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Research Article

Mathematics for Life Sciences: A Case Study from Rural India

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Abstract

This paper presents a two-year pilot study investigating the impact of a contextualized, activity-based mathematics education model on academic outcomes and practical application in rural India. By embedding mathematical concepts within life sciences contexts relevant to local agrarian communities—including crop management, fisheries, and epidemiology—the intervention aimed to bridge the gap between abstract curriculum and real-world problem-solving. Grounded in Realistic Mathematics Education (RME), the program trained local fellows to deliver supplemental modules to 500+ primary-grade students across 20 underserved schools. Using a mixed-methods design, results demonstrated a 28% improvement in standardized mathematics scores among participants compared to a 12% gain in control groups. Applied outcomes included a 15% increase in agricultural yield in participating households through the use of optimized irrigation ratios informed by student-led calculations. Qualitative findings revealed enhanced student engagement, reduced mathematics anxiety, and greater participation among girls and marginalized learners. The study highlights a replicable framework for integrating mathematics with life sciences, contributing to STEM equity, community resilience, and sustainable development in resource-limited settings. Findings align with national educational goals and underscore the potential of localized, experiential learning to transform rural mathematics education.

Abbreviations

ABL: Activity-Based Learning; RME: Realistic Mathematics Education; BPL/APL: Below/Above Poverty Line; SIR: Susceptible-Infectious-Recovered; STEM: Science, Technology, Engineering, Mathematics; NGO: Non-Governmental Organization; PRI: Panchayati Raj Institution

Introduction

Agriculture employs over 60% of rural India's population, yet mathematics curricula in these regions often lack relevance to real-world challenges, contributing to high dropout rates and poor quantitative skills [1]. Traditional rote-learning methods fail to engage students or address local needs such as pest modeling, yield optimization, and health tracking. Grounded in Realistic Mathematics Education (RME), this case study evaluates a two-year Activity-Based Learning (ABL) pilot program (2023–2025) implemented across 20 underserved schools in rural clusters. The program trained 50 local fellows to deliver context-sensitive mathematics instruction to 500+ students in Grades 1–5, integrating arithmetic, geometry, and discrete models with life sciences contexts such as crop management, fisheries, and epidemiology.

Improvements in mathematics performance were evaluated through pre- and post-tests (n = 800) covering foundational numeracy and applied modeling, with gains measured in percentage score improvements. Agricultural yield improvements (reported as a 15% increase) were assessed through student-led field projects in which participants applied optimized irrigation ratios and simple growth models to family or community plots, with yield data collected before and after intervention and verified through parent and local farmer interviews. The program aimed to reduce math anxiety

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and foster quantitative resilience by making learning tangible and locally relevant.

Grounded in Realistic Mathematics Education (RME), this case study evaluates an ABL intervention (2023–2025) that supplemented—rather than replaced—the existing mathematics curriculum. The intervention trained 50 local fellows to deliver context-sensitive mathematics instruction to 500+ students across 20 underserved schools, connecting core curricular topics to real-world applications without altering official syllabi. This approach ensured alignment with state learning outcomes while enhancing relevance through applied, life-science contexts.

Literature review

Recent scholarship in mathematics education, STEM equity, and rural pedagogy underscores the growing emphasis on contextualized and applied learning, particularly in underserved regions. This review synthesizes key contributions from 2022 to 2025 that inform the design and evaluation of activity-based, life-science-integrated mathematics interventions in rural settings.

A central theme in contemporary literature is the **relevance gap** in rural mathematics education. Singh, Verma, and Sharma [1] argue that traditional curricula in rural India remain abstract and disconnected from agrarian realities, contributing to high dropout rates and persistent quantitative skill deficits. Their work highlights the need for pedagogical models that connect mathematical concepts to local socio-economic and environmental contexts, a view supported by Patel and Desai [2], who demonstrated that context-rich problem-solving significantly improves engagement and retention among rural learners.

The theoretical underpinning of such contextualized approaches is often traced to Realistic Mathematics Education (RME). Recent applications of RME in low-resource settings are explored by Kumar and Nair [3], who documented the successful integration of local agricultural data into middle-school mathematics modules across several Indian states. Their findings show that students exposed to RME-inspired modules not only performed better on standardized tests but also demonstrated improved ability to apply mathematical reasoning to familiar problems, such as calculating seed ratios or interpreting weather data trends.

Concurrently, there is a growing advocacy for introducing quantitative modeling early in the educational pipeline. In their 2024 report, the Global STEM Education Initiative called for the inclusion of basic dynamical systems—such as population growth and epidemic models—in primary curricula to build foundational data literacy. This aligns with the work of Chen and Oyelere [4], who found that simplified versions of models like the logistic growth and SIR frameworks are accessible to upper-primary students when taught through simulation and storytelling, fostering what they term "pre-disciplinary STEM intuition."

The role of activity-based learning (ABL) as a vehicle for this integration is well-documented. A 2025 meta-analysis by the Jain Education Trust reviewed 17 studies from South Asia and sub-Saharan Africa and concluded that ABL interventions consistently produce larger learning gains in mathematics than traditional instruction, particularly in rural areas. The analysis notes that gains are most pronounced when activities are anchored in locally meaningful scenarios, such as resource management or public health.

Finally, the intersection of education, equity, and community development is a critical area of recent inquiry. Research by the Partnership for Rural Education [5] emphasizes that successful interventions in rural India often depend on leveraging local human capital—such as training community fellows—and aligning with existing governance structures like Panchayati Raj Institutions. Furthermore, Iyer and Kapoor [6] stress the importance of gender-responsive design in STEM education, noting that girls' participation and confidence increase markedly when mathematics is framed as a tool for solving community-level challenges rather than as an abstract academic filter.

In summary, the literature from 2022–2025 converges on several key insights: the urgency of making mathematics relevant to rural livelihoods, the efficacy of RME and ABL frameworks, the value of early exposure to applied modeling, and the necessity of community-embedded, equity-focused implementation. The present study builds directly on this foundation by designing and evaluating an ABL pilot that explicitly connects primary-grade mathematics to life-science contexts in rural India.

Methodology

The pilot targeted Grades 1–5, using low-tech workbooks and field-based activities to ensure accessibility. A mixed-methods design was employed, with pre- and post-tests ($n = 800$) and regression analysis to control for socio-economic factors. Qualitative insights were drawn from classroom observations and parent interviews.

Intervention components

Drawing from Realistic Mathematics Education (RME) principles, which emphasize context-rich problem-solving [3], the intervention was organized into three complementary domains, each designed to enrich the existing mathematics curriculum by linking standard topics to experiential, real-world applications. The intervention did not replace school programs but rather supplemented them with contextualized modules that could be integrated into regular class hours or conducted as after-school activities.

- **Foundational Skill Building**: Students engaged in tactile and social games to reinforce number sense, arithmetic, and basic geometry. Activities included seed-sharing simulations to teach division and fractions, and farm-plot mapping exercises using ropes and sticks to estimate area and perimeter. These were conducted

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in small groups to encourage collaboration and verbal reasoning.

- **Life Science Modeling**: Through structured activities, students explored two core mathematical models applied to local contexts: the logistic growth model for fisheries management and the SIR model for epidemiology. Using low-cost materials (beads, cards, role-play) and guided workbooks, learners simulated population dynamics and disease spread, then formalized their observations using discrete and differential equations adapted to their grade level.
- **Community Engagement**: Local fellows conducted home and farm visits with students and their families, facilitating discussions on how mathematical reasoning could optimize daily practices such as irrigation scheduling, seed spacing, and harvest planning. Special emphasis was placed on involving girls and students from marginalized groups, with activities designed to build confidence and demonstrate the practical value of mathematics in household and agricultural decision-making.

Mathematical models used and pedagogical implementation

To bridge abstract mathematical concepts with real-world applications, two foundational models were introduced to students: the logistic growth model for population dynamics and the SIR model for epidemiology. These were selected for their relevance to local agrarian and health contexts. The implementation followed a three-phase pedagogical approach:

1. **Contextual introduction**: Real-world scenarios (e.g., pond fish populations, village disease outbreaks) were presented through stories, local news, or field visits.
2. **Simplified modeling**: Concepts were broken down using tactile and visual aids (e.g., bead counters for population sizes, colored cards for SIR compartments).
3. **Mathematical formalization**: The simplified scenarios were connected to mathematical equations through guided group activities and workbook exercises.

Logistic growth model (Fisheries Management): This model was chosen as the first applied framework because it is directly connected to a visible and vital local resource—the village pond fishery. It provided a tangible way to introduce the core mathematical concepts of exponential growth, limits, and system equilibrium.

Equation:

$$N(t+1) = N(t) + r \times N(t) \times [1 - N(t)/K]$$

Where:

- $N(t)$ = population size at time t
- r = intrinsic growth rate
- K = carrying capacity of the environment

Application: Used to model fish population dynamics in local ponds and teach exponential growth concepts.

Implementation with Students: Students first conducted a field observation of a local pond, estimating fish numbers visually and through discussion with fishers. They then used colored beads to simulate population growth over several "seasons," adjusting for limited resources (food/space). The discrete logistic equation was introduced as a way to "predict" next season's population, with students filling in tables and plotting growth curves in their workbooks. Parameters r and K were estimated from local ecological knowledge shared by community members.

SIR model (Epidemiology): Complementing the logistic growth model for environmental resources, the SIR model was introduced to connect mathematical modeling to community health—a critical concern in rural settings. This epidemiological framework provided students with a powerful tool to understand and visualize disease dynamics, reinforcing concepts of rates, proportions, and graphical analysis in a deeply relevant context.

Equations:

$$dS/dt = -\beta \times S \times I$$

$$dI/dt = \beta \times S \times I - \gamma \times I$$

$$dR/dt = \gamma \times I$$

Where:

- S = number of susceptible individuals
- I = number of infected individuals
- R = number of recovered individuals
- β = transmission rate
- γ = recovery rate

Implementation with students: A classroom simulation was conducted where each student represented a villager. Cards labeled S, I, or R were distributed. Through role-play, students experienced "infection spread" based on dice rolls representing transmission probability (β). Recovery was timed to introduce γ. Data from multiple rounds were recorded on the board, and students worked in small groups to sketch curves of S, I, and R over time. The differential equations were then presented as a compact way to describe the patterns they observed.

Pedagogical implementation and assessment: The logistic and SIR models were introduced through guided, participatory simulations designed to make abstract concepts tangible for primary-grade students. The focus was on experiential learning through parameter manipulation and outcome prediction.

Logistic growth model – Fisheries management: Students engaged in a hands-on population simulation using a physical grid representing a village pond and counters to denote fish. Working in small groups, they applied a simplified version of

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the logistic equation to project fish populations over several "harvest seasons." Each group was assigned different values for the intrinsic growth rate (r) and carrying capacity (K). By plotting their results on large graph papers, students visualized the impact of these parameters—observing how higher r accelerated growth and how K set a sustainable limit. This led to discussions on overfishing and stock management. Understanding was assessed through structured group worksheets in which students predicted outcomes under new parameter sets and provided written explanations of the growth patterns in their own words.

SIR model – Epidemiology: Disease spread was simulated through a collaborative classroom activity modeled as a dice- or token-based game. Each student was assigned a health status (Susceptible, Infected, or Recovered). Each round (representing a day) involved probabilistic transitions based on transmission rate (β) and recovery rate (γ), enacted using colored tokens or dice rolls. Students altered β and γ between simulations—for example, by simulating the effect of handwashing (lower β) or faster treatment (higher γ). The class collectively tracked daily counts of S, I, and R on a large wall chart, generating SIR curves. Comprehension was evaluated through facilitated debrief sessions, where students answered scenario-based questions (e.g., "What if half the class was vaccinated initially?"), and through creative summaries such as drawing comic strips that illustrated the outbreak narrative and control measures.

These interactive applications ensured that students did not merely learn equations but developed modeling intuition—understanding how parameters influence system behavior. The qualitative and quantitative outputs from these activities (worksheets, predictions, and discussion responses) served as formative assessment tools, complementing the standardized metrics reported in Section 3.

Data from model-based activities were analyzed using paired t-tests and effect size measures.

Measurement of applied agricultural outcomes

To assess the practical impact of the intervention on local agriculture, the Yield Improvement metric was measured through a structured, community-participatory process focused on a single, widely cultivated staple crop (e.g., paddy rice or millet) across multiple participating family farms.

Baseline Establishment (Pre-Intervention):

- For the preceding agricultural season (2022), historical yield data (in kg per hectare) were collected via self-report from the families of participating students (n = 50 farms). Where records were unavailable, estimates were corroborated through interviews with local agricultural extension officers and Panchayati Raj Institution (PRI) members to establish a reliable baseline.

Intervention & Data Collection (2023-2024 Seasons):

- Students, applying skills from the Foundational Skill Building module (specifically ratio and area calculation), worked with their families to implement an optimized irrigation scheduling technique. This involved calculating plot areas and determining water volume ratios based on simple formulas taught in class.
- Each participating farm maintained a simple logbook to record: (a) irrigation dates/amounts, (b) observed crop health, and (c) final harvest weight. Project fellows made bi-monthly visits to support data recording and verify measurements using standardized weight measures.

Yield Calculation and Attribution:

- Post-harvest, the yield (kg/hectare) for the 2023 and 2024 seasons was calculated for each monitored plot.
- The percentage yield improvement was calculated as: [(Post-Intervention Season Yield - Baseline Yield) / Baseline Yield] * 100
- The reported aggregate 15% increase represents the average improvement across all monitored farms from baseline to the 2024 season. Qualitative feedback from parents and local farmers was simultaneously gathered to contextualize the quantitative data and identify other contributing factors (e.g., seed quality, rainfall).

Note on reproducibility: This method relies on community engagement and low-tech data collection, making it suitable for resource-limited settings. Future replications should ensure a clear definition of the baseline season, consistent use of local measurement units with conversion to standard units (kg/hectare), and documentation of co-occurring agricultural factors.

Results

ABL participants outperformed controls across academic and practical metrics (Table 1). Upper-quartile math scores rose by 28% versus 12% in traditional settings. The primary academic outcome, 'Math Score Gain,' was assessed using a dual-measure approach:

1. **Traditional standardized test:** A district-wide mathematics examination (common to all schools in the study region) was administered as a pre- and post-test to all participants.
2. **Innovative contextual assessment:** A project-based assessment was developed specifically for the ABL group. This assessment required students to apply mathematical models (e.g., logistic growth, SIR) to

Table 1: Outcome Comparison Between Traditional and ABL Groups.

Outcome Metric	Traditional (n = 400)	ABL (n = 400)	Effect Size
Math Score Gain (%)	12%	28%	1.2σ
Number Recognition (Grade 1)	38%	72%	High
Yield Improvement (%)	Baseline	15%	N/A
Engagement (Visits/Hour)	0.5	2.1	4×

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solve a novel, locally-relevant problem scenario and explain their reasoning.

The 28% gain reported for the ABL group represents the aggregate improvement from the pre-test to the post-test on the standardized examination. This gain is directly comparable to the 12% gain in the control group (*n = 400*), which consisted of demographically similar students from the same village clusters who continued with the traditional, non-ABL curriculum during the study period. The control group was subject to the same standardized pre- and post-testing schedule but did not participate in the contextual project assessment.

Applied outcomes included a 15% increase in crop yield (observed in a subset of 120 participating households) through optimized irrigation ratios and the use of outbreak models in local health campaigns.

Sustained effects included improved classroom interaction and higher retention in Grade 6.

Note: σ (sigma) represents standard deviation units, a statistical measure of variability. An effect size of 1.2σ indicates a large educational impact, where the average gain in the ABL group exceeded that of the control group by 1.2 standard deviations. Engagement (Visits/Hour) refers to spontaneous student-initiated interactions with the instructor per classroom hour.

Discussion

The findings of this study underscore the transformative potential of contextualized, activity-based mathematics education in rural India. By embedding mathematical concepts within life sciences frameworks relevant to local agrarian communities, the ABL intervention achieved significant improvements in both academic performance and practical application. This discussion examines these outcomes in relation to educational theory, scalability, equity considerations, and future research directions.

Theoretical alignment and pedagogical efficacy

The 28% gain in mathematics scores among ABL participants aligns strongly with principles of Realistic Mathematics Education (RME), which posits that learning is enhanced when abstract concepts are grounded in meaningful, real-world contexts [7]. By situating mathematical reasoning within familiar scenarios—such as modeling fish populations in village ponds or simulating disease spread—students were able to transition from procedural computation to conceptual understanding. This approach not only reduced math anxiety but also fostered what may be termed *quantitative agency*: the confidence and competence to apply mathematical tools to problems affecting daily life.

The success of the logistic growth and SIR models in particular illustrates the value of introducing dynamical systems thinking early in the curriculum. These models served as accessible entry points into topics often reserved for higher education, demonstrating that even young learners can engage with predictive modeling when it is contextualized appropriately. This finding resonates with emerging literature on early quantitative literacy in low-resource settings, which emphasizes the importance of integrating modeling and data interpretation from primary grades onward [8,9].

Bridging the relevance gap in rural education

A persistent critique of rural education in India has been its disconnection from local economies and ecological realities. The ABL model directly addresses this by linking mathematical learning to livelihood-relevant domains such as agriculture, resource management, and community health. The reported 15% increase in crop yield—achieved through student-led optimization of irrigation ratios—exemplifies how education can contribute to tangible economic and environmental outcomes. This aligns with the broader discourse on education for sustainable development, in which learning is designed to support both individual empowerment and community resilience [1].

Moreover, the focus on local fellows as facilitators proved instrumental in sustaining engagement and mitigating high teacher turnover. By training community members—many of whom share lived experiences with students—the program fostered trust and cultural relevance. This model echoes successful initiatives in participatory education and *community-based pedagogies*, which leverage local knowledge systems to enhance learning legitimacy and retention.

Equity, inclusion, and gender considerations

The intervention's deliberate outreach to girls and other marginalized learners reflects an equity-centered design. Qualitative feedback indicated that girls, in particular, benefited from the non-traditional, collaborative nature of ABL activities, which contrasted with the often rigid and hierarchical dynamics of conventional classrooms. By framing mathematics as a tool for solving community problems—rather than as an abstract measure of intelligence—the program helped disrupt gendered stereotypes around STEM aptitude.

However, the moderating effect of socio-economic status observed in related studies suggests that contextualized learning alone may not fully overcome structural barriers. Future iterations should integrate explicit support mechanisms such as scholarships, mentoring, and digital access for learners from economically disadvantaged backgrounds. This aligns with Sen's Capability Approach, which emphasizes expanding substantive freedoms through complementary social and economic interventions [1].

Scalability and systemic integration

While the pilot demonstrated efficacy at a small scale, its true potential lies in systemic adoption. The low-tech, workbook-based design ensures accessibility in settings with limited infrastructure, but scalability will depend on strategic partnerships between governmental education bodies, NGOs, and local governance institutions such as Panchayati Raj. The

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pilot demonstrated that contextualized mathematics education can be delivered alongside existing curricula without structural overhaul. For systemic integration, however, embedding life sciences-oriented mathematics in state curricula would require teacher training reforms, resource allocation, and alignment with national educational frameworks such as the National Education Policy (NEP) 2020, which advocates for experiential and multidisciplinary learning [10].

Additionally, the integration of digital tools—where feasible—could extend reach and personalization. Mobile-based learning platforms, offline-enabled apps, and generative AI for content localization offer promising avenues for scaling contextualized mathematics education without sacrificing interactivity or relevance.

Limitations and future research directions

This study has several limitations that warrant acknowledgment. Its relatively short duration (two years) limits insights into long-term retention and lifelong application of quantitative skills. The absence of a randomized control trial design also restricts causal attribution, though mixed-methods triangulation strengthens validity. Furthermore, the sample, while diverse, did not include remote tribal regions or conflict-affected zones, where educational challenges may differ significantly.

Future research should pursue longitudinal tracking of ABL participants to assess sustained academic and socio-economic outcomes. Experimental and quasi-experimental designs would help isolate the effects of specific intervention components. Additionally, investigations into the cost-effectiveness of ABL compared to traditional instruction could inform policy and funding decisions. Finally, there is a pressing need to explore the adaptation of this model for learners with disabilities and for integration with emerging fields such as climate science, biotechnology, and data literacy [11,12].

Conclusion

This pilot study demonstrates the profound potential of a contextualized, activity-based learning (ABL) model to transform mathematics education in rural India. By strategically embedding primary-grade mathematical concepts within life sciences contexts directly relevant to local agrarian livelihoods—specifically, fisheries management and community epidemiology—the intervention successfully bridged the persistent gap between abstract curriculum and tangible, real-world problem-solving. The results, grounded in the principles of Realistic Mathematics Education (RME), affirm that when learning is anchored in familiar, meaningful scenarios, it catalyzes significant gains not only in academic proficiency but also in practical application and learner empowerment.

The study's methodological approach, detailed in Section 3, centered on a low-tech, community-embedded pedagogy. The training of 50 local fellows as facilitators was instrumental, ensuring cultural relevance and sustaining engagement, a finding that resonates with the community-led models highlighted in the literature [5]. The hands-on implementation of the logistic growth and SIR models—using beads, role-play, and field data—provided students with an experiential gateway to dynamical systems thinking. This pedagogical translation of complex models into accessible activities, as called for by Chen and Oyelere [4] and the Global STEM Education Initiative [11], proved that young learners can develop foundational modeling intuition and quantitative agency.

The empirical outcomes presented in Section 4 validate the model's efficacy. The 28% improvement in standardized mathematics scores among ABL participants, compared to a 12% gain in the control group, provides strong quantitative evidence of enhanced conceptual understanding over rote learning. More compelling, however, are the applied outcomes: the documented 15% increase in agricultural yield on participating family farms. This tangible result, achieved through student-led optimization of irrigation ratios, moves beyond academic metrics to demonstrate education's direct role in socio-economic development and household resilience. It powerfully addresses the "relevance gap" critiqued in the literature review (Section 2) and embodies the intervention's core aim of making mathematics a tool for livelihood improvement.

The discussion (Section 5) situated these results within broader theoretical and practical discourses. The success of the ABL model underscores the importance of gender-responsive and equity-centered design, as noted by Iyer and Kapoor [6], with qualitative feedback indicating increased participation and confidence among girls and marginalized learners. The study also confronts its limitations, including its scale and duration, while charting a clear path for future research. Longitudinal studies, cost-effectiveness analyses, and adaptations for digital tools or learners with disabilities are essential next steps to translate this pilot into systemic policy.

In summary, this research offers a replicable and scalable framework for educational innovation in resource-limited settings. Its key pillars—contextualization within life sciences, activity-based pedagogy, community fellow engagement, and the integration of simple mathematical modeling—collectively foster STEM equity, quantitative resilience, and sustainable development. The framework aligns seamlessly with the experiential and multidisciplinary imperatives of India's National Education Policy (NEP) 2020. Ultimately, this study contends that mathematics education, when reconceived as a life science applied to local challenges, can empower a new generation of rural learners to become not just proficient students, but active problem-solvers and architects of their communities' sustainable future.

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