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Cultivating 21st century skills as graduate attributes among life sciences pre-service educators through fieldwork and investigations

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Abstract

This conceptual paper explores how fieldwork and investigative learning can develop 21st-century skills among Life Sciences pre-service educators through the integration of Indigenous Knowledge Systems (IKS) and Western science. It argues that effective science teacher education should extend beyond classroom instruction to include contextual, inquiry-based, and experiential learning experiences. Fieldwork and investigations provide opportunities for pre-service teachers to apply theory in real-life contexts and to engage actively with their environment. These approaches help to build essential skills such as critical thinking, collaboration, problem-solving, and environmental literacy. The paper highlights that learning in natural settings encourages curiosity and reflection while deepening understanding of scientific and cultural perspectives. It also proposes a conceptual model that positions Indigenous ecological knowledge alongside Western scientific methods. This model promotes a balanced and holistic understanding of science, where both systems of knowledge contribute to meaningful learning. By integrating these perspectives, the paper suggests that pre-service educators can adopt more sustainable, inclusive, and contextually relevant teaching practices suited to 21st-century classrooms.

Keywords: 21st century skills, Culturally responsive teaching, Experiential learning, Fieldwork, Life Sciences education, Pre-service teachers.

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1. Introduction

The 21st century calls for educators who are not only content experts but also critical thinkers, problem-solvers, and innovators [1]. In the Life Sciences, this expectation extends to the ability to connect scientific concepts with real-world environmental and social issues. Pre-service teacher education, therefore, must provide authentic learning experiences that

foster these competencies. Fieldwork and scientific investigations are central to this process, as they immerse student teachers in natural contexts that stimulate inquiry and reflection.

However, traditional Life sciences education often emphasizes Western epistemologies while marginalizing Indigenous Knowledge Systems [2, 3] which offer rich, place-based understandings of biodiversity, ecology, and sustainability. Integrating these two knowledge systems can create more inclusive, contextualized, and relevant learning experiences. This paper conceptualizes how fieldwork that involves investigative approaches in Life Sciences can cultivate 21st-century skills when Indigenous and Western scientific knowledge are integrated.

In South Africa, where diverse cultural epistemologies coexist, integrating Indigenous Knowledge Systems, particularly those rooted in Zulu ecological traditions into field-based learning is vital. Zulu knowledge emphasizes harmony with nature, respect for ancestral wisdom, and sustainable resource use. For example, Zulu communities observe animal migration, plant phenology, and celestial changes to predict seasons, practices aligning with Western ecological science. When pre-service educators engage with such local wisdom during fieldwork, they not only learn scientific concepts but also appreciate cultural relevance and sustainability, both crucial for 21st-century education.

2. Theoretical and Conceptual Framework

The paper is underpinned by constructivist and decolonial pedagogical frameworks. Constructivism emphasizes learning as an active process in which learners build knowledge through experience and reflection [4]. Fieldwork provides the setting for such construction, as pre-service educators engage with real-world problems and develop conceptual understanding through observation, hypothesis formation, and experimentation.

The decolonial lens, on the other hand, challenges the dominance of Western scientific paradigms and recognizes the epistemic value of Indigenous knowledge [5]. Indigenous worldviews view humans as interconnected with nature, emphasizing balance, respect, and sustainability. Integrating these perspectives within teacher education encourages epistemological pluralism and critical consciousness. Together, these frameworks support a pedagogy that nurtures both cognitive and socio-emotional dimensions of 21st-century learning.

3. Cultivating 21st-Century Skills through Fieldwork and Investigation

3.1. Critical Thinking and Problem-Solving

Field investigations require learners to observe, question, and interpret natural phenomena. This process mirrors scientific inquiry and promotes critical thinking. During field investigations, pre-service educators encounter real-world ecological issues that demand observation, data analysis, and reasoning. For instance, when studying water quality, they might compare scientific methods such as pH testing with Zulu traditional indicators, like the clarity of water where sacred plants such as *umhlonyane* grow. These Indigenous indicators reflect long-term ecological observations passed through generations. Engaging both knowledge systems allows pre-service educators to analyze phenomena critically and consider sustainability from multiple perspectives.

Example 1: Investigating climate change and traditional seasonal indicators in rural KwaZulu-Natal communities

Many rural Zulu communities rely on Indigenous ecological indicators to predict seasonal changes, such as rainfall and planting times. These include observing bird migration patterns, the flowering of certain plants, and the behavior of insects such as *izintethe* (locusts). However, with recent climate change effects of irregular rains, droughts, and shifts in seasonal timing, some of these indicators are becoming unreliable.

Pre-service Life Sciences educators can conduct field investigations in collaboration with local elders and farmers to compare traditional seasonal predictions with scientific climate data (temperature, rainfall, and soil moisture records). They might start by interviewing community members about Indigenous weather prediction methods. Collect and analyze local rainfall and temperature data from weather stations. Then, examine how changes in ecological indicators correspond to recorded climate changes. Critical thinking and problem-solving element comes in when student teachers evaluate the reliability of both traditional practices and scientific approaches and identify patterns. They can propose adaptive strategies for sustainable agricultural practices. For instance, they might suggest integrating Indigenous plant-based forecasting with modern meteorological tools (like rain gauges and digital weather maps). This requires analytical reasoning, data comparison, and contextual problem-solving, helping pre-service educators think critically about the intersection of culture, environment, and science education.

Example 2: Exploring water quality and natural water conservation practices in local communities

In many rural KwaZulu-Natal areas, communities depend on natural springs and rivers for domestic use. The Indigenous worldview considers water as sacred and prescribes spiritual and ecological practices for protecting it, such as avoiding pollution of sacred rivers and performing cleansing rituals. However, modern challenges, such as agricultural runoff and waste dumping are threatening these water sources. Pre-service educators can investigate water quality using both Western scientific methods and Indigenous ecological observations. They might collect water samples from community rivers or springs and test for pH and bacterial content. Observe aquatic organisms as biological indicators of ecosystem health. Engage with local elders to understand traditional conservation norms and rituals related to water purity. Critical thinking and problem-solving elements may be observed when the pre-service educators analyze differences between Indigenous perceptions of water purity and scientific findings. They then formulate strategies for water conservation that honor cultural values while applying scientific reasoning.

For example, they could design a community awareness project. Promoting safe water practices informed by both Indigenous respect for sacred sites and scientific understanding of contamination and prevention. This process strengthens

systems thinking, ethical reasoning, and evidence-based decision-making, core components of 21st-century critical thinking.

3.2. Collaboration and Communication

Fieldwork naturally promotes teamwork. Students need to be assisted in planning investigations, collecting data, and sharing interpretations collaboratively. Drawing from Zulu Indigenous traditions, knowledge transmission often occurs through *indaba* (communal discussions) and *storytelling*. For example, elders may recount how certain bird species signal rainfall or drought. Incorporating these oral traditions into science fieldwork not only enhances communication but also teaches respectful dialogue and collective reasoning. Pre-service educators thus learn to value participatory learning, a cornerstone of 21st-century collaboration.

Beyond this, fieldwork that involves community interaction strengthens interpersonal skills and deepens cultural understanding. When pre-service educators engage with local communities, they participate in reciprocal knowledge exchange where communication is not merely about transmitting information but also about listening and co-constructing meaning. Collaborative learning thus becomes a social process rooted in mutual respect, empathy, and collective inquiry.

Example 1: Biodiversity mapping through community-elder collaboration

In many parts of KwaZulu-Natal, Zulu elders possess rich ecological knowledge of local biodiversity, including the medicinal, nutritional, and cultural uses of indigenous plants such as *umhlonyane* (African wormwood), *ibhucu* (Aloe marlothii), and *umthombothi* (Spathodea campanulata). Pre-service Life Sciences educators can work collaboratively with community members to document and analyze local plant species within a particular area.

In this field-based project, student teachers form teams that include both peers and local knowledge holders. They conduct guided nature walks with elders to identify and classify native plant species. They record local names and ecological functions through interviews and storytelling sessions and compare these Indigenous classifications with scientific taxonomy from formal Life Sciences curricula.

This collaborative inquiry requires intercultural dialogue, active listening, and respectful communication as students engage with elders and peers to reconcile diverse forms of knowledge. Through *indaba* discussions, they practice participatory decision-making and learn how community-based learning fosters shared understanding. Furthermore, they translate Indigenous ecological narratives into formal scientific communication. This is to strengthen their ability to communicate complex ideas clearly across cultural and disciplinary boundaries, an essential 21st-century teaching competence.

Example 2: Investigating soil fertility using indigenous and scientific approaches

Many rural farmers sustain soil fertility through Indigenous methods such as using cow dung, ash, and composted organic matter, and by observing indicator plants that reflect soil health. Western scientific approaches complement these methods through empirical soil testing for pH, nitrogen, and mineral content.

Pre-service Life Sciences educators can engage in collaborative fieldwork by forming small teams to investigate soil fertility in local agricultural settings. Their tasks include gathering soil samples and conducting scientific analyses to determine nutrient levels. They also consult with community farmers about traditional soil assessment techniques, such as evaluating soil texture, color, and the presence of earthworms. The process is supported by group reflection sessions that allow participants to discuss the similarities and differences between Indigenous and scientific perspectives.

This investigation fosters collaborative teamwork, as each member contributes to data collection, interviewing, and analysis. It also enhances communication skills, as pre-service educators must engage respectfully with farmers and translate scientific findings into accessible language. They document Indigenous practices in culturally sensitive ways. By synthesizing these two knowledge systems, students learn to communicate effectively across social and epistemological boundaries, embodying the essence of Ubuntu, learning and working together for the collective good.

In both examples, collaboration and communication transcend academic teamwork. They become vehicles for cultural exchange, ethical engagement, and mutual learning. By integrating Indigenous dialogic traditions and Western scientific collaboration, pre-service educators cultivate the interpersonal, intercultural, and intellectual agility required to thrive as educators in the 21st century.

3.3. Creativity and Innovation

By engaging with diverse ecosystems and knowledge systems, student teachers learn to approach scientific problems creatively. Integrating Indigenous ecological technologies, such as sustainable water management, traditional agriculture, or herbal medicine, encourages innovative thinking grounded in local contexts. Creativity emerges from reimagining science not as a universal truth but as a dynamic and situated human endeavor.

Incorporating Indigenous and Western science during fieldwork inspires pre-service educators to think beyond conventional laboratory methods. It encourages them to explore how local traditions can inform sustainable innovation in Life Sciences. By recognizing that Indigenous technologies often embody centuries of experimentation and observation, pre-service educators learn to approach scientific challenges with curiosity, adaptability, and cultural sensitivity.

Example 1: Designing eco-friendly pest control using indigenous and scientific knowledge

In many rural KwaZulu-Natal communities, crop production is often threatened by pests such as locusts, beetles, and aphids. Traditionally, Zulu farmers have relied on natural repellents such as ashes combined with cow dung, to protect their crops. These Indigenous methods are environmentally safe and sustainable, in contrast to modern chemical pesticides that often harm soil health and biodiversity.

Pre-service Life Sciences educators can collaborate with community farmers to investigate the effectiveness of these traditional pest control methods alongside scientific techniques. They might prepare natural repellents like chili-garlic sprays or *umhlonyane* infusions, design controlled experiments to measure pest reduction, and compare results with crops treated using synthetic pesticides.

This study fosters creative problem-solving and critical thinking as student teachers explore ways to integrate Indigenous ecological wisdom with modern agricultural science. The outcome may be the development of hybrid, eco-friendly pest management solutions that are both scientifically validated and culturally relevant. Such activities promote innovation that is grounded in sustainability, community collaboration, and respect for Indigenous ingenuity.

Example 2: Developing sustainable water purification techniques through indigenous and scientific integration

In certain rural communities, access to clean water remains a pressing issue. Traditional purification techniques, such as filtering water through charcoal-sand, plant fibers and sedimentation in calabashes, reflect deep ecological understanding and sustainable engineering principles. Pre-service educators can conduct field-based investigations comparing these Indigenous purification methods with Western scientific water treatment processes. They might collect water samples from rivers or springs, apply Indigenous filtration systems (like charcoal-sand filters), and then test the water for pH and microbial content using laboratory instruments. Based on their findings, they can collaboratively design low-cost hybrid water purification systems that merge Indigenous practices with modern scientific efficiency.

This activity cultivates creative and critical inquiry by encouraging pre-service teachers to design innovative, culturally relevant solutions to real-world problems. It also demonstrates how Indigenous technologies embody sustainability principles, using locally available materials, reducing waste, and protecting ecosystems. By bridging ancestral wisdom with scientific innovation, student teachers experience science as a living, adaptive, and community-empowering practice.

In both examples, creativity arises through engagement with real environmental challenges that require combining Indigenous insight and scientific reasoning. By grounding innovation in local contexts, pre-service educators not only strengthen their scientific problem-solving abilities but also learn to view Indigenous ecological practices as sources of innovation. These experiences nurture open-minded, reflective, and inventive educators who can model creative inquiry for their future learners.

3.4. Environmental Literacy and Ethical Citizenship

Field-based learning helps pre-service educators develop ecological consciousness and moral responsibility toward the natural environment. In the Life Sciences, environmental literacy extends beyond knowing ecological concepts. It involves understanding human nature relationships, sustainable living, and ethical decision-making. Indigenous worldviews, particularly within Zulu culture, view nature as sacred and emphasize interconnectedness among all living beings. This belief, rooted in the principle of *Ubuntu* ("I am because we are"), encourages a collective sense of care for the environment and responsibility toward future generations.

Integrating these values into Life Sciences education deepens student teachers' understanding of environmental ethics while aligning scientific learning with social responsibility. By engaging in fieldwork activities informed by both Indigenous wisdom and scientific ecology, pre-service educators learn to make informed, ethical choices about conservation, sustainability, and biodiversity management.

Example 1: Forest conservation and sacred ecology practices

In many rural communities, certain forests and hills known to be sacred are protected as spiritual spaces where ancestors are believed to dwell. Cutting trees or hunting within these areas is traditionally forbidden, ensuring natural preservation and biodiversity conservation. These cultural taboos have functioned as informal but effective environmental management systems for generations.

3.4.1. Fieldwork Application

Pre-service Life Sciences educators can collaborate with local elders and community leaders to explore the ecological significance of sacred forests and compare them with nearby non-protected areas. As part of this investigation, they may document biodiversity differences between sacred and exploited sites. Conduct soil and vegetation surveys to assess the impact of human activity and record oral histories or spiritual narratives that explain why certain areas are protected. Through this process, student teachers gain a deeper appreciation of how Indigenous conservation practices contribute to biodiversity preservation and how these insights can enrich scientific understanding and environmental education.

3.4.2. Environmental Literacy and Ethical Citizenship Element

This study teaches pre-service educators that conservation can emerge from cultural respect and moral responsibility, not only from formal environmental policies. Through such investigations, student teachers critically examine how Indigenous protection systems align with Western conservation science. They develop ethical sensitivity, recognizing that sustainable environmental stewardship often stems from community values and spirituality as much as from scientific regulation.

Example 2: wetland restoration and indigenous water stewardship

Wetlands (*amahlathi amanzi*) are vital ecosystems that purify water, control floods, and support biodiversity. In Zulu ecological thought, wetlands are seen as living entities deserving respect. Traditional customs prohibit overgrazing or dumping waste in these areas, reflecting an intuitive understanding of ecological balance. Yet, modern agricultural and settlement practices have led to wetland degradation in many rural regions.

Pre-service Life Sciences educators can participate in wetland restoration projects that integrate Indigenous environmental ethics with scientific rehabilitation methods. Such activities may include mapping degraded wetland zones using simple field sketches and interviewing community members. Aiming to document traditional wetland uses and taboos that have guided sustainable resource management for generations. They can also implement practical restoration steps, such as planting native vegetation or constructing buffer zones to prevent erosion and water pollution. Furthermore, pre-service teachers can compare the effectiveness of traditional restrictions with modern conservation science in protecting water quality and soil stability. Thereby deepening their understanding of how Indigenous wisdom and scientific methods can complement each other in promoting ecological sustainability.

3.4.3. Environmental Literacy and Ethical Citizenship Element

Through this hands-on fieldwork, student teachers gain a deep appreciation for eco-spiritual ethics and environmental responsibility. They learn that Indigenous water stewardship principles, such as respect for sacred springs and communal water sources align with global sustainability goals. The integration of these systems cultivates pre-service educators who are ethically grounded, environmentally literate, and socially responsive, capable of guiding learners toward responsible ecological citizenship. Both examples illustrate how environmental literacy and ethical citizenship can be nurtured through fieldwork that bridges Indigenous and scientific ecological frameworks. By engaging with local communities, pre-service educators learn that protecting the environment is both a scientific and moral act, rooted in cultural wisdom and ecological awareness. Such integration empowers future Life Sciences teachers to promote sustainability not as an abstract concept, but as a lived practice grounded in both cultural heritage and contemporary science, a vital 21st-century skill for building resilient and ethical societies.

The following section builds on the conceptual flow of this paper and demonstrates how fieldwork and investigations can serve as powerful pedagogical tools to integrate Zulu Indigenous knowledge (IKS) and Western scientific epistemologies in Life Sciences education. It includes two detailed practical integration models and collaborative teaching strategies, aligned with 21st-century skills like critical thinking, collaboration, creativity, environmental literacy, and ethical citizenship.

4. Integrating Indigenous and Western Scientific Knowledge Systems

Integrating Indigenous Knowledge Systems (IKS) and Western science in Life Sciences teacher education offers a holistic approach to understanding the natural world. It promotes epistemological inclusivity, recognizing that multiple ways of knowing can coexist and complement each other. While Western science is often empirical, reductionist, and data-driven, according to Solberg Söilen [6] Indigenous knowledge is relational, holistic, and grounded in lived experience. Merging the two enhances not only content knowledge but also the pedagogical competence and cultural sensitivity of pre-service educators. This integration supports the development of 21st-century skills by encouraging pre-service teachers to think critically about the origins, validity, and purpose of knowledge. It also challenges them to create meaningful learning experiences that connect science to students' cultural and environmental realities.

4.1. Theoretical Foundations for Integration

The integration of Indigenous and Western science is supported by constructivist and socio-cultural theories of learning, which view knowledge as co-created through interaction, dialogue, and contextual experience [4]. According to Vygotskian perspectives, learning occurs within a social and cultural framework [7]. Therefore, valuing Indigenous perspectives affirms the learner's identity and promotes cognitive growth.

Similarly, the African philosophy of *Ubuntu* reinforces the idea that knowledge serves communal well-being rather than individual achievement. When Life Sciences pre-service educators engage with IKS through fieldwork and investigations, they bridge traditional ecological wisdom with modern scientific inquiry. Cultivating critical reflection, respect, and inclusivity in scientific reasoning.

4.2. Practical Integration Model 1

Indigenous weather forecasting and modern meteorology

Zulu communities have long used environmental indicators, such as the behavior of insects, bird migration patterns, flowering cycles, and wind direction, to predict rainfall and seasonal changes. For example, the early appearance of *amacimbi* (mopane worms), the blooming of certain trees or sparrows flying in the vicinity are seen as signs of approaching rain. These Indigenous forecasting methods are embedded in daily life and decision-making about planting or harvesting.

4.2.1. Fieldwork Application

Pre-service educators can conduct comparative investigations that document Indigenous weather forecasting methods and compare them with data from modern meteorological instruments and reports. They might:

- Record Indigenous observations shared by community elders.
- Collect daily temperature, humidity, and rainfall data using digital sensors.
- Analyze correlations between Indigenous indicators and meteorological outcomes.
- Facilitate reflective group discussions on how both systems interpret natural patterns.

4.2.2. Integration Outcome

This investigation demonstrates that Indigenous knowledge is evidence-based and experiential, though encoded in cultural metaphors rather than numeric data. Through such field-based comparative learning, pre-service teachers enhance their critical thinking and scientific literacy, recognizing that both knowledge systems offer valuable insights. The experience promotes collaborative dialogue, respect for local wisdom, and the ability to teach Life Sciences in ways that affirm learners' cultural identities while maintaining scientific rigor.

4.3. Practical Integration Model 2

Indigenous soil fertility practices and modern agricultural science

Traditional Zulu farming practices demonstrate a deep understanding of soil health and nutrient cycles. Farmers have historically used ash, animal manure, composted organic waste, and intercropping techniques to maintain soil fertility. These practices promote biodiversity and sustainable production, aligning with modern principles of organic agriculture.

4.3.1. Fieldwork Application

Pre-service Life Sciences educators can design and conduct soil fertility investigations that compare traditional and modern soil management strategies. Such activities may involve visiting rural homesteads to document Indigenous composting and crop rotation methods that have sustained agricultural productivity over generations. They can collect soil samples from both traditionally and chemically managed fields and test for soil pH, nitrogen, phosphorus, and organic carbon content using laboratory tools. Additionally, discussions with local farmers and agricultural scientists can help pre-service teachers evaluate the long-term ecological impacts of each method. This deepens their understanding of how Indigenous and scientific practices can be integrated to promote sustainable agriculture and environmental stewardship.

4.3.2. Integration Outcome

This practical model shows that traditional soil enrichment techniques embody scientific logic, even if expressed through non-Western epistemologies. Pre-service teachers learn to appreciate that Indigenous methods are grounded in observational evidence and ecological balance. The comparative analysis cultivates creativity and problem-solving, encouraging educators to design hybrid sustainable farming models that draw from both Indigenous and scientific systems.

By linking cultural heritage to modern ecological science, pre-service educators are empowered to promote environmental ethics, intercultural competence, and community-based innovation in their teaching practice.

4.4. Collaborative Teaching Strategies for Integration

To successfully integrate Indigenous and Western scientific knowledge in Life Sciences education, the following pedagogical strategies are recommended:

4.4.1. Community-Linked Fieldwork

Life Sciences lecturers may partner with local elders, healers, and farmers as co-educators during students' investigations. This fosters intergenerational knowledge exchange and situates learning in real-world contexts.

4.4.2. Dialogical Teaching and Indaba Circles

Lecturers may also use *indaba*-style discussions to facilitate collaborative meaning-making. These communal dialogues promote respectful communication and allow diverse voices to shape scientific understanding.

4.4.3. Inquiry-Based Learning (IBL)

Encourage pre-service educators to formulate research questions that explore both Indigenous and scientific perspectives on a phenomenon, promoting critical inquiry and evidence-based reasoning.

4.4.4. Reflective Practice Journals

This practice requires students to keep journals documenting their observations, reflections, and shifts in perception during fieldwork. This deepens metacognition and ethical awareness in integrating knowledge systems.

4.4.5. Collaborative Curriculum Design

Involve pre-service teachers in developing Life Sciences lesson plans that align Indigenous knowledge with curriculum outcomes. This fosters curriculum innovation and culturally inclusive pedagogy.

The integration of Indigenous and Western scientific knowledge transforms Life Sciences education from a one-dimensional content-based subject into a multidimensional inquiry of culture, ecology, and ethics. Fieldwork becomes a site of reconciliation between different ways of knowing; where pre-service educators learn that science is not universal, but contextual and collaborative. Such integration cultivates reflective, innovative, and ethically grounded educators who can guide learners to see science as both a global and local human endeavor, anchored in respect for cultural diversity and environmental sustainability.

5. Proposed Conceptual Model

The integration of Indigenous and Western scientific knowledge in Life Sciences teacher education carries profound implications for curriculum design, pedagogy, and professional practice. In the 21st century, teacher education must

prepare pre-service educators to operate within pluralistic knowledge systems, fostering culturally responsive teaching and scientific literacy that resonate with local and global realities.

Fieldwork and investigative learning provide ideal platforms for such integration. They allow pre-service teachers to engage directly with the community, environment, and cultural traditions that shape learners' worldviews. By embedding Indigenous knowledge within practical, inquiry-based experiences, Life Sciences education becomes a transformative process that bridges cultural heritage and modern scientific reasoning.

5.1. Curriculum Relevance and Contextualization

A major implication for Life Sciences teacher education is the need to restructure the curriculum to reflect the plurality of knowledge systems. Traditional curricula often privilege Western scientific paradigms, marginalizing Indigenous ecological wisdom [2]. Incorporating Indigenous perspectives ensures contextual relevance, helping student teachers connect abstract scientific concepts to familiar community experiences. For example, when studying biodiversity, pre-service educators can explore local species classifications, traditional medicinal plant use, and conservation taboos within Zulu communities. These contextualized examples promote deeper conceptual understanding and foster cognitive linkages between classroom science and lived experience. Such a curriculum transformation positions Life Sciences as a culturally inclusive discipline, one that validates Indigenous ways of knowing while upholding the rigor of empirical science. This balance encourages pre-service teachers to become culturally competent and ethically conscious educators.

5.2. Pedagogical Innovation Through Field-Based Learning

Integrating fieldwork and community investigations into teacher preparation programs promotes experiential and inquiry-based pedagogy. When student teachers engage with natural ecosystems, local farmers, and traditional knowledge holders, they move from passive learning to active knowledge construction.

Fieldwork cultivates essential 21st-century teaching competencies among pre-service Life Sciences educators. It develops critical thinking through the evaluation of diverse claims of knowledge. Furthermore, it fosters creativity as student teachers design innovative experiments that merge Indigenous and scientific approaches. Collaboration and communication are strengthened as they work in groups and engage with community elders during indaba dialogues, while problem-solving skills are cultivated through addressing authentic environmental and social challenges. These field experiences also build teachers' confidence in delivering contextually relevant Life Sciences lessons. Enabling them to design learning activities that are both culturally meaningful and scientifically accurate.

5.3. Professional Development and Teacher Identity Formation

Exposure to Indigenous knowledge during teacher training reshapes professional identity by broadening educators' understanding of what it means to be a "scientist" and a "teacher." Pre-service educators learn to view science not merely as laboratory experimentation, but as a human enterprise shaped by culture, values, and ethics. Professional development programs should therefore include workshops co-facilitated by Indigenous knowledge holders and scientists and opportunities to co-design community-based science projects that promote sustainability and cultural preservation.

These initiatives foster a professional identity rooted in humility, inclusivity, and ethical responsibility. Aligning with the African philosophy of *Ubuntu*, that knowledge should serve the community and the environment.

5.4. Policy And Institutional Support

For the integration of IKS and Western science to succeed, policy frameworks and institutional structures must actively support this epistemological inclusivity. Teacher education institutions should:

a. Incorporate Indigenous knowledge explicitly within Life Sciences education modules and assessment criteria.
b. Develop partnerships with local communities and traditional leaders to sustain long-term fieldwork programs.
c. Provide funding for interdisciplinary projects that unite cultural studies, environmental science, and education.
d. Recognize Indigenous experts as legitimate co-educators within formal academic settings.

Such institutional commitment ensures that integration efforts are systematic, sustainable, and transformative.

5.5. Long-Term Impact on Learners and Communities

The ultimate implication of integrating Indigenous and Western knowledge systems lies in its transformative impact on future generations of learners. When Life Sciences teachers model intercultural respect and ethical environmental ownership, they empower learners to see science as relevant to their lives and communities.

This approach strengthens learners' cultural identity and self-esteem. It promotes sustainable practices rooted in local contexts, encourages scientific curiosity grounded in social responsibility, and builds bridges between schools, families, and communities. Thus, pre-service teachers trained in this integrated paradigm become agents of educational transformation, capable of nurturing scientifically informed, culturally grounded, and environmentally responsible citizens.

The cultivation of 21st-century skills in Life Sciences pre-service educators through fieldwork and Indigenous–Western knowledge integration represents a paradigm shift in teacher education. It moves beyond content mastery toward holistic, ethical, and community-centered science education. By embracing multiple epistemologies, pre-service educators not only become more effective teachers but also custodians of both cultural heritage and scientific innovation. This integrated approach ensures that Life Sciences education contributes meaningfully to sustainable development, social justice, and intercultural understanding in South Africa and beyond.

6. Implications for Teacher Education

Teacher education programmers should intentionally design fieldwork experiences that promote epistemic pluralism and 21st-century competencies. Partnerships with Indigenous communities and environmental organizations can enrich these experiences. Assessment strategies must value reflection, collaboration, and problem-solving rather than rote memorization. By bridging Indigenous wisdom and Western science, teacher educators can cultivate graduates capable of leading transformative science education for a sustainable future.

7. Conclusion

The cultivation of 21st-century skills as Life Sciences pre-service educators' graduate attributes requires a shift from traditional, content-driven instruction toward experiential, contextually grounded, and culturally inclusive pedagogies. Fieldwork and investigative learning provide an ideal foundation for this transformation. Offering pre-service teachers' opportunities to engage directly with local ecosystems, communities, and Indigenous knowledge holders.

By integrating Indigenous Knowledge Systems (IKS) with Western scientific approaches, teacher education programs nurture pre-service educators who are not only scientifically literate but also socially conscious, ethically grounded, and culturally responsive [8]. This epistemological integration reflects the understanding that science is not a universal, culture-free domain, but rather a living human enterprise shaped by place, history, and relationships.

Through the fusion of Zulu Indigenous ecological wisdom, including sustainable agriculture, water management, weather forecasting, and sacred conservation practices with empirical scientific inquiry, student teachers cultivate essential 21st-century competencies. These include:

- Critical thinking and problem-solving, developed through comparative investigations and contextual analysis.
- Collaboration and communication fostered through community partnerships, *indaba* dialogues, and shared interpretation of data.
- Creativity and innovation, emerging from the synthesis of traditional ecological technologies and modern scientific reasoning.
- Environmental literacy and ethical citizenship, grounded in the recognition of interconnectedness between humans and the natural world.

Such integration transforms pre-service educators into reflective practitioners capable of bridging cultural divides and reimagining science education as a tool for sustainability and social cohesion. It also empowers them to design curriculum-aligned, community-centered investigations that engage learners in both ancestral wisdom and contemporary science.

In this way, fieldwork becomes more than an academic exercise it becomes a pedagogical bridge between worlds of knowing. Life Sciences education thus evolves into a holistic process of learning *with* and *from* the environment, the community, and the cultural heritage that sustains it.

Ultimately, preparing pre-service Life Sciences educators through integrated fieldwork ensures that future classrooms will not only teach science but also embody the spirit of Ubuntu, where knowledge is shared, relationships are honored, and learning serves the collective good. This approach positions teacher education as a vital force for cultivating scientifically capable, ethically responsible, and culturally grounded citizens ready to face the challenges and possibilities of the 21st century.

8. Recommendations

Based on the conceptual analysis presented, the following recommendations are proposed to strengthen Life Sciences teacher education and ensure effective integration of Indigenous and Western scientific knowledge systems through fieldwork and investigations:

8.1. Curriculum Reform and Policy Alignment

Teacher education programs should integrate Indigenous ecological knowledge and practices explicitly into Life Sciences curricula, ensuring equal recognition alongside Western scientific content. Policy frameworks such as DHET [9] and Life sciences CAPS guidelines [10] should be revised to require context-based fieldwork modules that emphasize cultural relevance and environmental sustainability. Additionally, assessment criteria should be developed to value both empirical inquiry and community-based knowledge interpretation, thereby promoting balanced and inclusive approaches to scientific understanding.

8.2. Strengthening Fieldwork and Community Partnerships

It is essential to establish long-term collaborations between universities, traditional leaders, and local communities to co-design meaningful field investigations. Indigenous experts, healers, and elders should be involved as co-educators to facilitate *indaba* dialogues, share oral histories, and support the transmission of Indigenous knowledge. Furthermore, pre-service teachers should be encouraged to conduct community-action projects that address local ecological issues through scientific approaches that blend Indigenous wisdom with modern scientific methods.

8.3. Professional Development for Teacher Educators

Ongoing training should be provided for Life Sciences lecturers and mentors on how to integrate Indigenous Knowledge Systems (IKS) both pedagogically and epistemologically into teaching and supervision. Capacity-building workshops should be offered to enable teacher educators to engage with Indigenous science frameworks and develop

culturally responsive teaching materials. In addition, interdisciplinary collaboration between departments of education and environmental science should be promoted to strengthen the holistic integration of Indigenous and Western scientific knowledge in teacher education.

8.3.1. Research and Knowledge Production

Pre-service educators should be encouraged to conduct action research and case studies on Indigenous ecological practices to generate contextually relevant knowledge that informs teaching and learning. Universities should establish dedicated research units focused on the integration of Indigenous and Western scientific knowledge within STEM education. Furthermore, collaborative research with local knowledge holders should be published, ensuring appropriate acknowledgment, ethical engagement, and the protection of intellectual property rights.

8.3.2. Ethical and Inclusive Pedagogical Practice

Ethical guidelines for engaging with Indigenous communities should be embedded within teacher education programs, emphasizing respect, reciprocity, and informed consent. The use of *Ubuntu*-oriented pedagogy should be promoted, as it foregrounds relational learning, empathy, and collective responsibility in educational practice. Additionally, pre-service educators should be encouraged to adopt multilingual and multimodal teaching approaches that integrate storytelling, observation, and experimentation to create inclusive and culturally responsive learning environments.

8.3.3. Sustainability and Future Outlook

Teacher education institutions should organize annual community-based science field camps. In these camps, pre-service teachers can conduct ecological investigations that integrate Indigenous and Western scientific perspectives. Open-access resource repositories should also be developed to include Indigenous case studies, lesson plans, and digital archives of local biodiversity knowledge. This will ensure accessibility and encourage continuous learning. In addition, policy dialogues should be supported to place Indigenous knowledge integration at the center of efforts to achieve the Sustainable Development Goals (SDGs), especially those related to quality education and environmental ownership.

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