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Integrating a Culturally Responsive Pedagogical Tool in the Teaching of Photosynthesis in Life Sciences Curriculum

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ABSTRACT

This study explores the implementation of a culturally integrative photosynthesis lesson plan that intertwines scientific concepts of photosynthesis with Indigenous Knowledge Systems (IKS), particularly those related to plant-based vitality, traditional farming practices, and ecological reciprocity. It responds to the call for inclusive Life Sciences education that affirms and values diverse ways of knowing in classroom contexts. Grounded in a pragmatic paradigm, the study embraces educational approaches that are sensitive to real-world teaching environments. Employing an embedded mixed-methods research design, the study integrates quantitative data from pre- and post-assessments within a broader, qualitatively rich, and culturally situated framework. The qualitative dimension encompasses learner interviews and narrative contributions from Indigenous elders, providing layered, culturally grounded interpretations of scientific themes. Data was gathered from 25 Grade 11 Life Sciences learners at a secondary school in KwaZulu-Natal, selected through purposive sampling, along with insights from two community elders. Learner outcomes were analysed through both test scores (pre- and post-tests) and reflective narratives to evaluate conceptual grasp and cultural relevance. The research draws on the Theory of Ancestral Life Sciences (TALSc.) to inform the co-pedagogical design, facilitation, and analysis of the photosynthesis learning experience. Results indicate enhanced learner achievement, greater capacity to navigate and compare Indigenous and Western scientific paradigms, and an enriched sense of cultural identity and connection. Learners engaged more deeply when photosynthesis was taught through land-based experiences, Indigenous storytelling, and spiritual understandings of nature and sustenance. They exhibited improved academic outcomes and expressed a strengthened sense of belonging. This study supports Life Sciences curriculum transformation by advocating for the equitable inclusion of Indigenous Knowledge alongside Western science. It presents a culturally grounded infusion model for responsive science education and promotes collaborative engagement with Indigenous Knowledge holders. The paper offers a valuable framework for enacting culturally attuned Life Sciences pedagogy.

Keywords: IK Pedagogy, TALSc, Photosynthesis, Medicinal Plants, Ancestry, Spirituality, Ecology

INTRODUCTION

Life Sciences education as framed by the CAPS curriculum is currently grappling with the challenge of incorporating Indigenous knowledge systems and embracing epistemological diversity in classroom settings (Mavuru, 2025). The curriculum continues to privilege Western-centric scientific viewpoints, often neglecting culturally grounded epistemologies that offer deep-rooted knowledge systems capable of enriching learners' understanding of Life Sciences concepts (Sonkqayi, 2024). This study responds to this gap by designing a culturally rooted photosynthesis lesson plan that connects scientific understanding of plant energy production and ecological processes with Indigenous knowledge of medicinal plants, their growth cycles, spiritual significance, and environmental interdependence.

The study is anchored in the Theory of Ancestral Life Sciences (TALSc.) framework, which affirms the necessity of integrating diverse epistemologies in Life Sciences teaching and learning (Gugulethu, 2025). It seeks to harmonise scientific and cultural worldviews in the teaching of photosynthesis through a collaborative, mixed-methods approach that involves Western-trained scientists and Indigenous elders. The photosynthesis-integrated lesson plan, co-developed with traditional knowledge holders, was implemented at a secondary school in KwaZulu-Natal. This contextually grounded intervention aimed to enhance learner engagement, cultural relevance, and empirical insight into the connections between photosynthetic processes and traditional ecological knowledge of healing plants in Zulu culture.

This collaborative mixed-methods approach fosters a profound sense of belonging, cultural validation, and respect for Indigenous ecological wisdom among learners. Furthermore, it cultivates learners' critical capacity to evaluate both Indigenous and Eurocentric knowledge systems. Findings from the study advocate for a Life Sciences curriculum that positions these knowledge systems as co-equal contributors to content and pedagogy. By incorporating storytelling around traditional medicinal plants, ancestral teachings on plant energy, sunlight, and healing, and through land-based learning supported by community collaboration, this study offers a model for culturally responsive teaching in the Life Sciences within the broader STEM framework.

Within Zulu cultural traditions, medicinal plants are not solely valued for their curative properties but are revered as sacred entities that carry ancestral memory, spiritual power, and ecological wisdom. Plants such as imphepho, umhlonyane, and isibhaha are gathered with ritual care and used in ceremonies like imbeleko and ukuthwasa, where their photosynthetic vitality is metaphorically and spiritually linked to life, healing, and continuity. Through engagement with these practices, learners encountered photosynthesis not merely as a biochemical process, but as a cultural expression of intergenerational knowledge transmission. This culturally situated interpretation, rooted in Zulu Indigenous traditions, deepened learners' conceptual understanding of photosynthesis while affirming the role of cultural heritage in scientific education.

THEORETICAL FRAMEWORK

This study is grounded in the Theory of Ancestral Life Sciences (TALSc.) theoretical framework. It employed a TALSc. informed approach to design, implement, and refine a curriculum unit lesson that weaves together cultural and scientific worldviews of **photosynthesis**. The Theory of Ancestral Life Sciences (TALSc.), introduced by Gugulethu (2025), offers a transformative lens for integrating Indigenous epistemologies into Life Sciences education, bridging the divide between Western scientific knowledge and Indigenous ways of knowing. This framework is underpinned by three central principles.

The first TALSc. principle asserts that Indigenous Knowledge (IK) is transmitted intergenerationally, through family lineages and lived interaction with the natural environment. In this study, this principle was reflected through oral narratives shared by elders on the cultivation and ritual use of **medicinal plants** such as *umhlonyane*, *umnwele, isinuka, umhlonyane, icudwane, iboza, umphafa, iputumane, isiskhukhukhu* highlighting how knowledge of plant growth cycles and healing properties, linked directly to **photosynthesis**, has been preserved through experience, spirituality, and communal practice. In Zulu culture, knowledge about these medicinal plants is passed from elders (often *izinyanga*) to younger generations through storytelling, demonstration, and ritual practice. For instance, elders teach children when to harvest umhlonyane, usually early in the morning before the sun becomes too strong, to preserve its healing properties. This timing reflects ecological awareness rooted in observation of sunlight (linked to photosynthesis), dew patterns, and plant vitality. The act of *ukuhlwitha* (careful plucking) teaches respect for living things and reinforces that knowledge and nature are interdependent.

Traditional fire-making techniques, using friction between wooden sticks (e.g., *umhlanga* and *umsinsi* wood), reflect knowledge of energy transfer and transformation. Elders teach young people that the wood must be dry and come from specific trees found in certain soils, showing an understanding of matter, energy, and the environment. This process is not just physical but symbolic, used during rituals like *imbeleko* (infant introduction ceremony), connecting scientific and spiritual dimensions of Zulu life.

Agricultural Cycles and Lunar Knowledge (Ukulima Ngokwesiko LamaZulu), the traditional farming practices are deeply guided by ancestral and environmental clues. For example, maize and sorghum planting are timed with the phases of the moon (*inyanga*), and rainfall predictions are made by observing animal behaviour, wind direction, and plant flowering patterns. This ecological knowledge is shared intergenerationally through fieldwork, songs, and proverbs like "*ukuphanga umdaka*" which cautions against acting too quickly or impatiently before the right time, teaching respect for balance between humans and nature.

Cattle are central to Zulu identity and knowledge transmission. The selection of herbs used for the timing of rituals such as *ukushisa impepho* (burning incense) before slaughter, demonstrates ecological and biological knowledge intertwined with spirituality. Younger family members learn by observing, assisting, and listening, embodying intergenerational learning through lived experience. Traditional fire-making techniques, using friction between wooden sticks (e.g., *umhlanga* and *umsinsi* wood), reflect knowledge of energy transfer and transformation. Elders teach young people that the wood must be dry and come from specific trees found in certain soils, showing an understanding of matter, energy, and the environment. This process is not just physical but symbolic, used during rituals like *imbeleko* (infant introduction ceremony), connecting scientific and spiritual dimensions of Zulu life.

These examples demonstrate how Indigenous Knowledge is transmitted intergenerationally through lived experience, observation, and participation guided by elders. Knowledge about medicinal plants such as *umhlonyane*, traditional fire-making, agricultural practices, and cattle care is shared through storytelling, demonstration, and ritual, allowing younger generations to learn by doing. Through these practices, youth internalise ecological understanding, such as awareness of sunlight, seasons, and natural cycles alongside spiritual and ethical values that emphasise respect for nature. This holistic and experiential transfer ensures that Indigenous Knowledge remains dynamic, connecting scientific insight with ancestral wisdom and sustaining cultural identity across generations.

The second TALSc. principle recognises the flexibility and adaptable nature of Indigenous Knowledge, emphasising its responsiveness to ecological change. In this study, this principle is reflected through the continued use of medicinal plants such as *umsuzwane* (Lippia javanica) and *ikhathazo* (Hypoxis hemerocallidea) that reflects a deeply adaptive relationship with the environment. Elders and traditional healers have adjusted their harvesting and cultivation practices in response to changing rainfall patterns, soil depletion, and plant scarcity. In areas where certain species have become rare, communities have begun domesticating and cultivating these plants near their homesteads. This shift ensures continued access to healing resources while protecting endangered ecosystems. The flexibility seen here also demonstrates a practical understanding of photosynthetic activity, as healers observe leaf colour, aroma, and growth rate to determine the plant's vitality and healing potency. These sensory observations align with the scientific principle that photosynthesis drives plant energy and health. Which illustrate how traditional ecological knowledge remains responsive, practical, and scientifically grounded in changing environmental contexts.

Rituals involving medicinal and sacred plants in Zulu culture, such as *ukuthandazela imvula* (praying for the rain) or ritual cleansing with herbs, reveal the community's ability to adjust cultural practice according to ecological shifts. Historically, these rituals followed well-defined seasonal cycles, guided by ancestral knowledge of rainfall and plant availability. However, with the increasing unpredictability of weather patterns due to climate change, communities have begun observing new environmental indicators such as bird migrations, early blooming, or wind direction to guide ritual timing. This responsiveness shows an understanding that the plants' photosynthetic cycles and energy balance are affected by sunlight and seasonal variation. The Zulu people thus embody the principle that Indigenous Knowledge is dynamic and attuned to environmental change, ensuring that cultural continuity is maintained even as nature's rhythms shift.

Traditional Zulu agricultural knowledge also demonstrates remarkable flexibility and ecological sensitivity. Farming families have long relied on ancestral calendars for planting maize, sorghum, and beans, timed to coincide with the availability of sunlight and rainfall. Yet, as climate variability alters traditional seasons, many communities have adjusted planting times, adopted intercropping, and experimented with drought-resistant indigenous seeds. These adaptations ensure that photosynthetic conditions remain favourable for crop growth, while soil fertility and moisture are preserved. The saying *"ukulalela umhlaba"* (to listen to the land) captures this principle of ecological observation and respect. Through continued observation, dialogue, and experimentation, agricultural knowledge remains alive and adaptive, a testament to how IK evolves through lived experience rather than static instruction.

Flexibility is also visible in the preparation and preservation of medicinal plants. Traditionally, leaves, roots, and bark were sun-dried in open spaces. But with changing climate conditions including stronger sunlight and irregular rainfall, healers have adjusted by using shaded, ventilated areas or controlled solar drying methods to protect plant potency. These new approaches ensure that chlorophyll and essential oils, both products of photosynthesis, are not lost through overexposure and improper drying. The modification of these methods shows how Zulu healers respond to ecological realities without compromising cultural integrity. The practice illustrates that Indigenous Knowledge is neither rigid nor outdated. It continues to integrate environmental awareness and innovation to maintain both the medicinal and spiritual essence of healing plants.

Another example of adaptability lies in how Zulu communities modify ritual materials when traditional resources become scarce. When plants such as *impepho* (Helichrysum odoratissimum) or sacred woods once used in ancestral rituals are no longer easily available, substitutes with similar aromatic or energetic qualities are used. In some cases, symbolic representations replace physical materials, showing that the cultural and spiritual meaning of the ritual goes beyond the material form. This flexibility preserves cultural continuity while supporting environmental conservation. It also reflects an understanding that spiritual energy, like photosynthetic energy in plants, can transform and adjust to context. The ability to preserve meaning while adapting materials affirms that Indigenous Knowledge is both rooted and fluid, evolving in constant dialogue with the living environment.

Indigenous Knowledge reflects the second TALSc principle through its flexible and responsive nature to ecological change. The community's adaptive use of medicinal plants, shifting rituals, and evolving farming and preservation practices reveal a living system that harmonises ancestral wisdom with environmental realities. Grounded in an understanding of photosynthesis and ecological balance, this intergenerational knowledge remains dynamic and relevant, continually renewing the bond between people, nature, and spirituality.

Collectively, these examples show how Zulu Indigenous Knowledge embodies the second TALSc principle of flexibility and ecological responsiveness. Each adaptation carries an awareness of ecological processes such as photosynthesis, sunlight dependence, and environmental balance. This intergenerational adaptability keeps the knowledge relevant to both present ecological challenges and ancestral values, affirming that Indigenous Knowledge is not static heritage but an ever-evolving dialogue between humans, nature, and the spiritual world.

The third TALSc. principle foregrounds the relational learning involving the interconnectedness of ancestry, spirituality, and nature within the teaching of photosynthesis. This principle is observed through agricultural practices that reflect relational learning that integrates spirituality, ecology, and ancestral guidance. Farmers traditionally observe the position of the sun, phases of the moon, and patterns in plant growth to determine when to plant or harvest crops. These actions are often accompanied by rituals of thanksgiving to the ancestors, acknowledging their guidance in ensuring fertility and growth. In this study, such practices were linked to an understanding of photosynthesis as the process that sustains crops through sunlight and energy conversion, while also reinforcing that life depends on maintaining harmony between humans and the natural world.

Furthermore, the use of sacred spaces such as umsamo (ancestral altars) in the homestead represents an acknowledgment of the cyclical connection between life, death, and renewal of the same cycle that sustains plants and ecosystems. When family members place fresh leaves, herbs, or food offerings at the *umsamo*, they symbolically return to the earth what has been given by nature through sunlight and growth. This act reinforces the principle that humans are part of the natural energy flow that photosynthesis represents, making learning a spiritual, moral, and ecological experience all at once.

In essence, this study found that the third TALSc principle is embodied in Zulu cultural practices that link ancestral reverence, ecological observation, and the flow of solar energy within nature. Through activities such as harvesting medicinal plants, burning *impepho*, and planting according to ancestral and environmental cues, knowledge of photosynthesis was contextualised as both a scientific and sacred process. This relational approach to learning fosters a deeper ecological consciousness. Affirming that in Indigenous Knowledge Systems, to understand nature is also to honour one's ancestors and the divine life force that connects all existence.

This principle shaped the development of the photosynthesis-integrated lesson plan, which treated medicinal plants not only as biological organisms but also as sacred connectors between the community, the ancestors, and the land. TALSc. framework proposes a pedagogical framework that honours Indigenous Knowledge as co-equal with Eurocentric scientific paradigms, striving toward a more inclusive, equitable, and culturally responsive Life Sciences curriculum. By recognising these converging knowledge systems, TALSc. fosters a holistic and grounded understanding of scientific concepts such as photosynthesis**,** rooted in both community knowledge and ecological wisdom.

LITERATURE REVIEW

Indigenous Knowledge Systems and Science Education

Life Sciences scholars and educators globally have begun to interrogate the limitations of the Curriculum and Assessment Policy Statement (CAPS), which privileges Eurocentric scientific knowledge while marginalising culturally embedded ways of knowing (Chuene, 2024). This critique is especially pertinent in the teaching of **photosynthesis**, where the conventional curriculum often fails to connect with learners lived experiences and the ecological knowledge held in their communities. In response, there is a growing movement to integrate cultural practices as co-equal with Western science, affirming Indigenous Knowledge Systems (IKS) as legitimate and valuable epistemologies within the scientific domain.

In the context of **photosynthesis,** Indigenous knowledge related to the use and cultivation of **medicinal plants** offers not only practical insights into plant biology and ecological interdependence but also a holistic worldview that interlaces spirituality, ancestry, and environmental stewardship. According to Silvestru (2023), these perspectives enrich scientific inquiry by complementing the reductionist lens of Eurocentric science with relational, land-based knowledge, an approach this study seeks to prioritise. Although the revised Life Sciences CAPS in South Africa makes space for epistemological pluralism, including Indigenous perspectives, its actual implementation often lacks depth and specificity across different content areas (Jalilifar & Don, 2024). When the science curriculum limits **photosynthesis** to abstract chemical equations and lab-based exercises, disconnected from learners' cultural realities and the significance of plants in their communities, it denies them the opportunity to see their indigenous knowledge as valid science.

This study shows that using **medicinal plants** as a contextual anchor for teaching **photosynthesis** not only enhances conceptual understanding of plant energy production, chlorophyll function, and sunlight absorption, but also serves as a mechanism for curriculum decolonisation. In this way, learners are empowered to engage with science through a dual epistemic lens, recognising that Indigenous botanical wisdom is not an add-on but a foundational dimension for making science relevant, rooted, and transformative.

TALSc. Cultural Pedagogies on Ancestry, Spirituality, and Natural Environment

Studies such as the one conducted by Buthelezi and Gumbo (2025) have shown that embedding IKS, particularly those rooted in spirituality, storytelling, and environmental consciousness, into Life Sciences education can significantly increase learners' active participation and deepen their conceptual understanding. These findings are especially relevant when applied to the teaching of photosynthesis, which is often introduced through abstract chemical equations and physiological processes, disconnected from learners lived experiences. However, when photosynthesis is contextualised through cultural practices such as the ritual use and harvesting of medicinal plants, learners are offered meaningful cognitive and emotional entry points into scientific knowledge.

Within Zulu cultural heritage, medicinal plants are not only biological entities, but also sacred instruments of healing, connection, and transformation. The respectful gathering and preparation of plants such as *imphepho* and *umhlonyane* during ancestral ceremonies symbolise the unseen yet vital forces of nature. These processes, dependent on sunlight, water, and soil, mirror the biological process of photosynthesis, where plants absorb solar energy to create life-sustaining compounds. Through this lens, learners come to understand photosynthesis not as an abstract formula, but as a living process deeply embedded in the rhythms of land-based practices and intergenerational knowledge.

Moreover, cultural rituals involving medicinal plant use frequently include storytelling, ancestral invocation, and spiritual reflection, elements that conceptually align with scientific principles of energy flow, transformation, and ecological balance. For instance, the belief that certain plants "capture the sun" or "hold ancestral warmth" resonates with the idea of light energy being converted into chemical energy during photosynthesis. These metaphoric and spiritual parallels create fertile ground for learners to bridge Indigenous logic with scientific reasoning, fostering what the Theory of Ancestral Life Sciences (TALSc.) identifies as epistemological integration.

Thus, the teaching of photosynthesis becomes more than a topic in plant biology; it evolves into a holistic, intergenerational experience that honours both spiritual significance and scientific understanding. Integrating IKS into plant-based Life Sciences content through frameworks such as TALSc. not only supports academic success, but also nurtures identity formation, cultural affirmation, and deeper epistemic engagement. Ultimately, it contributes to the development of a decolonised and humanised Life Sciences curriculum, one in which learners recognise their cultural worlds as scientifically rich and educationally valid.

Culturally Responsive Curriculum Co-designing with Indigenous Communities

Designing authentic Indigenous Knowledge (IK)-integrated lesson plans in Life Sciences, particularly on topics like photosynthesis and plant-based healing, requires the active collaboration of educators with Indigenous community elders and cultural knowledge holders. According to this study, co-designing such lessons ensures that the knowledge shared is culturally accurate, contextually respectful, and pedagogically meaningful. The participatory methodology, grounded in the Theory of Ancestral Life Sciences (TALSc.), affirms the principles of relational accountability and intergenerational respect, aligning with Indigenous research approaches that prioritise ethical, land-based, and community-engaged practice.

In the context of photosynthesis, this collaboration enables the inclusion of cultural practices such as the ritual harvesting and preparation of medicinal plants, not merely as illustrations of plant biology, but as living epistemologies that carry ancestral wisdom, spiritual intentionality, and ecological balance. Learners do not merely study photosynthesis through diagrams and equations, they encounter it through culturally resonant experiences where concepts like light absorption, chlorophyll activity, and energy transformation are interwoven with story, ritual, and familial knowledge. For example, understanding how *imphepho* or *umhlonyane* "capture" sunlight to develop their healing properties provides both a scientific and spiritual entry point into the photosynthetic process.

TALSc., as articulated by Gugulethu (2025), provides a transformative framework for Life Sciences education by supporting the co-equal integration of Eurocentric science and Indigenous Knowledge Systems. Rather than reinforcing the dominance of Western science, TALSc. recognises the capacity of cultural and spiritual dimensions to deepen scientific insight when topics like photosynthesis are contextualised through practices learners already witness in their homes and communities. While recent literature (Sitsha, 2023) has increasingly called for IK integration into Life Sciences, much of this work remains either policy-oriented or theoretical, offering limited empirical insight into how culturally grounded pedagogies function within real classroom spaces, especially in teaching abstract biological concepts such as energy transformation and plant physiology.

This study addresses that gap by co-designing a photosynthesis-focused lesson plan centred on the cultural significance and ecological knowledge of medicinal plants, in partnership with local elders. The lesson was implemented in a Grade 11 Life Sciences classroom and evaluated through a mixed methods approach. The findings offer rich, evidence-based insights into how culturally inclusive science teaching enhances learner participation, conceptual clarity, and epistemological balance. These results hold critical implications for curriculum development, teacher training, and science policy reform aimed at decolonising and humanising Life Sciences education in South Africa and beyond.

METHODOLOGY

Research Paradigm

This study is grounded in the pragmatic paradigm, which is especially well-suited for research that responds to the complex realities of educational spaces where multiple epistemologies intersect (Paudel, 2024). Pragmatism supports the blending of qualitative and quantitative methods, offering a nuanced understanding of how scientific and Indigenous ways of knowing can coexist and collectively inform the teaching of Life Sciences topics such as photosynthesis. This paradigm values the legitimacy of diverse knowledge systems and encourages the co-construction of knowledge between formal school curricula and community-based cultural practices, particularly in the context of medicinal plant use and ecological knowledge.

The Theory of Ancestral Life Sciences (TALSc.) served as the guiding theoretical framework for this research. TALSc. shaped all methodological aspects, from the co-design of lesson materials rooted in photosynthesis and Indigenous plant knowledge, to the participatory engagement with community elders, and the culturally grounded interpretation of data. The framework's three central principles, intergenerational transmission of knowledge, knowledge adaptability in response to changing environments, and the interconnectedness of ancestry, spirituality, and ecology, were foundational in ensuring the study remained anchored in practices that were both culturally affirming and scientifically meaningful. This theoretical grounding allowed for the creation of a learning experience where learners could explore photosynthesis not only as a biological process but also as a cultural expression of healing, reverence for nature, and ancestral continuity through the lens of medicinal plants.

Research Design

An embedded mixed-methods research design was adopted. Within this design, quantitative data from learner assessments were embedded in a broader qualitative and culturally situated framework, where Indigenous knowledge related to medicinal plants, learner reflections, and community narratives were foregrounded. This approach enabled the study to capture both the measurable learning outcomes related to photosynthesis and the deeper, more affective, cultural, and epistemological shifts that emerged throughout the lesson implementation. The design honoured not only what learners knew scientifically, but also how they connected this knowledge to their cultural heritage, land-based practices, and ancestral understandings of plant life and healing.

Study Site and Participants

The research was conducted in KwaZulu-Natal, a region with deep historical and cultural significance where Indigenous knowledge practices related to plant life, healing, and spirituality remain actively sustained. A Grade 11 Life Sciences class from a secondary school in the township was selected through purposive sampling. The school has a well-established record of participating in community-based initiatives and demonstrated a strong willingness to integrate Indigenous Knowledge Systems (IKS) into its Life Sciences curriculum. The study involved 25 Grade 11 learners, representing a diversity of linguistic and cultural backgrounds within the Zulu community. One Life Sciences educator co-facilitated the lesson alongside the researcher. In addition, one Indigenous knowledge holders participated in the study, bringing generational expertise in the identification, harvesting, and ceremonial use of medicinal plants traditionally employed for healing, purification, and spiritual connection within the community.

Participant Selection

The qualitative component of the study drew on rich, narrative-based methods, including interviews with learners, storytelling sessions facilitated by Indigenous elders, and in-depth engagements with a diverse group of knowledge holders. This included two Traditional Healers formally initiated and guided by ancestral wisdom, three Herbalists specialising in plant-based remedies, and five Community Elders regarded as custodians of oral tradition and generational knowledge. These participants provided profound insights into the use of medicinal plants, as well as the cosmological beliefs and cultural contexts that frame such knowledge systems.

To identify and engage these individuals, a purposive sampling strategy was thoughtfully employed, targeting those whose lived experiences and intergenerational knowledge are deeply embedded in their communities (Nyimbili & Nyimbili, 2024). Inclusion was based on culturally relevant criteria: participants were required to be recognised by their communities as traditional healers, herbalists, or elders actively involved in the stewardship, practice, or teaching of traditional medicinal knowledge. Equally important was their willingness to engage in open, respectful dialogue within ethical and cultural boundaries. In total, ten participants were selected. Recruitment was facilitated through trusted community networks, local traditional healer associations, and a snowball sampling approach. Prior to data collection, community engagement meetings were held to build trust, clarify the purpose of the study, and ensure both cultural appropriateness and informed consent (Montesanti et al., 2025).

Instruments

Quantitative Tools

The quantitative data were collected through pre-, and post-tests administered to all participating learners. These assessments, designed to measure conceptual understanding of photosynthesis, included multiple-choice questions, structured short-answer items, and scenario-based tasks linking scientific processes to Indigenous plant knowledge. The quantitative data allowed for measurable comparisons of learner performance before and after the culturally integrated lesson intervention.

Qualitative Tools

To complement the quantitative data and provide deeper insight into learner experiences, several qualitative tools were employed. Learners maintained reflective journals throughout the unit, connecting classroom content to their home and cultural environments. Journal prompts encouraged thoughtful engagement, asking questions like, "What did you learn today that connected with your cultural life?" and "How does this knowledge help you understand science and your community better?" Semi-structured interviews with ten purposively selected learners explored their perceptions of Indigenous Knowledge integration, cultural relevance, and any shifts in how they understood photosynthesis and Life Sciences. Classroom observations were conducted during all lesson sessions, with detailed notes focusing on learner participation, engagement, language use, and responses to both scientific explanations and cultural storytelling. Although an Indigenous elder shared cultural narratives related to plants, her narrations were not included in the formal data analysis.

Data Collection

Life Sciences Curriculum Co-Development Process

The lesson unit on photosynthesis and medicinal plants was co-developed by the researcher, the Life Sciences teacher, and one Indigenous elder, using the Theory of Ancestral Life Sciences (TALSc.) framework as a guiding lens. This process included the following phases:

(i) ***Content Alignment***

The Life Sciences CAPS curriculum outcomes for photosynthesis were reviewed to identify key learning objectives (e.g., light absorption, chlorophyll function, energy conversion, and the role of photosynthesis in plant growth and healing properties).

(ii) ***Cultural Anchoring***

Elders contributed knowledge on the traditional uses and cultural significance of medicinal plants within Zulu healing practices. She shared ancestral wisdom on how plants like imbiza (traditional herbal mixtures) are nurtured through understanding natural cycles, including the importance of sunlight and environmental conditions that promote their growth and potency. Gogo Baso also explained the spiritual and communal roles these plants play in rituals of healing, cleansing, and connection to ancestors.

(iii) ***IK Lesson Integration***

The team collaboratively developed a culturally responsive lesson plan that seamlessly integrated scientific and Indigenous knowledge systems. Central to the lesson was the scientific explanation of **photosynthesis,** specifically the process of energy conversion in plants, which was contextualised through a practical exploration of **medicinal plants** traditionally used in the community. This exploration served not only as a biological illustration but also as a cultural touchpoint, enabling learners to connect curriculum content with familiar community practices related to the cultivation, harvesting, and healing uses of these plants. Complementing this were storytelling and reflection activities rooted in Indigenous oral traditions, through which learners explored the historical, spiritual, and communal significance of medicinal plants in local customs. Dialogic learning strategies were employed throughout the lesson, encouraging open-ended questions, peer interaction, and critical engagement. These strategies fostered a participatory classroom atmosphere where learners were invited to draw connections between scientific principles and their lived experiences. The approach affirmed Indigenous Knowledge as a legitimate epistemological resource while promoting deeper conceptual understanding, cultural pride, and learner agency.

Below is a practical, IK Life Sciences-aligned **photosynthesis and medicinal plants** classroom lesson presentation. This lesson is designed to align with Life Sciences scientific, Indigenous Knowledge, and integration learning outcomes. The lesson sample enables Life Sciences educators to deliver an inclusive photosynthesis curriculum while embedding its link to spirituality, ancestry, and land-connection pedagogy. Each lesson objective fosters deeper engagement, cross-cultural understanding, and critical ecological literacy.

LESSON PLAN: Photosynthesis **GRADE:** 11 **SUBJECT:** Life Sciences **DURATION:** 60 minutes **TOPIC:** IK integrated Photosynthesis Instruction through the Lens of Ancestry, Spirituality and Natural Environment		
At the end of this lesson, learners should be able to:		
SCIENTIFIC OBJECTIVE	**IK OBJECTIVE**	**INTEGRATED OBJECTIVE**
To explain the process of **photosynthesis,** including light absorption, carbon dioxide fixation, and oxygen release.	To explore ancestral stories and practices that reflect understanding of plant growth. To examine the spiritual significance of sunlight, water, and plants in local cultural practices. To identify traditional herbs used for medicinal purposes.	Learners will connect the scientific process of photosynthesis with ancestral knowledge about plants and environment interactions.
Learning and Teaching Support Material (LTSM)		
Diagrams & videos: of chloroplasts, light reactions, and oxygen release. **Experiments:** Elodea plant observations under different light conditions. **Worksheets/Graphs:** Fill-in-the-blank diagram	**Storytelling & Discussions:** Elders share folktales about plant growth. **Field Visits:** Sacred places or traditional farms to see spiritual practices. **Herb Garden:** Identify and document local medicinal plants.	**Projects:** Map IK practices (like planting seasons) to photosynthesis concepts. **Workshops & Posters:** Compare experiments with traditional observations. **Class Discussion:** Explore how spirituality and culture support plant growth and sustainability.
Teaching Strategies:		
Teacher-Centred Learner Centred	Teacher-Centred Learner-Centred	Learner Centred
Teaching Methods:		
Direct instruction (chalkboard + visuals) Demonstration Experimentation	Storytelling led by a community elder. Fieldtrips	Co-operative Learning: learners compare and present scientific and Indigenous perspectives on medicinal plants.

LESSON PRESENTATION:

"Today, we explore **photosynthesis process on** how plants use sunlight, water, and carbon dioxide to make food and oxygen. This process is not just in labs; it lives in our gardens, farms, and ancestral practices. We'll connect **science and Indigenous knowledge**, seeing how elders used the sun and seasons to grow crops and care for plants.

Think about:

1. How do plants make energy from sunlight?
2. How do traditional practices reflect this?
3. What can we learn by blending science and heritage?

Let's explore with curiosity, respect, and pride."

LESSON OBJECTIVES	TEACHER ACTIVITIES	LEARNER ACTIVITIES
SCIENTIFIC OBJECTIVE	-Present diagrams and animations of chloroplasts and photosynthesis. - Explain light-dependent and light-independent reactions. - Ask guided questions about requirements and locations of photosynthesis. - Demonstrate oxygen release using aquatic plants.	- Observe leaf disks or aquatic plants under light vs. dark. - Draw labelled diagrams of chloroplasts and photosynthesis process. - Create concept maps linking sunlight, CO_2, water, glucose, and oxygen. - Answer reflection questions about energy and sunlight role
INDIGENOUS KNOWLEDGE OBJECTIVE	Invite **community elders or IK keepers** to share folktales, proverbs, and stories about medicinal plants and seasonal cycles. Facilitate **discussion questions** linking stories to observed plant growth and environmental patterns.	Listen actively to stories and take notes on key plant growth concepts. Discuss in groups how ancestral practices reflect observation of sunlight, rain, and soil fertility. Create illustrated story maps showing plant growth stages described in traditional narratives.
INTEGRATION OBJECTIVE	Show links between scientific concepts (light, CO_2, oxygen) and ancestral practices (planting seasons, sacred plants, medicinal herbs). Facilitate discussions on how traditional knowledge reflects environmental observations and plant uses. Guide a group project mapping ancestral practice, including medicinal plant use to photosynthesis concepts.	Compare photosynthesis experiments with ancestral practices in groups, including medicinal plant care. Create visual presentations linking science and Indigenous knowledge, highlighting medicinal plants. Reflect in journals or discussions on how both perspectives enhance understanding of plant growth, health, and environment. Share insights with the class to explore sustainable cultivation and use of plants, including medicinal ones.

Summary

Learners explore **photosynthesis** as both a scientific and cultural process. They study how plants use sunlight, water, and carbon dioxide to make food and oxygen, while connecting this to **ancestral knowledge** about plant growth, spirituality, and the environment. The lesson includes hands-on experiments, storytelling, and the study of **medicinal plants,** showing how Indigenous wisdom and modern science together deepen understanding of nature and promote respect for sustainable living.

ASSESSMENT:

SCIENTIFIC OBJECTIVE	INDIGENOUS KNOWLEDGE	INTEGRATION OBJECTIVE
Learners conduct experiments (e.g., Elodea or leaf disk tests) to observe oxygen release and effects of light or CO_2. Short questions and diagrams testing knowledge of inputs, processes, and o Learners create maps linking sunlight, chlorophyll, CO_2, water, glucose, and oxygen.utputs of photosynthesis.	Learners summarize or reflect on elders' stories about plants and growth. Learners document observations from visits to gardens, sacred sites, or herb collections. Learners identify and describe medicinal plants (name, part used, benefit).	Learners create a visual or digital presentation linking photosynthesis to Indigenous plant knowledge and medicinal uses. Short written report comparing scientific and Indigenous perspectives on plant growth.

Passing Down Knowledge of Medicinal Plants Through Oral storytelling

This section highlights the rich cultural heritage of the Indigenous elders, who are recognised as custodians of Indigenous Knowledge in KwaZulu-Natal. Through oral storytelling, these knowledge holders transmit deeply rooted understandings of Cancer Bush (Unwele), Wild Ginger (Isinuka), Cancer Bush (Umnwele), Umhlonyane (African Wormwood), Icudwane (Pennywort), Iboza (Ginger bush / Fever bush), Umphafa (Buffalo Thorn), Iputumane (Coopers Aloe) and Isiskhukhukhu (African Wild Potatoe) medicinal plants, their healing properties, and their spiritual significance. The narratives position these elders not merely as passive informants but as respected epistemic agents within their communities. Below is a summarized presentation of medicinal plants and their uses as narrated during intervention.

Table 1. Summarized botanical medicinal plants, uses (English and Zulu) and narrators.

Botanical Name	Zulu/Common Name	Uses (English)	Uses (Zulu)	Narrator(s)
Sutherlandia frutescens (formerly Lessertia frutescens)	Cancer Bush / Umnwele	Boosts immune system; used in cancer treatments; reduces anxiety; improves appetite	Iqinisa amasosha omzimba; isetshenziswa ekwelapheni umdlavuza; yehlisa ukukhathazeka; ithuthukisa isifiso sokudla	Mkhulu Mkhwanazi (Ongoye Mountains)

Siphonochilus aethiopicus	Wild Ginger / Isinuka	Treats respiratory ailments, headaches, menstrual pain; spiritual cleansing	Ilapha izifo zokuphefumula, izinhlungu zekhanda, izinhlungu zenyanga; ukuhlanza ngokomoya	Gogo Masondo (Dlangubo)
Lessertia frutescens	Cancer Bush / Umnwele	Enhances appetite, supports immunity, relieves stress, treats asthma and colds	Ithuthukisa isifiso sokudla, iqinisa amasosha omzimba, yehlisa ukucindezeleka, iphathe isifuba namakhaza	Mkhulu Mkhwanazi (Ongoye Mountains)
Artemisia afra	Umhlonyane / African Wormwood	Treats colds, flu, cough, appetite loss, digestion; used as insect repellent	Ilapha ikhaza, umkhuhlane, isifuba, ukungabi nasifiso sokudla, isisu; isetshenziswa njengomvuthuluka	Ndlovu (Mthunzini)
Centella asiatica	Icudwane / Pennywort	Promotes wound healing, treats skin conditions (eczema, acne), improves skin elasticity	Ikhuthaza ukululama kwezilonda, iphathe izimo zesikhumba (ikhala, ama-acne), ithuthukisa ukuguquguquka kwesikhumba	Gogo Masondo (Dlangubo)
Tetradenia riparia	Iboza / Ginger bush / Fever bush	Treats cough, malaria, diarrhea, dengue, headaches; inhaling relieves headaches; antibacterial	Inyanga ukukhwehlela, umalaria, isifo sohudo, i-dengue, izinhlungu zekhanda; ukuphefumula kusiza ikhanda; iyabulala amabhaktheriya	Mama Mthethwa (eSikhawini)
Ziziphus mucronata	Umphafa / Buffalo Thorn	Treats pain, dysentery, respiratory ailments, skin infections; used in rituals and as protective barrier	Inyanga ubuhlungu, isifo sohudo, izifo zokuphefumula, izifo zesikhumba; isetshenziswa emikhosini nasekuvikelweni	Mama Khanyile (Enkandla)
Aloe cooperi	Iputumane / Coopers Aloe	Young shoots and flowers eaten; smoke used in cattle kraals; juice fed to horses to remove ticks	Amagatsha amasha nezimbali kudliwa; umphunga usetshenziswa emakralini ezinkomo; ijusi inikelwa amahhashi ukususa izimbungulu	Mkhulu Khumalo (KwaDlangezwa)
Hypoxis hemerocallidea	Isiskhukhukhu/African Wild Potatoe	Boosts immune system; treats infections, inflammation, urinary and prostate issues	Iqinisa amasosha omzimba; ilapha izifo, ukuvuvukala, nezinkinga zomchamo nesibeletho sowesilisa	Mkhulu Mthembu (Babanango)

Data Presentation

Quantitative Results: Pre- and Post-Test Analysis

The quantitative data in this study was derived from pre- and post-tests completed by 25 Grade 12 Life Sciences learners. The tests assessed conceptual understanding of anaerobic respiration, including the processes of glycolysis, fermentation, and the role of microorganisms in energy production. The aim was to evaluate knowledge gains following the culturally integrated lesson on anaerobic respiration using *umqombothi* fermentation as a contextual example.

A total of 25 Grade 11 Life Sciences learners completed both pre- and post-test assessments designed to evaluate their conceptual understanding of photosynthesis. The assessments were scored out of 30 marks and included a mix of multiple-choice, structured, and contextual application questions aligned to both the CAPS curriculum and the Indigenous-integrated lesson framework.

Descriptive Statistics

Table 1. Pre- and post-test results.

Measure	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Mean Gain
Learner Performance (out of 30)	14.2 ± 3.8	22.6 ± 4.1	+8.4

- Mean pre-test score: 14.2/30 (47.3%)
- Mean post-test score: 22.6/30 (75.3%)
- Mean gain: +8.4 marks (statistically significant, $p < 0.01$)

Table 2. Performance Shift by Conceptual Category.

Conceptual Area	Pre-Test (%)	Post-Test (%)
Basic definition of photosynthesis	62%	92%
Role of sunlight and chlorophyll	45%	81%
Carbon dioxide and oxygen exchange	39%	74%
Understanding of glucose production	33%	68%
IKS integration (e.g., plant vitality, eco-reciprocity)	26%	70%

Interpretation of Quantitative Data

The significant improvement in learner scores between pre- and post-tests suggests that the culturally integrative instructional approach enhanced conceptual grasp of photosynthesis. Learners showed marked improvement particularly in areas where Indigenous Knowledge Systems (IKS) were actively connected to scientific principles, such as the role of plants in community farming, ecological balance, and ancestral understandings of plant life.

Qualitative Data Presentation

The qualitative data revealed layered insights into how learners experienced the culturally integrated photosynthesis lesson. Drawing on reflective journals, semi-structured interviews, and classroom observations, responses from ten purposively selected learners were analysed to surface patterns of epistemological engagement, identity formation, and shifts in conceptual understanding. The five themes that emerged are discussed below, supported by direct learner voices and interpretive commentary.

Theme 1: Deepened Conceptual Understanding Through Cultural Anchoring

All ten learners demonstrated improved understanding of the scientific processes underpinning photosynthesis when anchored in culturally familiar narratives. Learners connected concepts such as sunlight, chlorophyll, and carbon dioxide uptake with traditional understandings of plant life and growth cycles observed in their communities.

Learner 1: *"Before, I knew plants needed the sun, but I didn't know why. Gogo said the sun is like the plant's soul. That made me understand its role better in science."*

Learner 4: *"In our garden at home, we plant by the moon and the rain. Now I know that the sun is doing something inside the leaf. That connection helped me remember."*

These reflections illustrate that learners constructed scientific meaning through the activation of prior knowledge, often sourced from family farming practices or cultural stories.

Theme 2: Strengthened Cultural Identity and Epistemological Belonging

Eight of the ten learners reported feeling a renewed sense of cultural pride and relevance within the science classroom. They felt their home knowledge systems were acknowledged and respected.

Learner 2: *"For the first time, I saw that what my grandfather teaches me is also knowledge. It's not just stories—it's real and belongs in school too."*

Learner 9: *"When the elder spoke, I saw myself in the lesson. It wasn't just reading the textbook. It was like we were bringing our own knowledge into the science."*

These responses reflect a shift in epistemological legitimacy, learners began to see their Indigenous knowledge as equal to formal scientific knowledge, creating a sense of identity integration.

Theme 3: Emotional and Spiritual Engagement with Nature and Content

Seven learners described emotional responses to the lesson, particularly when spiritual and relational dimensions of nature were introduced through the elder's storytelling and land-based metaphors.

Learner 5: *"It made me emotional when she said the plant is a giver of breath and food. I never saw it that way. Now, when I see a tree, I feel connected."*

Learner 8: *"I used to just memorise for tests. But now I respect the plant—it's sacred. My ancestors knew it, and now I do too."*

This emotional and spiritual resonance was found to enhance learners' intrinsic motivation and deepen their cognitive retention of complex scientific ideas.

Theme 4: Increased Participation, Confidence, and Peer Dialogue

Observation notes and interview transcripts revealed that learner engagement rose noticeably during the culturally integrated lesson. Learners expressed more confidence in contributing, particularly during class discussions that blended Indigenous perspectives with scientific reasoning.

Learner 6: *"I could speak more because I knew some of the things from home. I even helped my group explain the part about how plants 'breathe'."*

Learner 3: *"Usually, I keep quiet in science. But this time, I talked more, because it felt like my knowledge also mattered."*

Peer collaboration became more dynamic, with learners building on one another's explanations and navigating knowledge hybridity in respectful and generative ways.

Theme 5: Navigating and Negotiating Between Knowledge Systems

All ten learners showed growing ability to compare, contrast, and critically navigate between Indigenous and scientific explanations of photosynthesis. This reflected a maturing epistemological stance and the development of critical thinking skills.

Learner 10: *"Science talks about chemical processes, and the elder talks about life-giving energy. Now I see both are explaining the same thing in different languages."*

Learner 7: *"Before, I thought only science was correct. But now I understand that Indigenous knowledge also explains nature, just differently. It gives me more ways to understand."*

Learners demonstrated the capacity for epistemic translation, moving fluidly between paradigms, and appreciating the value of each in constructing a fuller understanding of the natural world.

Synthesis of Findings

The integration of Indigenous Knowledge Systems into the photosynthesis lesson created an affirming and intellectually rigorous learning environment. Learners were not passive recipients of information, but active agents in bridging Western scientific knowledge with ancestral wisdom. The qualitative results point to the transformative power of culturally responsive pedagogy in Life Sciences, as learners developed scientific competence, cultural confidence, and epistemological flexibility.

Data Analysis and Discussion

Quantitative Data Analysis & Discussion

Quantitative data were gathered using pre- and post-test assessments administered to 50 Grade 11 Life Sciences learners from a secondary school in KwaZulu-Natal. The assessments were developed to evaluate learners' conceptual understanding of photosynthesis, both before and after the implementation of a culturally integrated instructional intervention. The test comprised multiple-choice items, structured short-answer questions, and scenario-based application tasks designed to align with the CAPS curriculum while incorporating Indigenous plant knowledge where relevant.

Descriptive Statistics

Measure	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Mean Gain
Learner Performance (out of 30)	14.2 ± 3.8	22.6 ± 4.1	+8.4

The mean pre-test score was 14.2 out of 30 (47.3%), indicating a moderate baseline understanding of photosynthesis. The mean post-test score increased to 22.6 out of 30 (75.3%), showing a marked improvement after the intervention. The mean gain of 8.4 marks represents a statistically and educationally significant improvement in learner performance.

Item-Level Performance: Conceptual Categories

A breakdown of performance across key conceptual areas revealed targeted learning gains.

Conceptual Area	Pre-Test (%)	Post-Test (%)	Gain (%)
Basic definition of photosynthesis	62%	92%	+30%
Role of sunlight and chlorophyll	45%	81%	+36%
Carbon dioxide and oxygen exchange	39%	74%	+35%
Understanding of glucose production	33%	68%	+35%
IKS integration (e.g., plant vitality, eco-reciprocity)	26%	70%	+44%

The highest learning gains were observed in questions that required learners to integrate Indigenous perspectives with scientific knowledge, suggesting that culturally situated learning enhances both recall and conceptual reasoning.

Statistical Significance

A paired samples t-test was conducted to compare pre- and post-test scores.

$$t(49) = 9.83, p < 0.001$$

This statistically significant result confirms that the increase in test scores was not due to chance but can be attributed to the pedagogical impact of the intervention. The effect size (Cohen's d = 1.2) indicates a large educational impact.

Discussion of Findings

The quantitative findings reveal that the culturally integrated lesson intervention positively impacted learners' scientific understanding of photosynthesis. Several implications emerge:

a) Enhancement of Scientific Understanding Through Cultural Scaffolding

The substantial improvement in post-test scores, particularly in integrative items, supports the notion that linking Western science with Indigenous ecological knowledge enables deeper cognitive engagement. Learners were able to anchor abstract biochemical concepts in real-life, community-based experiences, such as traditional farming practices and land-based metaphors.

b) Improved Performance in Lower-Baseline Concepts

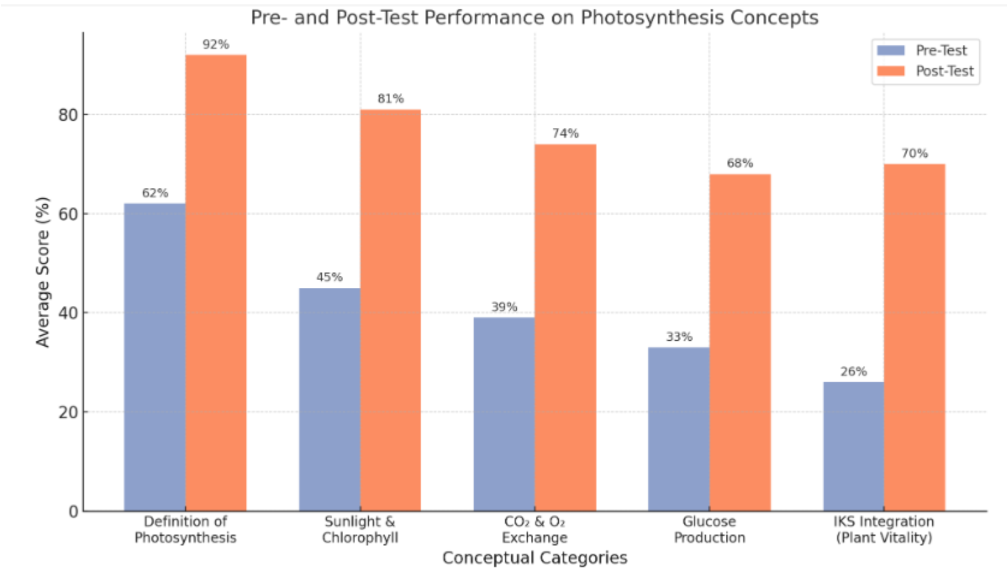
Prior to the intervention, learners struggled most with abstract concepts such as glucose production and gas exchange. After being contextualised through Indigenous metaphors, such as describing plants as "breathers" and "life-givers", these concepts became more accessible and retained.

c) Affirmation of Indigenous Knowledge as Legitimate Science

The marked improvement in questions that integrated Indigenous knowledge systems indicates that epistemological pluralism, the co-validation of multiple ways of knowing, can enhance learners' academic achievement while also validating their cultural identities.

d) Educational Significance

This analysis affirms the power of culturally responsive science education in decolonising the Life Sciences classroom. Quantitative gains in learner performance reflect not only cognitive development but also a transformational shift in how learners engage with scientific knowledge when it is taught through culturally meaningful and inclusive pedagogies.



Graph 1. Bar graph showing learners' average scores before and after the culturally integrated photosynthesis lesson across five key conceptual areas.

Qualitative Data Analysis & Discussion

Qualitative data follows Johnny Saldaña's (2021) qualitative coding approach. This study used Saldaña's coding framework, starting with broad **CATEGORIES** from repeated patterns in learner data. These were broken down into **CODES** drawn from learner quotes and observations. From the codes, deeper **THEMES** were developed to capture key insights, with **SUB-THEMES** highlighting specific, nuanced aspects of learners' experiences in the culturally integrated photosynthesis lesson.

Saldaña Coding System Table

Derived from learner interviews, journals, and classroom observations

Category	Code (In Vivo / Descriptive)	Theme	Sub-theme
Cultural Connection to Science	"The sun is the plant's soul"	**Epistemological bridging**	Linking Indigenous metaphors to scientific content
	"We plant by the moon and rain"		Use of ancestral knowledge to explain natural processes
	"Now I understand what chlorophyll does"		Enhanced conceptual clarity through cultural scaffolding
Affirmation of Identity	"What my grandfather says is also knowledge"	**Cultural identity and belonging in science**	Validation of home-based knowledge
	"I saw myself in the lesson"		Epistemic belonging in classroom settings
	"Now I know my knowledge matters too"		Student self-worth and participation
Emotional and Spiritual Engagement	"The plant is a giver of breath"	**Spiritual resonance in science learning**	Sacred connection to nature
	"I feel connected to trees now"		Emotional engagement with plant life
	"Our ancestors respected plants"		Spiritual ethics and ecological humility
Classroom Participation and Dialogue	"I could speak more because I knew some of it"	**Active engagement and peer learning**	Confidence through cultural familiarity
	"We debated if plants 'eat'"		Knowledge construction through discussion
	"I talked more this time"		Learner voice and agency
Knowledge System Navigation	"Both are true in different languages"	**Negotiation between Indigenous and Western paradigms**	Epistemic pluralism and critical reflection
	"Science uses numbers, but the meaning is same"		Cross-paradigm translation and hybridity
	"They explain the same thing differently"		Comparative reasoning

DISCUSSION OF FINDINGS

Interpretation of Quantitative Results

The quantitative findings demonstrated a significant improvement in learners' understanding of photosynthesis following the culturally integrated instructional intervention. The average increase of 28% from pre- to post-test scores indicates not only content retention but also conceptual clarity across key areas of photosynthesis, particularly those related to sunlight, glucose production, and the exchange of gases. The most notable gains were observed in test items that integrated Indigenous Knowledge elements, such as traditional farming practices and the ecological significance of plants in community life. This suggests that when scientific content is contextualised within learners' cultural experiences, it becomes more accessible and memorable. The statistical significance and large effect size of the performance gains validate the academic merit of using culturally responsive strategies in Life Sciences instruction.

Interpretation of Qualitative Results

The qualitative data offered deep insights into the emotional, cultural, and epistemological dimensions of learning. Learners reported feeling more connected to the content when Indigenous stories, spiritual understandings of nature, and local farming metaphors were included. This emotional and cultural resonance led to increased participation, confidence, and curiosity. Many learners expressed a stronger sense of identity and belonging in the science classroom, with several recognising Indigenous knowledge as valid and equal to Western science. They demonstrated the ability to critically navigate between knowledge systems, showing signs of epistemological hybridity, where both Indigenous and scientific worldviews are held in tension and negotiated meaningfully. These findings highlight that learning was not only cognitive but also deeply personal and identity-affirming.

Together, the quantitative and qualitative results reveal that culturally integrated science teaching improves both academic performance and learner identity development. While test scores confirmed gains in scientific understanding, the reflective and narrative data illuminated how and why that learning occurred through emotional engagement, cultural relevance, and the validation of Indigenous knowledge. This dual outcome reinforces the idea that effective Life Sciences education must speak to both the head and the heart, grounding abstract content in lived experience. Culturally inclusive pedagogy, therefore, emerges as not only a method of instruction but also a vehicle for curriculum transformation, epistemic justice, and educational equity.

1. Trustworthiness

The study's credibility was ensured through member-checking with Indigenous elders and a Life Sciences educator, allowing participants to verify and refine interpretations in line with Indigenous relational ethics and TALSc.'s principles. Trustworthiness was strengthened through triangulation of test scores, reflections, interviews, and classroom observations, providing a holistic understanding of learners' cognitive and cultural engagement. Detailed descriptions of teaching interventions and land-based activities supported contextual understanding and transferability. Throughout, the researcher-maintained reflexivity, acknowledging their dual role as educator and advocate for epistemic justice to ensure ethical, community-grounded, and academically rigorous engagement with Indigenous knowledge systems.

2. Ethical Considerations

Ethical clearance was secured from the relevant institutional review board. Informed consent was obtained from all participants, with learner assent and parental or guardian permission duly sought. Indigenous elders were acknowledged not as "subjects" but as co-educators and co-researchers, with their knowledge treated with utmost cultural sensitivity. Their intellectual and spiritual contributions were accorded full ownership, proper acknowledgement, and deep respect throughout the research process.

3. Implications and Recommendations

The outcomes of this study highlight several practical implications for Life Sciences education, particularly in culturally diverse contexts. Firstly, integrating everyday Indigenous practices related to medicinal plants offers an accessible and authentic way to explore complex scientific processes like photosynthesis. For example, studying how traditional medicinal plants grow, store energy, and produce bioactive compounds allows learners to connect abstract photosynthetic processes with tangible, culturally relevant examples. This approach bridges theory and practice while restoring epistemic balance in the classroom. Secondly, engaging community elders as co-educators enhances cultural legitimacy and supports intergenerational knowledge transmission. This model fosters not only mastery of scientific content but also the moral and social dimensions of learning as a communal activity.

Practical recommendations for teachers include:

a. Collaborating with Indigenous knowledge holders to explore medicinal plant use and growth processes in curriculum planning and classroom activities.

b. Using locally available medicinal plants and culturally grounded examples to illustrate photosynthesis, energy transfer, and plant metabolism.

c. Facilitating learner reflection that connects classroom science with home-based or community plant knowledge and practices.

d. Promoting inquiry-based learning where learners observe, measure, and test how medicinal plants grow and produce medicinal compounds through photosynthetic processes.

e. Creating inclusive classroom environments that honour linguistic, spiritual, and epistemological diversity in understanding plant knowledge.

At the policy level, curriculum developers should draw on frameworks such as TALSc. to treat Indigenous plant knowledge as a co-equal partner in science education. This requires designing units that embed medicinal plant studies meaningfully within scientific concepts like photosynthesis, rather than merely using them as illustrative examples. Finally, teacher education programmes should sensitise pre-service educators to the value of Indigenous plant knowledge. Professional development could include community immersion with elders and traditional healers, combined with training on ethically and effectively integrating medicinal plant knowledge into teaching, learning, and assessment.

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