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Integrating Mathematical Modelling of Disease Transmission into Life Sciences Classrooms: A Pedagogical Approach

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ABSTRACT

The COVID-19 pandemic has reawakened the world to the essential role of scientific literacy and the ability of citizens to interpret, trust and act upon scientific information. Within the school curriculum, Life Sciences education plays a critical role in cultivating such literacy. Yet, one area that remains underdeveloped is the integration of mathematical modelling, an approach that enables learners to visualise, quantify and predict biological processes. This conceptual paper explores how mathematical modelling can be integrated into Life Sciences teaching, particularly in the context of disease transmission and immunity. Drawing from both Western scientific frameworks and Indigenous Knowledge Systems of health and disease, the paper proposes a pedagogical model grounded in constructivist and culturally responsive paradigms. In addition, this paper introduces a BioMath Pedagogical Tool designed to guide teachers in implementing interdisciplinary, culturally grounded modelling activities within Life Sciences classrooms. In Life Sciences classroom, learners can simulate how an infectious disease spreads through peer-to-peer contact and use mathematical reasoning to interpret the data they collect, mirroring real-world epidemiological modelling. Such experiences allow learners to link abstract numerical patterns to tangible biological phenomena. The integration of mathematics and biology is shown not merely as a curriculum innovation but to humanise science education. It equips learners with critical reasoning, contextual understanding, and the capacity to engage meaningfully with global health challenges.

Keywords: BioMath Pedagogical Tool, Life Sciences Education, Mathematical modelling, Disease Transmission, Constructivist Pedagogy, Culturally Responsive Teaching, Epidemiology

INTRODUCTION

Education in the 21st century demands more than the passive acquisition of facts (Sibanda & Marongwe, 2022). Learners must engage with complex, interconnected systems that shape the living world and their own health. The global experience of pandemics such as HIV/AIDS, Ebola and COVID-19 has demonstrated how profoundly scientific understanding influences individual and collective action (Friedler, 2021). However, these crises have also revealed persistent gaps in the public's ability to interpret data, understand modelling outcomes and evaluate scientific predictions. During the COVID-19 pandemic, many people encountered daily infection graphs and "flatten-the-curve" diagrams, yet few understood how these visualisations were generated through mathematical models like the SIR (Susceptible–Infected–Recovered) framework (Saxena, Jadeja & Bhateja, 2022). Introducing these simple models in the Life Sciences classroom provides learners with the tools to interpret such information critically.

In South Africa and other contexts of epistemic plurality, learners' understanding of disease and wellness is deeply shaped by both Western biomedical paradigms and Indigenous health knowledge systems. While Life Sciences curricula emphasise biological processes of infection and immunity (DBE, 2011), the mathematical reasoning underlying disease spread, the quantitative "why" behind biological "how", is rarely made explicit. Consequently, learners often memorise facts without appreciating how mathematical models like the SIR framework enable scientists to simulate real-world phenomena.

Integrating mathematical modelling into Life Sciences teaching thus holds promise as a transformative pedagogical practice. It not only strengthens conceptual understanding but also bridges disciplinary boundaries, encourages inquiry-based learning and validates Indigenous understandings of disease dynamics, such as traditional quarantine practices, community-based prevention and ecological awareness. A practical application would involve learners comparing a mathematical model's infection curve with historical Indigenous disease-control practices. For example, communities often implemented the temporary isolation of individuals showing symptoms of measles or smallpox, an intuitive form of modelling that predates formal epidemiology.

LITERATURE REVIEW

The Intersection of Life Sciences and Mathematics

Mathematics and biology have historically evolved as distinct disciplines. Yet, at their core, both are languages of pattern, prediction, and relationship. As Muller (2025) observe, mathematical modelling provides a "conceptual bridge" that enables learners to perceive biology not as a collection of facts but as a dynamic system of change. Similarly, Awad, (2021) emphasise that STEM integration allows for "cross-fertilisation of disciplinary reasoning", fostering authentic problem-solving in classrooms. A classroom example of this bridge can be seen when learners record the number of classmates "infected" through a paper-based handshake simulation. After several rounds, learners plot their data to generate an exponential curve. This simple mathematical activity helps them visualise how diseases spread biologically through contact.

In the context of epidemiology, mathematical models have been instrumental in predicting and managing disease outbreaks (Meyer & Lima, 2023). Models such as the SIR and SEIR frameworks allow scientists to represent infection rates, recovery dynamics, and immunity thresholds. However, in educational contexts, these models remain largely confined to tertiary-level or specialised mathematical studies (Bishop, 1996).

Simplifying such models for school use for instance, using ratios or graphical representations instead of differential equations allows Life Sciences learners to appreciate the relationships between transmission rates, immunity, and public health interventions.

Scientific Literacy and Post-Pandemic Education

Scientific literacy is no longer an academic luxury but a civic necessity. Learners must understand not only what science says but also how scientific knowledge is generated and validated. The post-pandemic classroom thus presents an opportunity to reimagine Life Sciences education as a platform for nurturing critical, numerate and socially aware learners. In practice, a teacher might integrate a task where learners interpret newspaper graphs showing COVID-19 case numbers, mortality rates, or vaccination trends. Learners can calculate the rate of change between weeks or months, using basic mathematical operations to understand how scientific data informs health policy. The pandemic also exposed the challenge of misinformation and the difficulty many learners and adults face in interpreting graphs, rates, and probabilities. As Gugulethu, (2025) argues, true scientific literacy in African contexts must accommodate multiple knowledge systems, encouraging dialogue between Indigenous and Western epistemologies.

Indigenous Knowledge Systems and Health Education

Indigenous communities have long modelled disease and wellness through observation and relational thinking. Practices such as isolation of the sick, monitoring of seasonal disease patterns, and communal responses to epidemics are grounded in an intuitive understanding of transmission dynamics. An informal and cultural form of modelling.

For example, in many Xhosa and Zulu communities, individuals with contagious illnesses were traditionally isolated in separate huts or instructed to stay away from communal gatherings. A behavioural intervention that mirrors the principle of reducing the transmission coefficient (β) in mathematical terms.

By acknowledging these epistemologies, educators can help learners see that both Western mathematical models and Indigenous experiential models serve the same purpose. That is, explaining, predicting and managing life processes. Integrating Indigenous health understandings within Life Sciences classrooms thus supports epistemological pluralism and contributes to decolonial Life science education (Gugulethu, 2025), where learners recognise the value of both systems of thought.

THEORETICAL FRAMEWORK

This paper is anchored in three intersecting theoretical perspectives that inform the pedagogical approach viz Constructivist Learning Theory, Cultural-Historical Activity Theory (CHAT) and Culturally Responsive Pedagogy.

Constructivist Learning Theory

Learning is viewed as an active process of constructing meaning from experience. By engaging learners in modelling activities such as simulating an epidemic through role-play or data collection, they are encouraged to make sense of biological and mathematical concepts collaboratively.

Cultural-Historical Activity Theory (CHAT)

This framework explains how learning is mediated through cultural tools including language, models and representations that reflect specific worldviews (Vygotsky, 1986). Here, mathematical symbols and Indigenous narratives both serve as mediating tools for understanding disease. For instance, a graph of infection rates and an oral narrative of community response to disease both represent patterns over time and can be compared as forms of modelling.

Culturally Responsive Pedagogy

Gugulethu (2025) emphasises teaching that builds on learners' cultural backgrounds and knowledge systems. Integrating Indigenous understandings of disease supports learner identity and relevance, while linking these insights to quantitative models builds cross-epistemic competence.

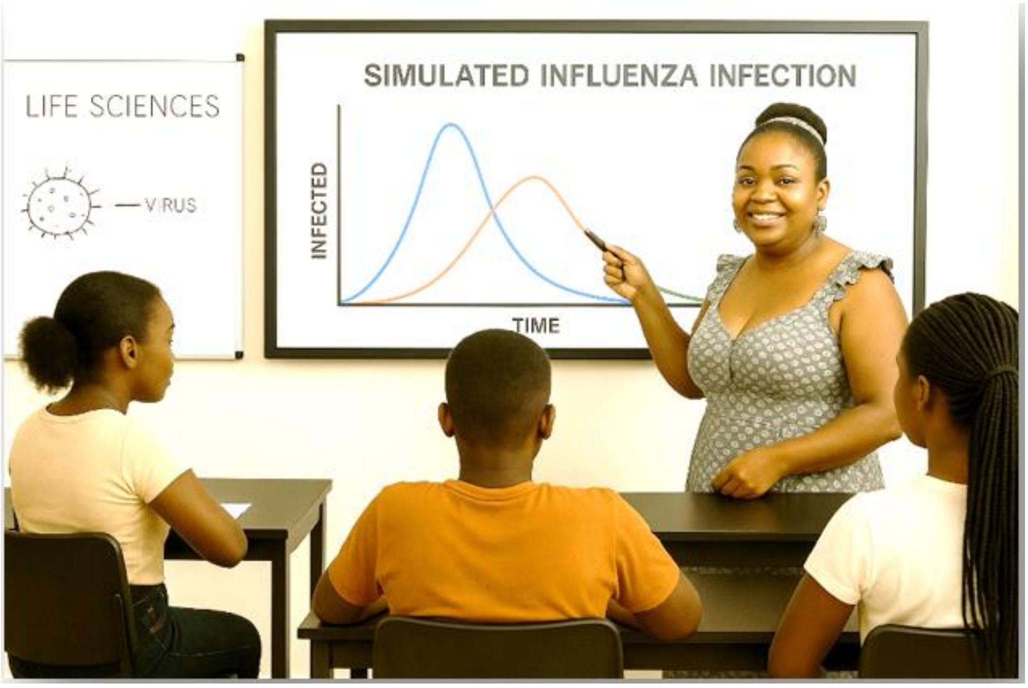
These theoretical perspectives collectively provide the foundations for understanding how learners construct knowledge at the intersection of Life Sciences and Mathematics.

CONCEPTUAL FRAMEWORK

The conceptual framework of this paper illustrates how theoretical perspectives translate into a practical pedagogical approach for integrating mathematical modelling in Life Sciences classrooms. It positions mathematics as a language for understanding biological processes, while also recognising Indigenous epistemologies as parallel forms of modelling disease and community health practices. The framework guides the design of classroom activities from simulations and spreadsheet modelling to reflective discussions, showing how learners move from conceptual understanding the mathematical representation to contextual application. This framework ensures that teaching strategies are not only cognitively rigorous but also culturally responsive, supporting learners' systems thinking, critical reasoning and ability to connect abstract models to real-world biological and social phenomena.

PEDAGOGICAL APPROACH OF INTEGRATING MATHEMATICAL MODELLING IN LIFE SCIENCES

The proposed pedagogical approach BioMath Pedagogical Tool (BMPT) emphasises the integration of biology and mathematics while centring the cultural dimensions of learning. This approach is suitable for use in conceptual frameworks where emotional, ethical and social aspects of science education are highlighted. This approach unfolds in four phases. It is designed to be adaptable across secondary and tertiary Life Sciences curricula.



The BioMath Pedagogical Tool (BMPT)

The BioMath Pedagogical Tool (BMP Tool) is proposed as a practical framework that guides teachers in facilitating the integration of mathematical modelling within Life Sciences classrooms. It operationalises the BioMath Pedagogy by providing a structured sequence of teaching activities that blend biological concepts with quantitative reasoning, grounded in learners' cultural contexts. The tool consists of four key components viz **(1)** the conceptual Grounding in Biology, **(2)** introduction to mathematical modelling, **(3)** collaborative modelling and simulation, as well as **(4)** reflection, integration, and application. By following these stages, teachers can help learners move from conceptual understanding to applied reasoning, linking community-based experiences with formal scientific models. The BMP Tool thus serves as both a teaching guide and a learning scaffold, promoting culturally responsive, inquiry-driven and humanised science learning experiences.

Phase 1: Conceptual Grounding in Biology

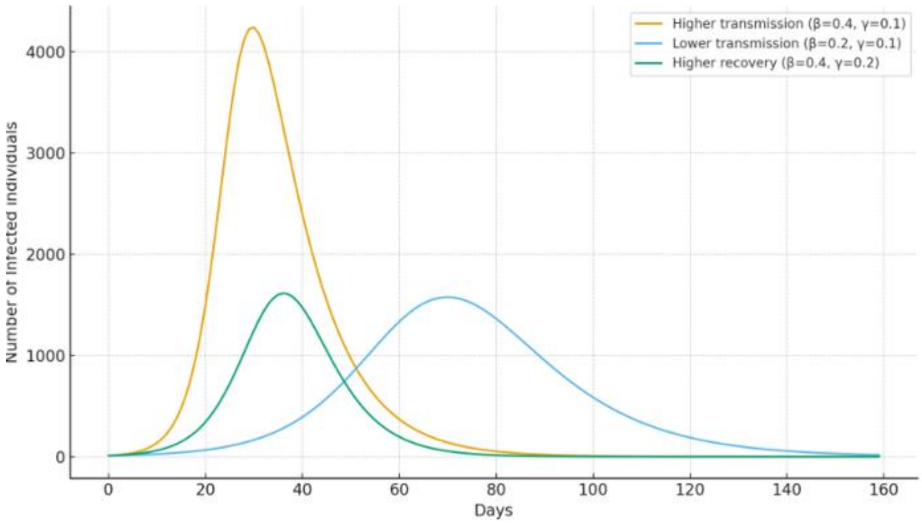
Grade 11 learners begin with conceptual discussions on the nature of infectious diseases, modes of transmission, immunity and vaccination. Teachers contextualise these topics using familiar examples such as HIV/AIDS, influenza, and COVID-19, alongside Indigenous understandings of disease and community health. The teacher could invite a community elder to share stories about how local communities have historically responded to disease outbreaks such as measles or cholera. This will allow learners to connect Indigenous experiences of epidemic management with contemporary scientific understanding. Learners can then compare these traditional methods of isolation and herbal treatment with modern vaccination and sanitation approaches. Learners discuss traditional disease-prevention methods, such as isolation, drinking herbs like *ikhathazo* and *umhlonyane*, and steaming with gumtree leaves. They also explore cleansing rituals as forms of early public health interventions grounded in observation.

Phase 2: Introduction to Mathematical Modelling

The teacher introduces and explains that the SIR model helps to show how diseases spread by grouping people into three categories. Those who can get sick or can be infected (**S-** susceptible), those who are sick or infected (**I**- infected), and those who have recovered and become immune to a disease (**R**-recovered), (Saxena, Jadeja & Bhateja, 2022).

Learners explore simplified equations and visual representations that show how changes in transmission and recovery rates affect infection curves. Graphs are used to make abstract equations tangible, allowing learners to see how biological processes translate into mathematical language.

For instance, learners could calculate the rate of infection in a simulated class activity where each "infected" learner passes a sticker to two others, representing person-to-person transmission. After several rounds, they record and plot the number of infections against time, observing the characteristic exponential increase that mirrors real-world disease spread. Such experiential modelling helps learners connect mathematical reasoning with biological understanding. Transforming numbers and equations into meaningful representations of life processes.



Graph 1. Simulated influenza infection curves (SIR model).

The graph representation plotted the number of infected individuals $I(t)$ over 160 days for the three scenarios. The plot shows:

Higher transmission (β=0.4, γ=0.1) — a sharp, early peak with many simultaneous infections (a "tall, narrow" curve). This illustrates why fast spread can overwhelm healthcare resources.

Lower transmission (β=0.2, γ=0.1) — a later, lower peak (a "flatter, wider" curve). Slowing transmission delays and reduces the peak burden on services.

Higher recovery (β=0.4, γ=0.2) — the peak occurs earlier than the low-transmission case but is substantially lower than the high-transmission/low-recovery scenario; faster recovery reduces the number of active infections at any time.

The simulation utilized (1) simplified discrete SIR equations to model the spread of infection within a classroom setting. (2) Three distinct parameter scenarios, each relevant to classroom dynamics, were explored to assess how variations in transmission and recovery rates influence disease progression. The resulting infection curves provide a clear (3) visual interpretation of these dynamics, illustrating how changes in parameters affect both the peak and duration of infection, thereby offering practical insights for understanding and managing disease spread in educational environments.

Below is the simplified discrete SIR equations used in the simulation, the three classroom-relevant parameter scenarios and a short interpretation of the resulting infection curves.

Simplified SIR Equations (Discrete Form)

For a population N and at each time step t:

$$
\begin{aligned}
S_{t+1} &= S_t - \beta \frac{S_t I_t}{N}, \\
I_{t+1} &= I_t + \beta \frac{S_t I_t}{N} - \gamma I_t, \\
R_{t+1} &= R_t + \gamma I_t.
\end{aligned}
$$

Here β is the transmission rate (probability of infection per contact × contact rate) and γ is the recovery rate (fraction of infected who recover each day).

How can a Life sciences teacher use this in class?

Run the handshake/sticker simulation to gather simple data, then compare your class curve to the simulated curves to discuss effects of β and γ. Use the three scenarios to illustrate concrete interventions: reducing β (masks, distancing, fewer contacts, cultural practices that limit gatherings) and increasing γ (effective treatment, faster recovery). Ask learners to suggest a culturally grounded intervention (e.g., temporary isolation, community cleansing ceremonies) and map it to a change in β or γ. Then re-run the model to see the effect.

Phase 3: Collaborative Modelling and Simulation

Learners work in groups to simulate disease spread using spreadsheets, interactive digital tools, or even manual calculations. By adjusting parameters, they observe how interventions (e.g., vaccination or isolation) influence outcomes. They can also explore Indigenous practices such as seasonal healing gatherings, use of medicinal plants for steaming, or community quarantines as additional variables, reinforcing the idea that models represent lived human practices. Learners may input data representing "reduced transmission" after a cultural event where herbal purification is practiced, comparing it to a model where no intervention is applied. Such activities highlight how both mathematical reasoning and cultural practices aim to limit disease spread.

Phase 4: Reflection, Integration and Application

Finally, learners interpret their findings. They discuss how mathematical patterns correspond to biological realities and societal behaviours. Reflection activities ask learners to connect Western models with Indigenous prevention methods, recognising that both aim to sustain community health. As a reflective task, learners could write a comparative report and create a poster showing how the mathematical SIR model and a traditional community response (e.g., isolation huts or restricted movement during sickness) achieve similar outcomes through different epistemic pathways. Through this process, learners develop systems thinking, numeracy and critical reflection the foundations of scientific literacy.

IMPLICATIONS FOR TEACHING AND TEACHER EDUCATION

For teachers, interdisciplinary teaching requires confidence in both Life Sciences content and basic mathematical reasoning. Teacher education programmes should thus provide training in pedagogical content knowledge (PCK) for integration. Teachers can benefit from collaborative workshops where they design interdisciplinary lessons, share culturally relevant examples and explore digital modelling tools. Pre-service teachers could participate in simulation workshops where they build lesson plans integrating disease-modelling spreadsheets and discussions of Indigenous health practices. Such training equips teachers to deliver balanced, contextually rich lessons.

Additionally, incorporating Indigenous perspectives requires cultural competence and respectful engagement with community knowledge holders. Teacher education institutions should foster dialogue between science educators and local elders to co-create contextually authentic learning materials.

DISCUSSION

The proposed integration of mathematical modelling into Life Sciences (BioMath Tool) represents a shift from content transmission to knowledge construction. It humanises science education by linking abstract equations to real-life experiences of disease and health. In this approach, mathematics is no longer seen as a gatekeeper but as a sense-making tool, a language through which learners can see the invisible workings of biology.

When learners use mathematical models to simulate influenza transmission and then compare their findings to Indigenous teachings on safe social behaviour and communal healing, they begin to recognise that different knowledge systems often share the same scientific logic of prediction and prevention. Moreover, by bringing Indigenous health epistemologies into the conversation, the classroom becomes a space of epistemic justice, where learners' cultural ways of knowing are respected and integrated. Such pluralistic pedagogy aligns with current decolonial movements in South African education and supports the vision of producing learners who can think critically, act ethically and appreciate the complexity of the natural world.

CONCLUSION

Integrating mathematical modelling of disease transmission into Life Sciences classrooms is not merely an academic exercise, it is an educational necessity. It prepares learners to navigate a world where health information is data-driven and interconnected. This interdisciplinary and culturally responsive pedagogy enhances conceptual understanding, fosters critical reasoning, and cultivates a sense of global citizenship rooted in local realities. Through activities such as simulation games, spreadsheet modelling and analysis of both biomedical and Indigenous responses to disease, learners not only learn science but live it quantitatively, contextually and culturally.

Ultimately, teaching learners to model disease spread is teaching them to model life itself, its patterns, its vulnerabilities, and its capacity for renewal. It is through such integrative and humanised teaching that Life Sciences education can truly serve humanity.

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