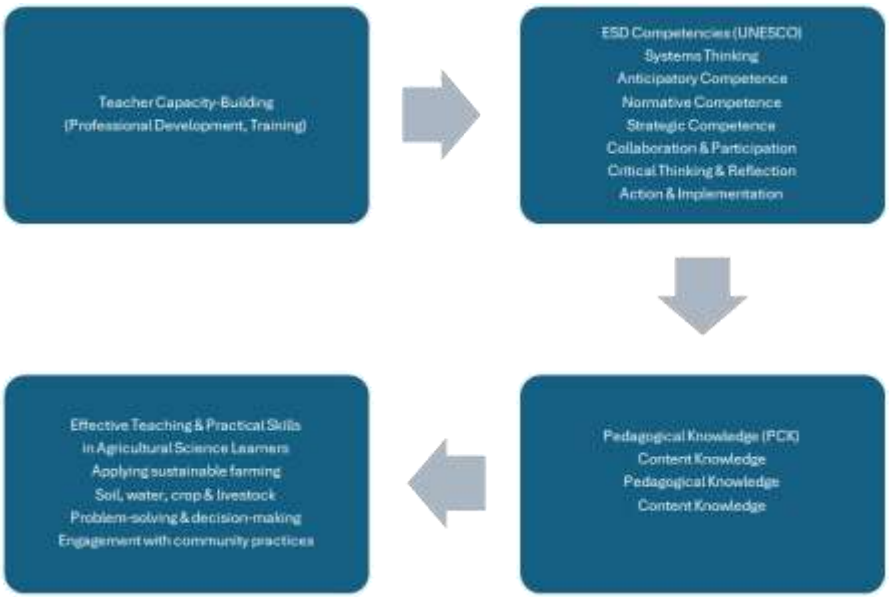
coherent pedagogical approaches that promote critical thinking, systems reasoning, and practical competence.

Embedding ESD competencies in teacher development is essential, but their impact depends on effective classroom enactment. This requires not only conceptual understanding of sustainability but also the ability to integrate it within subject-specific contexts. In agricultural education, this integration is mediated by PCK, which combines disciplinary content, pedagogy, and contextual insight. Examining PCK therefore offers a critical lens for understanding how sustainability principles can be implemented from policy to practice through coherent, learner-centered approaches.

While ESD competencies address the what of sustainability knowledge, values, and action-oriented skills, PCK focuses on the how of enacting these in classrooms. Integrating the two frameworks allows for a more holistic evaluation of teacher capacity: ESD competencies provide the evaluative lens for sustainability-oriented content and values, while PCK ensures these are translated into practical pedagogical strategies (Barth & Rieckmann, 2012; Wals, 2015). This integration is visualised in Figure 2 and operationalised in Table 2, where the two perspectives are combined to assess both knowledge and pedagogical application.

Figure 2.

Integrated Conceptual Framework of ESD Competencies and PCK in Agricultural Science Teaching



This integrated conceptual framework guided both the design and evaluation of the professional development intervention. By combining the ESD and PCK perspectives, the study captured changes not only in teachers' sustainability knowledge and values but also in their pedagogical reasoning and classroom practice. This dual lens ensures that professional development addresses both awareness and practical skill development with the key for empowering in-service agricultural teachers as agents of sustainability in South African education.

Table 2.

ESD merged PCK

Framework Component	Description
Teacher Capacity-Building	Professional development interventions enhance teachers' knowledge, skills, and attitudes for Education for Sustainable Development (ESD).
ESD Competencies	Teachers' awareness and understanding of sustainability principles are developed and assessed through the UNESCO 2030 framework.
Pedagogical Content Knowledge (PCK)	Evaluates teachers' ability to contextualize content, employ effective pedagogies, and facilitate practical learning experiences.
Learner Outcomes	Integration of ESD and PCK enables learners to acquire knowledge, skills, and attitudes necessary for sustainable agriculture, as well as develop critical thinking and problem-solving abilities.

METHODOLOGY

This qualitative study was grounded in the interpretivist paradigm, which seeks to understand participants' experiences and meanings within their specific contexts (Burns et al., 2022). The research was conducted in the Free State province of South Africa, across the Motheo and Lejweleputswa districts. A total of 30 in-service agricultural science teachers participated in the study. All 30 completed pre- and post-intervention instruments, while purposive sub-samples of eight teachers participated in focus group discussions, and five teachers were observed in classroom sessions to provide deeper insight into pedagogical reasoning and practice.

Table 3.

Demographic Profile of Participating Agricultural Science Teachers (N = 30)

Characteristic	Category
District	Motheo
Gender	Male
Age Range	20–30 years
Professional Seniority	0–5 years
Sub-Sample Participation	Focus Group Discussion
	Classroom Observations

Intervention Design

To support the integration of Education for Sustainable Development (ESD) into agricultural science teaching, a team of six teacher educators specialising in agricultural education, science education, environmental education, curriculum development, and research methodologies

collaboratively designed and implemented a professional development intervention. The educators had varying levels of prior exposure to ESD, with some newly introduced to its principles and others bringing previous experience. Their collective aim was to enhance teachers' awareness and knowledge of ESD, thereby strengthening their capacity to promote sustainability in secondary school agricultural education. Each teacher educator selected one of their courses and incorporated modifications such as new teaching materials, activities, assignments, and assessments that infused ESD skills, issues, perspectives, and values into classroom practice. These ESD-infused courses formed the professional development intervention experienced by the participating teachers. Table 3 summarises the activities, adapted from Roofe et al. (2021).

Table 4.

ESD Infusion Activities

Course	Infusion Activities
Changing Cultures, Changing Schools	Discussion of teachers' views on ESD (Week 1); Examination of agriculture in South Africa from commercial and emerging farmer perspectives (Week 8); Mini lecture and video presentation on ESD and "sustainability schools" (Week 10)
Environmental Education	Exploration of environmental education in agricultural sciences (Week 1); Video and discussion on local-to-global ESD imperatives (Week 3); Weekly in-class discussions on climate change, soil suitability, and hazardous waste; Guest presenters from the Department of Agriculture (Weeks 4 & 7); Completion of an action project with ESD focus as course assessment
Fundamentals of Data Analysis	Sensitization to research activity (Week 1); Guest lecture on ESD concepts (Week 3); Reading and summarizing at least three journal articles on ESD (Weeks 2–13); Mini project collecting teachers' views on ESD (Weeks 3–13); Two-page reflection on ESD infusion
History of Science and Science Teaching	Reflection on previous activities (Week 1); Presentation and discussion on sustainability, educational challenges, and ESD implications for scientific literacy (Week 4); Ongoing integration of ESD concepts throughout the course

Data Collection Procedures

At the beginning of the semester, the research team introduced the project to participating teachers, outlining its objectives, significance, and methodological procedures. Participation was voluntary, and informed consent was obtained from all participants. To evaluate the impact of the intervention, a purpose-designed instrument was administered to all 30 teachers at both the pre- and post-intervention stages. The instrument was aligned with UNESCO's ESD competencies and the Pentagon PCK model to capture changes across four key constructs:

sustainable development (SD), education for sustainable development (ESD), teachers' roles in promoting ESD, and ESD-related actions expected of teachers. It included demographic questions and a diagrammatic task, where teachers represented each construct as a circle and explained the relationships between them. This enabled systematic comparison of teachers' conceptions before and after the intervention. Triangulation was achieved through two additional qualitative methods. First, lesson observations were conducted with a sub-sample of five in-service teachers before and after the intervention to explore changes in classroom practices and the application of ESD principles (Cohen et al., 2018). Second, focus group discussions with eight in-service teachers examined their perceptions, experiences, and reflections on how the intervention influenced pedagogical reasoning and practice (Ahmed & Akyıldız, 2021). This combination of instruments, observations, and focus groups provided both breadth (all 30 participants) and depth (sub-sample insights), generating a rich understanding of how teachers interpreted and enacted ESD in classroom settings.

Data Analysis

Completed instruments were collected by a research assistant and stored securely. Responses were transcribed into Microsoft Word for initial coding. A preliminary set of codes and categories was developed and refined through iterative thematic analysis. Three researchers collaboratively analysed the data over six sessions to generate initial assertions, which were then reviewed by the other three researchers serving as peer reviewers. This process of independent coding, collaborative discussion, and peer validation enhanced trustworthiness, credibility, and rigour (Nowell et al., 2017).

Trustworthiness, Validity, and Reliability

To ensure the rigor of the findings, the study employed several measures aligned with qualitative standards for trustworthiness, specifically focusing on credibility, dependability, and confirmability.

Credibility through Triangulation: The study utilized methodological triangulation by combining data from pre- and post-intervention instruments, classroom observations, and focus group discussions. This allowed the researchers to cross-verify teachers' self-reported reflections with their actual classroom practices. Furthermore, the intervention and instruments were collaboratively designed by a team of six experts in agricultural, science, and environmental education to ensure content validity.

Peer Validation and Collaborative Analysis: Reliability was addressed through a robust peer review process. Three researchers performed the primary iterative thematic analysis, while the remaining three researchers acted as peer reviewers to validate the emerging codes and categories. This independent coding and subsequent collaborative discussion reduced individual bias and enhanced the rigor of the findings.

Dependability and Confirmability: All participant responses were transcribed verbatim and stored securely to maintain an audit trail. The use of the established Pentagon model of PCK

and the UNESCO 2030 Competency Framework provided a theoretical anchor, ensuring that the findings were grounded in the data and existing scholarly frameworks rather than researcher conjecture.

Transferability: While the study focuses on the Free State province, detailed descriptions of the participants, the South African educational context, and the intervention design are provided to allow other researchers to assess the relevance of the findings to similar under-resourced or high-need agricultural contexts.

RESULTS AND FINDINGS

Baseline Practices and Beliefs about Teaching Agriculture (pre-infusion)

Before the ESD intervention, eight agricultural teachers indicated that the concept of Education for Sustainable Development competencies (ESD) represented largely new knowledge, suggesting limited prior understanding. Teachers are familiar with the ESD framework, primarily associated it with four discrete themes: natural environment, environmental protection, social equity, and national development. Practical teaching of agriculture was sporadic and largely theoretical, reflecting gaps in Pedagogical Content Knowledge (PCK), particularly in instructional strategies, learner knowledge, and curriculum integration. The participants are represented by the letter (P).

Ecological sustainability

Teachers who focused on the natural environment emphasized replenishment and protection of agricultural and natural resources through measures such as reforestation and eco-friendly technologies. For example, participants stated:

"[P3] is about restoring and maintaining resources that have been depleted." Others noted:

"[P1] is the process of developing technological tools and skills that are environmentally friendly," and "Replant trees (reforestation) to sustain habitats, prevent air pollution, and provide food for all."

Although these responses focused primarily on one dimension, the natural environment is crucial as it supports the life cycles and resources necessary for both human and non-human species.

Sustainable ecosystem

From the teachers' perspective, environmental protection involved using resources for agricultural and societal development while ensuring their sustainability. Participants commented:

"[P5] is the way people use resources to carry out activities without depleting them."

Others reflected: *"[P2] Developments should not deplete present resources but instead preserve and maintain them" and "Resources should be used in a way that ensures future generations also benefit."*

These responses indicate that teachers were aware of the importance of protecting the environment to maintain resources, implicitly recognizing the intergenerational responsibility inherent in sustainable development.

Social Equity

Teachers also associated Education Sustainable Development (ESD) with social equity, emphasizing inclusive education and social and economic fairness through policy and practice. Participants stated:

"*[P4] Ensuring inclusive, equitable, quality education" and "Developing policies that incorporate everyone in society to enable productive contributions to the economy*."

For these teachers, the focus was on social inclusion, ensuring that all individuals can participate in productive agricultural and societal activities through policy development and implementation. This aligns with the notion that quality education is a prerequisite for enabling individuals to contribute meaningfully to society and the economy. Through emphasizing inclusive opportunities, teachers recognized the role of education in promoting equity and preparing learners to engage as active, responsible members of both local and broader agricultural communities.

National Development and Agricultural Capacity Building

Some agricultural teachers associated Education Sustainable Development (ESD) with national development, emphasizing the institutional responsibility to strengthen agricultural systems and human resource capacity. Their perspectives reflected the ESD competencies of Strategic Competence, Systems Thinking, and Action & Implementation, highlighting the role of teachers in connecting sustainability knowledge to broader societal and economic outcomes.

Participants described ESD as *"[P3] the overarching effort to enhance national agricultural productivity through education, training, and skills development"* and *"[P7] a process that enables the country to achieve self-sufficiency in food production and resource management."*

Others framed it as *"[P1] investing in human capital by equipping individuals with the knowledge and skills necessary for sustainable farming practices"* and *"[P3] an educational approach that enables learners to organize agricultural resources efficiently, in ways that are both economically productive and environmentally responsible, thereby contributing to societal and global improvements."*

During the pre-infusion phase, teachers' conceptualizations of ESD were often discrete, with limited recognition of how agricultural, social, and environmental dimensions interconnect. This highlights an early gap in Systems Thinking and Strategic Competence, demonstrating the need for ESD-infused teacher development programs that explicitly integrate multiple dimensions of sustainability into agricultural education practice.

Shifts in Pedagogical Reasoning and Classroom Practices (Post infusion)

Teacher educators reassessed agricultural teachers' understanding of Education for Sustainable Development (ESD) at the end of the semester following the ESD infusion. This is referred to as the post-infusion phase. At this stage, only one teacher indicated:

"[P3] Limited familiarity with ESD."

Overall, teachers' comments reflected a more integrated and complex understanding of sustainability concepts, highlighting connections between agricultural practices, environmental stewardship, and community well-being. Additionally, more responses demonstrated a future-oriented perspective, emphasizing the application of sustainable practices that benefit both current and future generations.

Integrated Conception of SD

post-infusion, agricultural teachers' narratives reflected a broader and more integrated understanding of Education for Sustainable Development (ESD) compared with Baseline Practices and Beliefs about Teaching Agriculture. Teachers highlighted ESD's social, economic, and environmental dimensions, as well as broader life aspects such as individual and community change, improved livelihoods, and poverty reduction. Participants commented:

"[P3] The focus of ESD is broader than just the environment; it's also about ensuring a strong, healthy, and just rural society." Another noted: *"[P4] Strategies include developing marketable skills so that community members are not dependent on government support, reducing poverty."* Others emphasized:

"[P2] People's mindsets and behaviors must change," and "Inclusion and creating equal opportunities are essential."

These post-infusion reflections illustrate a more holistic understanding of SD, demonstrating the interconnectedness of environmental, social, and economic dimensions. Recognizing these interdependencies is critical, as negative impacts in one area can undermine sustainability outcomes in the others.

Future-Oriented Conceptions of SD

Post-infusion, agricultural teachers demonstrated a more future-oriented perspective on Education for Sustainable Development (ESD), emphasizing the needs of generations beyond the present, through resource conservation and sustainable agricultural practices. Participants commented: "This is development that meets the needs of the environment, society, and economy without compromising future generations' ability to meet their needs." Another stated:

"[P3] It is about ensuring that decisions made today have a positive impact on future generations." Others highlighted: *"…conservation of available agricultural resources without limiting opportunities for future farmers."*

In contrast to pre-infusion themes, such as natural environment, environmental protection, social equity, and national development, which reflected disconnected, one-dimensional understandings, post-infusion responses revealed comprehensive, integrated, and forward-looking conceptions. These findings indicate that the ESD-infused intervention enhanced teachers' understanding of sustainability, promoting a holistic and future-oriented approach to agricultural education.

Education for Sustainable Development (ESD) – (Pre-Infusion)

Before the ESD infusion, seven agricultural teachers indicated that they "did not know or were unsure about the concept of ESD." After the infusion, no teacher reported such uncertainty, suggesting that the intervention positively influenced their understanding. Teachers who had some foundational knowledge of ESD emphasized facets such as individual development, civic responsibility, awareness of natural resources, and responsiveness to national and global agricultural development priorities.

Participants described ESD as *"[P5] a focus on self-development to achieve independence and a comfortable lifestyle", highlighting Anticipatory Competence."*

Others noted its role in "preparing citizens to identify, understand, and value sustainable agricultural development", reflecting Normative Competence and Collaboration & Participation. Some emphasized environmental stewardship: "Enlightening others to engage and participate in preserving natural resources in agriculture."

Additionally, teachers highlighted responsiveness to broader developmental imperatives:

"[P6] Strategies that educators need to implement to train individuals for the 21st century, ensuring they are innovative, skilled, and competitive in a global agricultural context."

Several teachers also discussed curriculum development, emphasizing the importance of embedding ESD into both formal and non-formal agricultural education programs. One participant stated it as

"[P2] aligning curriculum and training to meet the needs of emerging agricultural sectors in the country."

This aligns with Strategic Competence, demonstrating how teachers viewed ESD as a framework to integrate sustainability knowledge into actionable teaching and learning activities.

Education for Sustainable Development (ESD) – Post-Infusion

Following the ESD infusion, agricultural teachers' awareness and understanding of ESD were significantly improved, with their initial ideas broadened across various aspects. Teachers' focus on self-development expanded to

"[P2] Lifelong learning for present and future generations," reflecting Anticipatory Competence.

Their understanding of citizenship development became more explicit, emphasizing the acquisition of knowledge, skills, and attitudes needed to promote sustainable agricultural practices and community well-being. As one participant stated, ESD *"[P5] incorporates principles of sustainable development in lessons so that students can acquire the required knowledge and skills to advance sustainability in society."*

Teachers also recognized ESD as supporting the economic, environmental, and social dimensions of sustainability, with one noting:

"[P6] ESD allows individuals to make informed decisions and take responsible actions that promote economic viability, a peaceful society, and a healthy environment for present and future generations."

Beyond formal education, participants highlighted the importance of non-formal, community-based activities that reinforce lifelong learning and active engagement in sustainability.

Finally, teachers emphasized that ESD should respond to national and global imperatives through inclusive and equitable education. They advocated for a responsive curriculum facilitated via multidisciplinary approaches, integrating agriculture, social sciences, and natural sciences, delivered through both formal and informal means. This reflects Strategic Competence and Action & Implementation, illustrating teachers' enhanced capacity to integrate sustainability knowledge into practical, contextually relevant teaching and learning experiences.

DISCUSSIONS

The findings of this study illuminate a profound shift in agricultural teachers' knowledge, pedagogical reasoning, and professional identity following the infusion of Education for Sustainable Development. Prior to the intervention, teachers' understandings of sustainability were fragmented, reflecting what Tilbury (2011) has described as surface-level engagement, where attention is paid to individual sustainability themes but with little appreciation of their interconnectedness. Teachers often equated ESD with environmental protection or social fairness in isolation, and while these emphases revealed awareness of sustainability concerns, they lacked the systems perspective that is indispensable in agricultural education. This disjointedness is similar to the findings of Khoza et al. (2025), whose participants also reflected weaknesses in pedagogical content knowledge: although teachers could articulate ideas about protecting resources or promoting equity, they rarely translated these concepts into learner-centred practices, project-based activities, or context-sensitive assessments. The gap between theoretical awareness and practical enactment was evident in their limited ability to design sustainability-oriented agricultural tasks that could engage learners in critical thinking and real-world problem solving. In this sense, their baseline practices reflected knowledge possession without pedagogical reasoning, a phenomenon Park and Oliver (2008) argue undermines the transformative potential of subject matter knowledge.

The infusion of ESD catalysed significant changes, enabling teachers to move beyond isolated knowledge towards holistic, integrated, and future-oriented perspectives. Teachers began to articulate sustainability in terms of ecological stewardship, social inclusion, economic resilience, and national development, recognizing the interdependence of these domains. Importantly, they also embraced an intergenerational perspective, situating sustainability as a moral and ethical responsibility to future generations. Such reflections signal the development of anticipatory competence, which UNESCO positions as essential for preparing learners to navigate uncertain and complex futures. Teachers' emphasis on ensuring that agricultural

resources are conserved for the benefit of future farmers marked a shift from short-term pragmatic concerns to long-term ethical responsibility, deepening their pedagogical stance and aligning agricultural education with global sustainability imperatives.

A further dimension of this transformation was the emergence of action competence. Teachers no longer confined themselves to abstract discussions about sustainability but began to propose concrete strategies for embedding these principles into classroom and community practices. Project-based learning, reforestation initiatives, and participatory community projects were highlighted as avenues through which learners could both acquire knowledge and practice sustainability. This marked a transition from knowing about sustainability to knowing how to enact it. In the language of Barth and Rieckmann, this movement from declarative to procedural knowledge is central to bridging the persistent knowledge-action gap in sustainability education.

These shifts also illustrate how the infusion strengthened all dimensions of pedagogical content knowledge. Teachers broadened their content knowledge to include the ecological, social, and economic dimensions of sustainability; they demonstrated greater sensitivity to learner knowledge by recognizing the need for participatory and collaborative approaches; they diversified their instructional strategies through inquiry, demonstration, and problem-based learning; they acknowledged curriculum knowledge by highlighting the value of interdisciplinary approaches that link agriculture with the natural and social sciences; and they rethought their assessment practices to capture not only cognitive understanding but also values, skills, and dispositions necessary for sustainable living. Such integration illustrates how the infusion bridged the long-standing divide between subject knowledge and pedagogical enactment, positioning teachers to mediate sustainability in ways that are transformative rather than transmissive.

Perhaps most significantly, teachers' professional identities were reshaped. Prior to the intervention, they viewed themselves primarily as transmitters of agricultural knowledge or as facilitators of technical skills for production. Following the infusion, they began to perceive themselves as agents of change, entrusted with the responsibility of cultivating not only skilled farmers but also critically conscious citizens capable of advancing sustainability in their communities. These repositioning echoes critical emancipatory perspectives in education, which argue that teaching is inherently a moral and political act aimed at shaping more just and sustainable societies. Teachers' own reflections that ESD prepares learners "to acquire the required knowledge and skills to advance sustainability in society" underscore their recognition of this transformative role.

Nonetheless, these gains must be viewed with cautious optimism. The sustainability of teachers' new understandings depends heavily on ongoing professional development, institutional support, and systemic policy change. As Avalos has argued, professional learning is not a single event but a continuous process requiring reinforcement and contextual scaffolding. Without adequate support structures, teachers' newly developed competencies risk regression

under the pressures of rigid curricula, resource scarcity, and examination-driven teaching cultures. Furthermore, while teachers articulated ambitious visions of sustainability, their capacity to fully enact these ideas in under-resourced contexts remains a critical challenge. The findings, therefore, highlight the need for multi-level interventions that address not only teacher competencies but also the structural and institutional barriers that constrain pedagogical innovation.

CONCLUSION

This study has shown that the deliberate infusion of Education for Sustainable Development into agricultural teacher education can significantly transform teachers' understanding, pedagogical reasoning, and classroom practices. Teachers shifted from fragmented, one-dimensional views of sustainability to holistic, integrated, and future-oriented perspectives that link ecological stewardship, social equity, economic resilience, and national development. They also moved from theoretical awareness to action competence, embedding sustainability principles into concrete classroom and community practices. By engaging with the Pentagon model of pedagogical content knowledge, the findings reveal how ESD strengthens teachers' capacity to bridge content, pedagogy, learner engagement, curriculum knowledge, and assessment in ways that promote deeper learning and critical thinking.

The study underscores that when agricultural teachers are equipped with sustainability competencies, they are better positioned to act as change agents who not only impart agricultural knowledge but also nurture responsible citizens capable of addressing pressing global challenges. Yet the study also highlights that without sustained institutional support and systemic policy alignment, the transformative effects of ESD infusion may be difficult to sustain. The findings therefore, speak to the dual need for teacher empowerment and structural change, reminding us that sustainability education flourishes only when individual competence is supported by enabling environments.

Limitations of the Study

While this study provides significant insights into the transformation of teacher competencies, several limitations must be acknowledged. First, the research was geographically confined to the Motheo and Lejweleputswa districts within the Free State province of South Africa. Consequently, the findings may not be fully generalizable to teachers working in different provincial or socio-economic contexts. Second, while the study documented a profound shift in pedagogical reasoning and professional identity post-intervention, the long-term sustainability of these newly acquired competencies remains a challenge. As noted in the discussion, teachers continue to work under conditions of resource scarcity and within rigid curricula that may eventually hinder the practical enactment of ESD principles. Furthermore, the capacity of teachers to fully implement ambitious sustainability projects in under-resourced schools remains a critical hurdle that this single-semester intervention could not entirely overcome. Finally, while the dual lens of ESD and PCK allowed for a holistic evaluation, the reliance on self-

reported reflections in the post-infusion phase necessitates cautious optimism regarding the consistency of actual classroom practice over time.

Recommendations

The implications of this study point to several directions for practice and policy. Teacher education institutions must move beyond piecemeal interventions and systematically embed ESD principles across agricultural curricula, ensuring that sustainability becomes a foundational orientation rather than a peripheral topic. Professional development should be continuous, reflexive, and collaborative, providing teachers with spaces for dialogue, peer learning, and experimentation that consolidate their new competencies. Schools and ministries of education must also invest in the material and infrastructural resources, such as demonstration farms, laboratories, and appropriate technologies that enable teachers to translate sustainability concepts into practice. Curriculum policy should evolve to allow greater flexibility, encouraging interdisciplinary approaches and assessment systems that value critical thinking, systems reasoning, and participatory engagement as much as factual recall.

Finally, agricultural education should be firmly connected with community contexts, fostering partnerships that link classroom learning with local agricultural challenges and opportunities. By engaging learners in authentic projects that respond to real community needs, teachers can bridge the divide between theory and practice, nurture civic responsibility, and cultivate learners who view agriculture not only as a means of production but as a pathway to sustainability, equity, and resilience. These recommendations affirm that Education for Sustainable Development, when deliberately infused and institutionally supported, holds transformative potential for agricultural education and for society at large.

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