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Integrating a culturally responsive pedagogical tool in the teaching of bacteria in life sciences curriculum

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Abstract

The teaching of bacteria in the Life Sciences curriculum has traditionally been framed through a Western scientific lens, often neglecting Indigenous perspectives that hold valuable microbial knowledge. Indigenous Knowledge Systems (IKS) encompass rich understandings of bacterial processes such as fermentation, soil enrichment, food preservation, and healing practices, yet these remain underrepresented Life sciences classrooms. This study responds to the need for inclusive, contextually grounded pedagogies that recognise diverse epistemologies and foster meaningful learner engagement. The study investigates a culturally responsive pedagogical tool that integrates Indigenous microbial knowledge with conventional microbiological science to enhance learners' conceptual understanding, cultural identity, and appreciation of the ecological and health roles of bacteria. Guided by the pragmatic paradigm, this research employed an embedded mixed-methods design. Quantitative data were gathered through pre- and post-tests assessing conceptual shifts in understanding bacterial structure, function, and ecological importance. Qualitative data were derived from learner interviews, reflective journals, and storytelling sessions with Indigenous elder and healer knowledgeable in traditional microbial practices. Thirty Grade 11 Life Sciences learners from a public secondary school in KwaZulu-Natal, South Africa participated, were selected through random sampling. An elder was purposefully chosen for his expertise in traditional fermentation and herbal preparation. Results indicated significant improvement in learners' conceptual comprehension of bacteria. Furthermore, it heightened engagement when content was contextualised through community-based practices such as fermentation, soil regeneration, and probiotic use. Learners demonstrated an enhanced ability to compare Indigenous microbial worldviews with Eurocentric microbiological explanations, reflecting deeper cognitive and cultural integration. Anchored in the Theory of Ancestral Life Sciences (TALSc.), this study advocates for the transformative potential of culturally responsive tools in Life Sciences education. Integrating IKS within bacterial pedagogy promotes epistemic inclusivity, nurtures identity, and strengthens the connection between learners, science, and their cultural heritage. The study proposes an infusion model for microbial pedagogy that values Indigenous and Western sciences as co-equal, offering a replicable framework for curriculum transformation across science education disciplines.

Keywords: Bacteria education, Culturally responsive pedagogy (CRP), Epistemic inclusivity, Indigenous knowledge systems (IKS), Life Sciences curriculum transformation, Microbial pedagogy, Theory of ancestral life sciences (TALSc.).

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1. Introduction

Life Sciences teaching in South African classrooms is still shaped mainly by Western scientific traditions [1]. These traditions focus on rationality, objectivity, and empirical evidence. While they have advanced biological understanding, they often exclude Indigenous ways of knowing that have long guided human interaction with nature. In microbiology, this exclusion is especially visible in how bacteria are taught. Indigenous communities have used bacterial processes for centuries in fermentation, soil fertility, food preservation, and healing. These practices show deep ecological understanding that predates formal microbiological science. Yet, they are rarely recognised in Life Sciences lessons.

This disconnection between Western and Indigenous understandings of bacteria limits learners' scientific and cultural awareness. Many learners in township and rural schools are taught to see bacteria both as beneficial and as harmful, however, through a Euro-scientific lens. They are not exposed to the Zulu traditional practices that involve bacterial life. This narrow view also devalues Indigenous practices, such as fermenting milk to *amasi*, brewing *umqombothi*, and using bacterial cultures to enrich soil. Bringing these practices into the classroom can make the study of bacteria more meaningful and inclusive.

This study explores how a culturally responsive pedagogical tool can bridge Indigenous Knowledge Systems (IKS) and Western microbiology in Life Sciences teaching [2]. Culturally responsive pedagogy, as described by Gugulethu [3] values learners' cultural backgrounds as valid sources of knowledge. It encourages teachers to use these cultural experiences to explain scientific ideas. In Life Sciences, this means not just adding Indigenous examples, but creating shared learning spaces where teachers, learners, and community elders co-construct knowledge. When bacterial concepts are linked to familiar cultural and environmental practices, learning becomes relevant and connected to learners' daily lives.

The study is guided by the Theory of Ancestral Life Sciences (TALSc.). This framework emphasises the link between ancestral knowledge, spirituality, and scientific thinking. TALSc. shows that Indigenous and Western sciences can complement one another [2]. It views bacteria not only as biological organisms but also as symbols of balance, continuity, and health within ecosystems and communities. This research follows the pragmatic paradigm, which values approaches that respond to real classroom experiences [4]. It uses an embedded mixed-methods design [5]. Quantitative data measure learners' understanding before and after the lesson. Qualitative data come from interviews, reflections, and storytelling with Indigenous healers and elders who hold traditional microbial knowledge. This combination gives a fuller picture of both the cognitive and cultural impact of the lesson.

The study aims to contribute to the decolonisation and transformation of Life Sciences education. It proposes an infusion model for microbial pedagogy that treats Indigenous and Western knowledge systems as co-equal. Such a model values both scientific accuracy and cultural meaning [2, 6]. It allows learners to see their culture, community, and ancestral wisdom represented in science. In doing so, it helps them become scientifically literate and culturally grounded individuals who can move confidently between different worlds of knowledge.

2. Theoretical Framework

This study is grounded in the Theory of Ancestral Life Sciences (TALSc.), which recognises the spiritual and ancestral dimensions of scientific learning. TALSc. positions Indigenous knowledge as co-equal with Western science. It encourages teachers to present biological concepts in ways that acknowledge cultural values, ancestry, and spirituality [2]. In the context of bacteria education, TALSc. highlights how microbial life connects to cycles of growth, decay, and renewal, principles deeply embedded in Indigenous worldviews. Bacteria are understood not only as microscopic organisms but as life-sustaining agents that maintain balance within nature and human health. Using TALSc. as a framework supports the creation of co-pedagogical spaces where learners, teachers, and elders share knowledge as equals.

The first principle of TALSc. upholds the intergenerational transfer of Indigenous Knowledge (IK) through family lineages and continuous interaction with the environment. In the context of this study, this principle recognises that traditional bacterial knowledge, such as fermentation of milk to *amasi*, brewing of *umqombothi*, traditional compost and preparation of fermented herbal remedies is passed down across generations. These practices demonstrate ancestral understanding of microbial processes long before Western microbiology formalised them. By integrating these examples into the Life Sciences curriculum, learners can appreciate that bacterial knowledge is rooted in lived experience and observation. Classroom activities, such as preparing fermented foods under guidance from community elders, allow learners to connect ancestral wisdom with scientific explanations of bacterial growth, metabolism, and ecological function.

The second principle of TALSc. emphasises that Indigenous Knowledge is adaptable and flexible. In the context of this study, it highlights how microbial practices have evolved in response to environmental and cultural changes. For example, fermentation methods, soil enrichment strategies, and herbal treatments vary between regions and communities, reflecting local adaptation while maintaining core microbial principles. Communities produce amasi by leaving raw milk to ferment naturally at ambient temperatures. The fermentation relies on lactic acid bacteria (Lactobacillus, Leuconostoc), which convert lactose into lactic acid, thickening the milk and giving it a sour taste. Room temperatures, season, and type of milk (cow, goat, camel) influence fermentation speed and flavour. Using available milk types, containers, and climate conditions indicates adaptability of milk fermentation. Milk fermentation time, methods, and usage are adjusted for taste, nutrition, and preservation without changing the core science. Communities show flexibility of sour milk fermentation by adjusting timing and storage accordingly. Furthermore, the container choice e.g. clay pots and calabashes influence microbial communities, showing flexible use of local materials. In modern days milk can be consumed directly, used in cooking, or stored for several days without refrigeration because of genetically modified milk (e.g. long-life milk), pointing to both to its flexible and adaptive nature. Incorporating this principle into teaching enables learners to see that Indigenous microbial knowledge is not static folk tale but a responsive system of inquiry. Learners engage with bacteria as living agents in culturally and ecologically situated practices. They understand that both scientific and Indigenous methods can adapt to challenges like food preservation and soil restoration.

The third principle of TALSc**.** advocates for relational learning, an approach that bridges Euro-scientific and Indigenous perspectives in understanding content. Within the classroom, this approach enables learners to connect theoretical microbiological concepts with lived community practices. Learners compare and integrate Western microbiological ideas such as ecological roles with Indigenous knowledge of fermentation, composting, and medicinal applications. Storytelling by community elders and hands-on activities allow learners to see what they learn in class applies directly to real-life situations, where scientific reasoning and cultural knowledge inform one another. This relational approach helps learners recognise bacteria not only as microscopic organisms but as life-sustaining agents that link ecological balance, health, and cultural practices. Through such learning experiences, learners cultivate respect for multiple ways of knowing while deepening their conceptual understanding of microbiology in culturally and practically meaningful ways.

By applying these three principles in co-pedagogical practices aligned to *ancestral connectivity, ecological relationality,* and *spiritual continuity*, TALSc. transforms bacteria teaching into a holistic learning experience. It creates a co-pedagogical space where teachers, learners, and Indigenous knowledge holders collaborate. In this space, learners connect Western microbiological concepts such as bacterial cell structure, respiration, and ecological function with Indigenous narratives and practices. The integration of TALSc. into Life Sciences pedagogy thus nurtures epistemic harmony, a balance between ancestral wisdom and modern science. It allows learners to see bacteria as both scientific and spiritual beings that sustain health, soil, and community life. Through this framework, the teaching of bacteria becomes an act of cultural restoration and scientific empowerment.

3. Literature Review

3.1. Culturally Responsive Pedagogy in Science Education

Culturally responsive pedagogy (CRP) recognises that culture influences how learners understand and engage with scientific ideas [7]. According to the author, CRP involves using learners' cultural experiences and values as part of the learning process. It challenges the traditional view of science as a neutral or culture-free subject. In many African contexts, science classrooms still present Western scientific knowledge as the only valid truth. This approach can alienate learners whose everyday experiences are grounded in Indigenous knowledge and community practices.

Buthelezi [2] argues that CRP helps learners connect what they learn in school to their social and cultural identities. It allows teachers to link abstract science concepts to familiar cultural contexts. In Life Sciences, this means integrating community-based examples that illustrate scientific principles in culturally meaningful ways. Studies in science education have shown that when learners see their culture reflected in science, they develop stronger motivation, confidence, and understanding [8].

3.2. Indigenous Knowledge Systems and Microbial Understanding

Indigenous Knowledge Systems (IKS) provide deep insight into the natural world, including microorganisms. Long before modern microbiology, African communities used bacterial processes in food production, soil management, and healing practices. For example, fermented foods such as *amasi*, *umqombothi*, and pickled vegetables rely on beneficial bacteria to preserve and enhance nutrition. Traditional healers also use bacterial cultures and natural fermentation to produce herbal remedies.

These practices demonstrate empirical understanding of microbial behaviour, even without the use of microscopes or laboratory tools. They show that Indigenous knowledge is both scientific and spiritual, connecting human health with ecological balance. According to Black and Tylianakis [9] Indigenous knowledge should not be viewed as separate from science but as a complementary system of knowing. When Indigenous microbial knowledge is included in Life Sciences teaching, learners gain a more holistic understanding of bacteria as both biological and cultural entities.

3.3. Western Microbiology and the Curriculum Gap

The South African Life Sciences curriculum focuses strongly on Western microbiology. It introduces bacteria mainly through concepts of disease, antibiotics, and laboratory culture. This limited approach overlooks the beneficial and ecological roles of bacteria that Indigenous communities have long understood. As a result, learners often develop a fear-based view of bacteria, seeing them only as harmful.

Curriculum documents such as the Curriculum and Assessment Policy Statement (CAPS) aim to promote inquiry-based learning. However, they provide limited guidance on integrating Indigenous perspectives in microbiology. The gap between policy and practice leaves many teachers unsure of how to include cultural examples in their lessons [10]. The author shows that teachers need pedagogical tools and professional support to integrate IKS meaningfully into Life sciences education.

3.4. A Culturally Responsive Bacteria Pedagogy

A culturally responsive approach to teaching bacteria blends Western scientific content with Indigenous microbial knowledge. This approach values both empirical evidence and cultural meaning. It invites learners to see bacteria through multiple lenses: as pathogens, as agents of healing, and as partners in ecological systems.

Research in culturally responsive science education shows that such integration improves learner engagement, critical thinking, and identity formation [11]. For Life Sciences education in South Africa, this approach offers a pathway to curriculum transformation that affirms learners' cultural heritage while maintaining scientific rigor. It also opens opportunities for collaboration between teachers and Indigenous knowledge holders, making science learning more community-centred and sustainable.

3.5. Research Questions

1. How does the integration of a culturally responsive pedagogical tool impact on learners' performance on bacteria concepts in the Life Sciences curriculum?
2. In what ways does IK integrated approach influence learner engagement during bacteria instruction?

3.6. Research Objectives

1. To evaluate the effect of a culturally responsive pedagogical tool on learners' performance on bacteria concepts.
2. To examine changes in learner engagement during bacteria lessons when using IK integrated approach.

4. Methodology

This methodology demonstrates how TALSc. can operationalise culturally responsive bacteria pedagogy, creating learning experiences that are scientifically rigorous, culturally affirming, and experientially rich.

4.1. Research Design

This study adopted an embedded mixed-methods research design Hermina [5] guided by the pragmatic paradigm [4]. This approach allowed the integration of quantitative measures of learner understanding with qualitative insights into cultural and experiential learning. Quantitative data were collected through pre- and post-tests, assessing learners' conceptual knowledge of bacteria, including their structure, ecological roles, and practical applications in fermentation and soil health. Qualitative data were derived from learner interviews, reflective journals, and storytelling sessions with Indigenous knowledge holders, who demonstrated traditional bacterial practices.

The study design was informed directly by TALSc. principles. The first principle, *intergenerational transfer of IK*, informed the inclusion of elders as co-educators. The second principle, *dynamic and adaptable Indigenous knowledge*, guided the selection of flexible, contextually relevant bacterial practices for classroom activities. The third principle, *relational learning*, shaped activities that linked Western scientific concepts with Indigenous microbial knowledge, creating spaces for co-learning between teachers, learners, and elders.

4.2. Participants and Sampling

Participants were thirty Grade 12 Life Sciences learners from a secondary school in KwaZulu-Natal, South Africa. Learners were selected through random sampling to ensure representation. One Indigenous elder, recognised for her expertise in traditional fermentation and medicinal practices, was purposefully selected to provide cultural knowledge relevant to bacteria and facilitate storytelling sessions.

4.3. Lesson Design and Implementation

The bacteria lesson was designed using a co-pedagogical model informed by TALSc. The lesson comprised three components aligned with TALSc principles:

a. Learners explored traditional bacterial practices such as fermentation of *amahewu, amasi* and *umqombothi*, under guidance from the elder. These activities illustrated ancestral microbial knowledge and highlighted its intergenerational transfer.
b. Learners engaged in hands-on fermentation activities, demonstrating how microbial practices are adaptable to local environmental and cultural contexts. Learners observed bacterial activities, linking scientific concepts to flexible Indigenous practices. (CREATE AN IMAGE)

c. Through storytelling, reflection, and discussion, learners compared Western microbiological knowledge with Indigenous practices. They explored bacterial roles in ecological balance, health, and food preservation, recognising how multiple epistemologies complement each other.

Lessons were conducted over two days, with a combination of classroom instruction, laboratory demonstrations, and land-based experiential learning.

LESSON PLAN: Micro-organisms: Bacteria
GRADE: 11
SUBJECT: Life Sciences
DURATION: 120 minutes
TOPIC: IK integrated BACTERIA Instruction through the lens of ancestry and natural environment

At the end of this lesson, learners should be able to:

SCIENTIFIC OBJECTIVE (CAPS)	IK OBJECTIVE	INTEGRATED OBJECTIVE
▪ To draw and label the basic structure of a BACTERIA ▪ To explain how bacteria contribute to natural processes such as decomposition, nutrient cycling and disease prevention. ▪ To investigate bacterial roles in food, decomposition and disease prevention.	To explore traditional knowledge and practices related to food fermentation and food preservation, emphasizing ancestral awareness of natural microbial activity in food/beverages preparation and preventing spoilage.	To investigate both Indigenous and scientific understandings of microbial processes in food & traditional beverages. To link ancestral fermentation methods and natural preservation techniques with modern microbiology to promote cultural relevance.

Learning and Teaching Support Material (LTSM)

▪ Microscope slides, textbook diagrams and wall charts of bacterial structure ▪ Posters on nutrient cycles, compost samples or decaying plant matter for observation. ▪ Short video clip on *Bacteria hidden role*) ▪ Prepared slides showing yoghurt bacteria safe cultures. ▪ Materials for simple yoghurt-making experiment ▪ Case studies (written or visual) on decomposition and sanitation	▪ Learners listen Indigenous knowledge stories on soil fertility and traditional fermentation (e.g. amahewu, umqombothi, amasi) ▪ Community interview guides of elders on fermentation practices	▪ Compare scientific and traditional roles of bacteria

Teaching Strategies:

Teacher-Centred Learner Centred	Learner Centred	Learner Centred

Teaching Methods:

Demonstration and guided drawing	Discussion and storytelling method	Inquiry-based / investigative method

Lesson Presentation:

Teacher speaks to learners:

"Today, we're going to explore a living world that we cannot see with our eyes, the world of *bacteria*. These tiny organisms are everywhere: in the soil, in water, in our bodies, and even in the foods we eat.

Before we begin, I want you to think about your own home. Have you ever seen milk turns into *amasi*, or tasted traditional *umqombothi* or fermented vegetables? What do you think causes those changes? Many people from our traditional communities knew, even before microscopes were invented, that there are unseen living things that help food change and keep soil fertile. Today, science calls them bacteria.

By the end of this lesson, you'll realise that bacteria are not just 'germs', they are *helpers* in many natural processes that sustain life. We'll see how Western science and Indigenous knowledge both recognise their power in maintaining balance in nature."

Lesson Objectives	Teacher Activities	Learner Activities
Scientific Objective	The teacher demonstrates how to draw and label a bacterium, using diagrams and slides. Learners follow along, then work independently or in pairs to construct and label their own versions. This supports visual-spatial and kinaesthetic learning.	Learners work in groups to conduct small experiments, record results, and report findings through posters presentations.
Indigenous Knowledge Objective	Use local examples of traditional fermentation (e.g. *amasi*, *umqombothi*, *amahewu*) to show the beneficial role of bacteria in preserving and enriching food. Invite community elders to share how soil fertility and decomposition were understood before Western scientific terminology. Storytelling on Indigenous narrative about food preservation (e.g. fermented foods), followed by a guided discussion linking bacteria to ecological processes.	Learners engage in classroom/home investigations: e.g., a. observing decomposition of organic matter over time / b. preparing yoghurt and record observations. Learners document traditional practices (e.g. fermenting milk and composting) to connect science with community heritage.
Integration Objective	Describe bacteria's ecological functions from a Western science perspective (nutrient cycling, decomposition) and Indigenous knowledge systems (traditional composting, use of microbes in food preservation).	Compare bacteria's functions from a Western science and Indigenous Knowledge Systems perspectives focusing on: nutrient cycling, decomposition, traditional composting, use of microbes in food preservation, use of bacteria in fermentation). Integrate both perspectives in discussion and reflection activities

Summary

In this lesson, learners explore bacteria from both Western scientific and Indigenous knowledge perspectives. The teacher demonstrates how to draw and label a bacterium. Learners then create their own diagrams to reinforce understanding. Through group investigations, they observe bacterial activity in decomposition and traditional fermentation processes such as *amasi*, *umqombothi*, and *amahewu*. Indigenous storytelling and community insights highlight traditional understandings of soil fertility and food preservation. Learners then compare these with scientific explanations, recognising bacteria's vital roles in nutrient cycling, decomposition, and fermentation, and appreciating their importance in both nature and culture.

Assessment:

Scientific Objectives	Indigenous Knowledge	Integration Objective
Learners' understanding is assessed through a practical drawing activity where they accurately draw and label the parts of a bacterium (e.g. cell wall, plasma membrane, flagella, cytoplasm, nucleoid). Learners complete a short-written explanation, supported by examples showing how bacteria recycle nutrients. Learners conduct guided experiments or observations. They record observations, analyse results, and present findings through a short report or poster. *Assessment focuses on the scientific process: observation, data recording, interpretation, and conclusion.*	Learners gather and present information from community elders, family members, or local traditions on how fermentation and preservation were traditionally understood and practised. Evidence may include written notes, short oral presentations, or posters. *The teacher assesses learners' ability to describe traditional methods, recognise the role of microbes, and demonstrate respect for Indigenous knowledge systems.*	Learners produce a comparative report, group poster, or class presentation linking traditional fermentation methods (e.g. *amasi*, *umqombothi*, *amahewu*) with scientific explanations of bacterial activity. Assessment focuses on learners' ability to integrate both knowledge systems, show conceptual understanding, and appreciate cultural significance. *The teacher uses a rubric assessing comprehension, integration of perspectives, and presentation quality.*

4.4. Data Collection

Data collection involved multiple approaches to gather comprehensive insights into learners' understanding and experiences. Pre- and post-tests were administered to assess changes in conceptual understanding of bacterial structure, growth, and ecological roles. Semi-structured interviews were conducted with learners to capture their reflections on the integration of Indigenous microbial knowledge. Storytelling sessions led by an Indigenous elder provided culturally grounded explanations of bacterial processes, enriching learners' contextual understanding. In addition, learner journals were used to document personal insights, cultural connections, and developing awareness of bacterial functions within both scientific and Indigenous frameworks.

5. Data Analysis

5.1. Quantitative

5.1.1. Data Presentation

Pre- and post-test scores were collected to assess learners' understanding of bacterial concepts. Engagement and affective outcomes were recorded from reflective journals and interviews, summarized in Table 1. Pedagogical impact across TALSc. principles [2] are summarized in Table 2.

Pre-Test vs Post-Test Scores shows clear improvement in learners' bacterial knowledge across all groups, indicating cognitive gains from the culturally responsive lesson. Below is a table presenting pre-test, post-test, and percentage gain in bacterial knowledge.

Table 1.
Pre-Test, Post-Test, and Percentage Gain in Bacterial Knowledge.

Learner Group	Pre-Test (%)	Post-Test (%)	Percentage Gain (%)
Group 1	55	80	25
Group 2	60	82	22
Group 3	50	73	23
Group 4	65	89	24
Group 5	58	79	21

Table 2.
Pedagogical Impact Across TALSc. Principles.

TALSc. Principle	Evidence	Outcome
Ancestral Connectivity	Learners related classroom content to family practices (fermentation, soil care)	Strengthened cultural identity and relevance of science
Dynamic Knowledge	Learners compared Indigenous and Western explanations	Recognition of science as adaptable and evolving
Relational Learning	Storytelling sessions, dialogue with elders	Fostered mutual respect between knowledge systems and collaborative learning

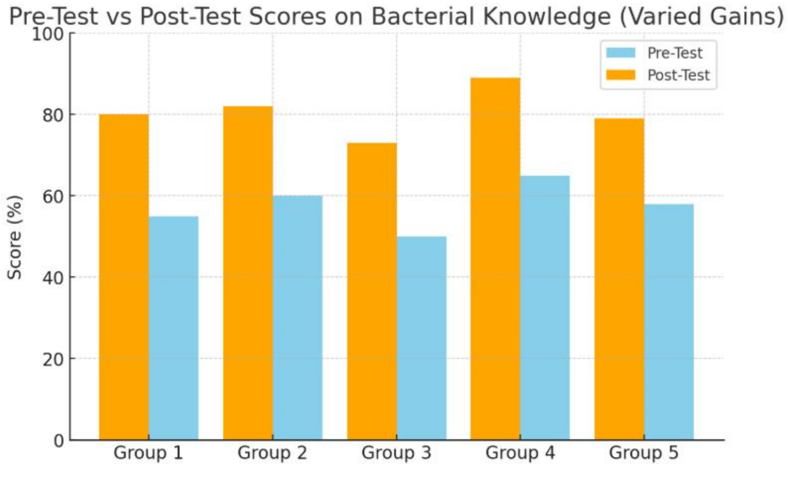

Figure 1.
Representing cognitive gains of pre- vs post-test scores.

Figure 1 shows improvement in bacterial knowledge across all learner groups, with varying gains indicating differentiated learning responses.

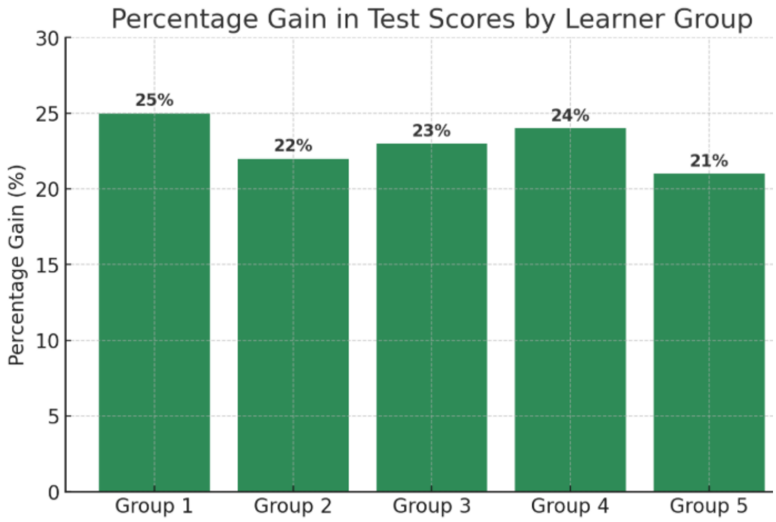

Figure 2.
Representing percentage gains per group in %.

Figure 2 **v**isualises each group's improvement, demonstrating that while all learners benefited from the culturally responsive approach, the extent of gain varied slightly suggesting nuanced influences such as prior knowledge and engagement with Indigenous content.

5.1.2. Findings

Learners' means test scores improved from 48% (pre-test) to 76% (post-test). Before the intervention, learners primarily associated bacteria with diseases; after the lesson, they recognized broader bacterial roles in fermentation, decomposition, and soil enrichment. Reflective journals and interviews showed high motivation (18 learners), high participation (19 learners), and high cultural pride (17 learners). Learners connected classroom content to family practices, compared Indigenous and Western explanations, and participated in storytelling sessions with elders.

5.1.3. Analysis

Pre- and post-test data revealed a clear improvement in learners' understanding of bacterial concepts after the culturally responsive lesson. Before the intervention, most learners associated bacteria mainly with diseases and hygiene practices. Post-test results showed a significant shift in perceptions, with learners demonstrating broader understanding of bacterial diversity, ecological functions, and beneficial roles in fermentation, decomposition, and soil enrichment. Learners' means test scores improved from 48% in the pre-test to 76% in the post-test, indicating deeper conceptual comprehension. The improvement was particularly strong in areas related to bacterial growth conditions, reproduction, and ecological significance. This suggests that integrating Indigenous examples such as the fermentation of milk to *amasi* or soil renewal through organic composting, enhanced learners' ability to link abstract concepts to real-world applications.

Conceptual comprehension increased particularly in areas of bacterial growth, reproduction, and ecological functions, suggesting that Indigenous examples (e.g., *amasi* fermentation, soil composting) enhanced learners' ability to link abstract concepts to real-world applications. Engagement data indicates strong affective outcomes: learners were motivated, participated actively, and expressed cultural pride. TALSc. principles structured the lessons, enabling learners to integrate cultural heritage with scientific understanding.

5.1.4. Discussion

These findings affirm the value of TALSc.'s first and second principles. The intergenerational transfer of knowledge created meaningful connections between learners' cultural experiences and scientific content, while the dynamic adaptability of Indigenous knowledge helped contextualise bacteria as both ancient and evolving agents in human and environmental life.The results support the growing body of literature advocating for culturally responsive science teaching [12]. By embedding bacterial concepts within Indigenous practices, this study demonstrated that cultural relevance improves learner motivation, participation, and retention of scientific knowledge.

The improvement in test scores and the richness of learners' reflections reveal that integrating Indigenous microbial knowledge enhances both cognitive and affective learning outcomes. TALSc. offered a framework that connected theory to practice, positioning learners as co-constructors of knowledge rather than passive recipients. This pedagogical shift aligns with calls for decolonisation of the Life Sciences curriculum, where local knowledge systems are recognised as valid, dynamic, and essential to understanding biology in African contexts. By incorporating Indigenous bacterial practices, the study not only improved scientific literacy but also restored cultural confidence and identity among learners.

In practical terms, this culturally responsive bacteria lesson serves as a model for integrating IKS into other Life Sciences topics, such as ecology, genetics, and human physiology. It demonstrates that culturally grounded pedagogy does not compromise scientific integrity, it enhances it by rooting learning in relevance, heritage, and community wisdom. Integrating Indigenous knowledge improved both cognitive (scientific understanding, motivation, participation) and affective (cultural pride, engagement) outcomes. The lessons fostered cultural confidence, strengthened learner identity, and demonstrated that decolonising the Life Sciences curriculum can enhance learning without compromising scientific integrity. This model is transferable to other Life Sciences topics, providing a framework for culturally responsive and contextually relevant science education.

5.2. Qualitative

5.2.1. Data Presentation

Qualitative data from interviews, reflective journals, and storytelling sessions revealed strong cultural engagement and a deepening awareness of Indigenous knowledge among learners, demonstrating the integration of TALSc. principles.

5.2.1.1. Cultural Engagement

Learners described the lesson in rich and varied ways, using terms such as “familiar,” “spiritual,” and “eye-opening.”

One learner remarked, “I didn’t know that what my grandmother does when making *amasi* is science. Now I understand that bacteria are involved to make food safe and healthy. It makes me proud of my culture.” (L5, journal)

Another shared, “I was surprised that the soil with cow dung in our gardens works the same way bacteria do in the lab. It makes me see my home differently.” (L6, interview)

A third learner reflected, “Hearing the stories about traditional fermentation made me feel connected to my ancestors and their knowledge.” (L7, interview)

A fourth commented, “I never thought that what we call ‘old ways’ in my family is actually part of science we learn in school.” (L2, journal)

A fifth learner noted, “The lesson opened my eyes to how Indigenous knowledge and science can work together, not against each other.” (L16, interview)

These reflections collectively illustrate Ancestral Connectivity, showing how learning bridges family traditions with scientific understanding. Storytelling sessions led by an Indigenous elder reinforced this engagement, with cultural narratives about microbial life enhancing learners’ comprehension of natural cycles of growth, decay, and renewal. The elder’s explanations of how bacteria sustain health and fertility added spiritual and ecological depth to scientific content, exemplifying TALSc.’s relational learning principle and fostering respect between Indigenous and Western knowledge systems.

5.2.1.2. Identity Awareness

Through these experiences, learners began to form a stronger sense of personal and cultural identity.

One learner said, “I feel proud that *amahewu* and *umqombothi* that my family has been fermenting for generations in preparation for traditional ceremonies are actually science.” (L10, interview)

Another reflected, “Connecting what I see and do at home with what we learn in Life science class makes me realise that science has always been part of my culture and my ancestors were scientists.” (L13, interview)

A third learner shared, “I never thought my grandmother’s way of making *amasi* could teach me about bacteria, it makes me respect and appreciate our traditional practices even more.” (L3, journal)

A fourth commented, “Learning that traditional soil fertilizers in our yards works on the same principles as lab experiments makes me value my home knowledge.” (L18, interview)

A fifth learner noted, “It’s exciting to see that Indigenous knowledge and school science are talking about the same things, just in different ways.” (L24, journal)

A sixth learner expressed, “I now feel like I can take pride in my heritage while understanding modern science, it gives me confidence in who I am and what I know.” (L29, journal)

By connecting classroom science to ancestral knowledge and home practices, learners recognised their cultural heritage as a legitimate and valuable source of scientific understanding. They reported increased pride in their communities and family traditions, understanding that ancestral practices, such as food fermentation and soil stewardship, are not only culturally significant but also scientifically informed. This process helped learners see themselves as active participants in a knowledge system that values both heritage and scientific inquiry, supporting the development of confident, culturally grounded learner identities.

Together, these outcomes created an epistemic balance, where multiple knowledge systems coexist in the classroom. Learners came to appreciate bacteria not only as microscopic organisms but also as agents sustaining health, soil fertility, and cultural continuity.

5.2.2. Findings

As evidence of engaging with culture, learners described lessons using terms like “familiar,” “spiritual,” and “eye-opening.” They recognized ancestral practices, such as *amasi* fermentation and traditional soil fertilizers, as forms of science. For example:

“I didn’t know that what my grandmother does when making *amasi* is science… It makes me proud of my culture.” (L5, journal)

“The lesson opened my eyes to how Indigenous knowledge and science can work together, not against each other.” (L6, interview)

Identity Awareness: Learners reported enhanced personal and cultural identity through connecting classroom science with home practices. Responses highlighted pride, respect for traditions, and confidence in bridging heritage and modern science:

"Connecting what I see at home with what we learn in class makes me realise that science has always been part of my culture and my ancestors were scientists." (L13, interview)

"I now feel like I can take pride in my heritage while understanding modern science; it gives me confidence in who I am and what I know." (L29, journal)

5.2.2.1. Integration of TALSc. Principles

The programme fostered ancestral connectivity by strengthening cultural pride and historical awareness among learners. It also promoted dynamic knowledge, encouraging an understanding of science as adaptable and continuously evolving within both Indigenous and Western knowledge systems. Furthermore, it cultivated relational learning through dialogue and mutual respect, enabling learners to view concepts such as bacteria as shared knowledge rather than points of cultural conflict.

5.2.3. Analysis

Table 3.
Distribution of student engagement, motivation, cultural pride, and participation in reflective activities.

Learning Outcome	Cognitive / Affective Domain	Low	Moderate	High
Motivation	Cognitive	2	5	18
Cultural Pride	Affective	1	7	17
Participation	Cognitive	0	6	19

Learner Engagement and Cultural Connection illustrate affective outcomes, with most learners reporting high motivation, participation, and cultural pride, highlighting the impact of integrating Indigenous knowledge. The table below complements bar graphs and clearly communicates both cognitive (e.g., understanding, motivation, participation) and affective (e.g., cultural pride, emotional engagement) learning outcomes from reflective journals and interviews:

Learners' reflections indicate strong affective engagement, showing motivation, pride, and emotional connection to Indigenous knowledge. The integration of home and cultural practices with classroom content demonstrates that learning is situated in lived experiences, enhancing comprehension of abstract scientific concepts. TALSc. principles acted as pedagogical scaffolds, linking cultural heritage to scientific inquiry and promoting co-construction of knowledge. Storytelling sessions with elders enriched learners' understanding of microbial life, adding spiritual, ecological, and relational dimensions to scientific content. These outcomes suggest that culturally responsive pedagogy supports both cognitive understanding (scientific principles, microbial roles) and affective growth (identity, pride, motivation).

5.2.4. Discussion

The qualitative data indicate that integrating Indigenous knowledge with Western science enhanced learners' cultural engagement, identity formation, and conceptual understanding, an outcome consistent with Grant [7] argument that culturally responsive pedagogy (CRP) transforms science from a culture-free subject into a contextually grounded practice. Learners described the lesson as *"familiar," "spiritual,"* and *"eye-opening,"* highlighting the relevance of ancestral practices such as fermentation and soil care to scientific concepts. This echoes Buthelezi [2] view that CRP enables learners to link abstract science concepts to culturally familiar contexts, strengthening their social and cultural identities.

Storytelling sessions with an Indigenous elder reinforced this engagement, helping learners connect bacterial processes to natural cycles of growth, decay, and renewal principles reflected in Mavuru [8] finding that learners show greater motivation and understanding when their culture is represented in scientific learning. These practices embody TALSc.'s principles of ancestral connectivity and relational learning, positioning Indigenous knowledge as co-equal with Western science. TALSc. encourages teachers to present biological concepts in ways that acknowledge cultural values, ancestry, and spirituality. Within bacterial education, this framework highlights how microbial life connects to cycles of renewal and balance concepts deeply embedded in Indigenous worldviews and consistent with Black and Tylianakis [9] who argue that Indigenous and Western systems are complementary rather than opposing ways of knowing.

Identity formation emerged as a key pedagogical outcome. Learners expressed increased pride in their heritage and recognised ancestral practices as legitimate scientific knowledge, aligning with Grant [7] call for the validation of multiple epistemologies in science classrooms. Reflections such as *"I now feel like I can take pride in my heritage while understanding modern science"* illustrate the development of culturally grounded scientific identities, an aspect supported by Buthelezi [2] who links identity formation to the recognition of cultural relevance in science education.

Furthermore, the integration of TALSc. principles created co-pedagogical spaces where learners, teachers, and elders collaborated as equal contributors. This aligns with Gugulethu [3] observation that teachers require structured frameworks and professional tools to bridge the cultural gap in Life Sciences teaching. By operationalising TALSc., educators can overcome this gap and foster epistemic balance in the classroom.

Overall, the findings demonstrate that culturally responsive pedagogy, grounded in TALSc. principles, creates an epistemically balanced classroom where multiple knowledge systems coexist. Learners not only gain conceptual understanding of bacterial roles but also develop a deeper appreciation of cultural heritage, reflecting the interconnectedness between culture and science emphasised across the literature [2, 6-9]. Integrating Indigenous knowledge thus enhances engagement, relevance, and meaningful learning in Life Sciences education, effectively decolonising the curriculum and fostering culturally aware, confident learners.

Table 4.
Saldana coding system.

Category	Codes / Evidence	Theme	Sub-Themes
Cultural Engagement	Learners described lesson as “familiar,” “spiritual,” “eye-opening”; references to fermentation and soil care	Learner Connection to Indigenous Knowledge	• Recognition of ancestral practices • Cultural relevance of scientific content • Linking home practices to scientific principles
Identity Formation	Learner reflections: “I now feel proud of my heritage while understanding modern science”; pride in family knowledge	Culturally Grounded Scientific Identity	• Self-confidence in integrating cultural and scientific knowledge • Legitimising ancestral knowledge • Learner agency and epistemic validation
Relational Learning	Storytelling sessions with Indigenous elder; guided discussions	Integration of Knowledge Systems	• Dialogue between Indigenous and Western epistemologies • Respect for multiple ways of knowing • Linking cultural narratives to scientific concepts
Scientific Understanding	Drawing and labelling bacteria; observing fermentation and decomposition	Conceptual Learning	• Comprehension of bacterial structure and function • Application of scientific concepts to real-life contexts • Experiential and investigative learning
Epistemic Balance	Learners compared Indigenous and Western explanations; integrated knowledge in reflections and presentations	Knowledge Coexistence	• Recognition of complementary knowledge systems • Bridging traditional and modern science • Holistic understanding of bacteria in cultural and ecological contexts

Table 5.
Pedagogical Impact Across TALSc. Principles.

TALSc. Principle	Evidence	Outcome
Ancestral Connectivity	Learners related classroom content to family practices (fermentation, soil care)	Strengthened cultural identity and relevance of science
Dynamic Knowledge	Learners compared Indigenous and Western explanations	Recognition of science as adaptable and evolving
Relational Learning	Storytelling sessions, dialogue with elders	Fostered mutual respect between knowledge systems and collaborative learning

5.2.4.1. Integration of TALSc. Principles

The findings illustrate how TALSc**.** principles functioned as dynamic pedagogical tools. *Ancestral Connectivity* deepened cultural pride and historical awareness, linking Indigenous microbial knowledge to modern microbiology. *Dynamic Knowledge* encouraged learners to view science as evolving and responsive, recognising that both Indigenous and Western knowledge systems grow through observation and experimentation. *Relational Learning* promoted dialogue and mutual respect, enabling learners to understand bacteria as shared knowledge rather than a site of epistemic competition.

Ultimately, the qualitative findings affirm that culturally responsive Life Sciences teaching, informed by TALSc. and supported by CRP theory [2, 6-9] decolonises science education by validating Indigenous and Western knowledge as coexisting systems. Learners developed culturally grounded scientific identities, gaining both conceptual understanding and affective engagement. Through this process, the Life Sciences classroom became a space of epistemic balance—where knowledge is both cultural and scientific, where learning is both cognitive and relational, and where the spirit of science reflects the lived wisdom of community and ancestry.

6. Conclusion

This study explored how a culturally responsive pedagogical tool, grounded in the Theory of Ancestral Life Sciences (TALSc.), can transform the teaching of bacteria in the Life Sciences curriculum. The integration of Indigenous Knowledge Systems (IKS) provided a holistic approach that recognised both the scientific and cultural dimensions of microbial life.

Through this approach, learners engaged with bacteria not only as microscopic organisms but as agents of healing, renewal, and ecological balance within their cultural contexts.

The findings revealed that when bacterial concepts were taught through Indigenous practices, such as fermentation of *amasi*, composting, and traditional medicine preparation, learners' conceptual understanding and cultural identity were significantly strengthened. Quantitative results showed improved academic performance, while qualitative insights reflected increased cultural pride, engagement, and a deeper appreciation for the coexistence of Indigenous and Western knowledge systems.

Applying the TALSc. principles, *Ancestral Connectivity, Dynamic Knowledge,* and *Relational Learning* created meaningful connections between learners lived experiences and classroom science. Learners began to view their ancestral wisdom as scientifically valuable and relevant to contemporary microbiology. The study demonstrated that the inclusion of IKS in bacteria education fosters epistemic balance, cultural affirmation, and scientific literacy, advancing the broader goals of curriculum decolonisation in Life Sciences education.

7. Recommendations

Based on the findings, several recommendations are proposed for policy, curriculum design, and classroom practice.

7.1. Curriculum Integration

The Life Sciences curriculum should intentionally include Indigenous microbial knowledge and examples related to fermentation, soil fertility, and healing practices. Such inclusion can make the study of bacteria contextually relevant and culturally responsive, especially for learners in rural and township schools.

7.2. Teacher Professional Development

Teachers need structured professional learning programmes that expose them to Indigenous microbial knowledge and its scientific foundations. Training workshops and collaborations with community elders can equip teachers with confidence to integrate IKS meaningfully in their lessons.

7.3. Community Collaboration

Schools should form partnerships with Indigenous knowledge holders, including healers, elders, and traditional food practitioners. These collaborations can serve as co-teaching opportunities, ensuring that ancestral knowledge is accurately represented and valued in formal education.

7.4. Pedagogical Innovation

Educators are encouraged to use co-pedagogical models that combine scientific inquiry with storytelling, land-based learning, and practical demonstrations. This approach helps learners experience science as living knowledge connected to their culture and environment.

7.5. Research and Policy Support

Further research is needed to explore how TALSc. based pedagogy can be applied to other Life Sciences topics such as ecology, genetics, and human health. Education policymakers should also support curriculum transformation that recognises Indigenous Knowledge as a vital component of scientific literacy and sustainability education. This study affirms that culturally responsive pedagogy in Life Sciences is not about replacing Western science but reclaiming balance between different ways of knowing. By drawing on TALSc., the teaching of bacteria becomes a bridge between past and present, culture and science, community and classroom. When learners see their ancestral practices validated through scientific understanding, they not only learn more effectively but also develop a stronger sense of belonging in science.

Through this framework, Life Sciences education can evolve into a space that honours diversity, nurtures curiosity, and sustains cultural continuity, ensuring that the knowledge of the ancestors lives on in the laboratories and classrooms of today.

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