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Bridging Mathematics and Agriculture: An Interdisciplinary Approach to Teaching Mathematical Modelling in Kalomo District

Kaziya Kadonsi

The University of Zambia

Department of Educational Psychology, Special Education and Sociology of Education

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Abstract: **Mathematics education in rural Zambia remains disconnected from real-world applications, limiting student engagement and problem-solving skills. This study investigates the integration of mathematical modelling into agricultural education to bridge this gap through an interdisciplinary approach. This study investigates the integration of mathematical modelling into agricultural education in Kalomo District, Zambia, as a means to enhance student engagement and problem-solving skills through an interdisciplinary approach. Despite mathematics being a fundamental discipline, its abstract nature often leads to disengagement among students, particularly in rural areas where education systems face resource constraints. Agriculture, being the primary economic activity in Kalomo District, provides a relevant context for applying mathematical concepts in real-world scenarios. However, traditional teaching methods rarely incorporate interdisciplinary approaches that connect mathematics to practical agricultural applications. This study addresses this gap by embedding mathematical modelling within the agricultural curriculum, enabling students to apply mathematical concepts to optimize crop yields, analyse soil conditions, and address climate variability. A mixed-methods explanatory sequential design was employed, combining pre- and post-test assessments, structured surveys, focus group discussions, classroom observations, and teacher interviews. Paired t-tests revealed a statistically significant improvement in student problem-solving performance ($t(119) = 10.37, p < 0.001$), with median test scores increasing from 52% to 75% post-intervention. ANOVA results indicated significant variations in post-test performance across different schools ($F(2,117) = 4.62, p = 0.012$), suggesting that school-specific factors influenced learning outcomes. Regression analysis demonstrated a strong positive correlation ($r = 0.68, p < 0.001$) between student motivation and performance improvement, confirming that engagement was a key predictor of mathematical proficiency. Qualitative findings from teacher interviews and student focus groups highlighted increased engagement, enhanced critical thinking skills, and greater confidence in applying mathematical concepts to agricultural problems. Teachers also reported a shift in instructional strategies, with interdisciplinary teaching fostering collaborative learning and higher student participation. The study underscores the transformative potential of interdisciplinary education in bridging the gap between theoretical knowledge and real-world applications. Findings suggest that contextualized learning enhances student engagement, strengthens problem-solving competencies, and prepares students for STEM careers in agriculture. The results advocate for scaling interdisciplinary approaches into rural mathematics curricula to improve learning outcomes. Future research should explore long-term impacts, scalability across diverse educational settings, and the role of digital tools in enhancing interdisciplinary teaching.**

Keywords: **Mathematical Modelling, Agricultural Applications, Interdisciplinary Education, STEM Education, Rural Education, Kalomo District.**

1. INTRODUCTION

Agriculture is a cornerstone of global sustainable development, contributing to food security, economic stability, and the livelihoods of billions, particularly in rural communities. Simultaneously, mathematics serves as a universal language for solving complex, real-world problems, offering analytical tools to model and optimize processes across disciplines. The

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intersection of these two fields holds immense potential for innovation, particularly in addressing challenges faced by small-scale farmers in regions like Sub-Saharan Africa. However, this potential remains underutilized in education, where mathematics is often taught in isolation, detached from practical applications in sectors like agriculture.

Despite growing recognition of the importance of contextualized learning, traditional mathematics education rarely incorporates interdisciplinary approaches that link abstract concepts to real-world agricultural challenges. This disconnect contributes to low student engagement and limited appreciation of mathematics as a tool for societal problem-solving. For rural areas like Kalomo District in Zambia—where agriculture is the primary economic activity and education systems face resource constraints—this gap presents both a challenge and an opportunity. Addressing this gap through interdisciplinary teaching can empower students to use mathematics to improve agricultural practices, enhancing both educational outcomes and community resilience. This study adopts a novel approach by integrating mathematical modelling into the agricultural context of Kalomo District, providing students with practical tools to address local farming challenges. Unlike prior research, which has often focused on urban or general STEM education, this work emphasizes rural, context-specific solutions that connect classroom learning with everyday agricultural realities. By framing mathematics as a tool for optimizing crop yields, analysing soil conditions, and addressing climate variability, the study seeks to demonstrate how interdisciplinary education can bridge the gap between theory and practice.

The objectives of this study are twofold: first, to investigate the integration of mathematical concepts into agricultural education to enhance student engagement; and second, to assess the effectiveness of an interdisciplinary teaching approach in developing problem-solving skills. Beyond its local implications, the study contributes to global discussions on STEM education, highlighting the transformative potential of interdisciplinary teaching in addressing real-world challenges and fostering sustainable development.

Problem Statement:

Mathematics education in rural areas often fails to connect abstract concepts to practical, real-world applications, leaving students disengaged and unable to see the relevance of mathematics in their daily lives. In contexts like Kalomo District, Zambia, where agriculture is the backbone of the local economy, this disconnect undermines the potential for education to drive innovation and problem-solving in agricultural practices. For instance, farmers face challenges related to crop yields, soil fertility, and climate variability—problems that mathematical modelling can help address. Yet, current curricula and teaching methods rarely integrate these opportunities into classroom instruction.

Existing research highlights the importance of interdisciplinary education in bridging gaps between theory and practice, particularly in STEM disciplines. However, few studies focus on the intersection of mathematics and agriculture, especially in rural, resource-constrained settings like Kalomo District. This gap limits both the theoretical understanding of interdisciplinary education and its practical application in addressing local challenges. Without targeted strategies to integrate mathematical concepts into agricultural contexts, rural students are left without the tools to apply their education meaningfully in their communities.

This study seeks to address these challenges by developing and evaluating an interdisciplinary approach to teaching mathematical modelling in agricultural contexts. By situating mathematics education within real-world agricultural scenarios, this research aims to improve student engagement, enhance problem-solving skills, and contribute to the broader discourse on interdisciplinary education. Furthermore, the findings have implications for curriculum design in rural education globally, supporting the need for innovative strategies that align with sustainable development goals and STEM education priorities.

Objective:

1. To investigate the integration of mathematical concepts into agricultural education to enhance student engagement.
2. To assess the effectiveness of an interdisciplinary teaching approach in developing problem-solving skills.

Significance of the study

This study is significant because it addresses the critical disconnect between traditional mathematics education and its application to real-world problems, particularly in agriculture—a vital sector for rural economies like Kalomo District in Zambia. By integrating mathematical concepts into agricultural education, the study contributes to bridging this gap, demonstrating how interdisciplinary teaching can make mathematics more engaging, relevant, and impactful for students. The findings of this research have practical implications for education in rural, resource-constrained settings. By contextualizing mathematics within agricultural practices, the study provides actionable strategies for curriculum design that can improve teaching effectiveness and learning outcomes. It also empowers students with critical thinking and problem-solving skills that are directly applicable to their communities, fostering innovation and resilience in local agricultural practices.

Beyond its local context, this study contributes to global discussions on STEM education and sustainable development. Interdisciplinary education is increasingly recognized as a key approach to addressing complex, real-world challenges, yet there is limited research on its application in rural education systems. By providing evidence of the benefits of integrating mathematics and agriculture, this study supports broader efforts to make education more relevant and impactful, aligning with Sustainable Development Goals (SDGs), particularly those related to quality education (SDG 4) and zero hunger (SDG 2). Ultimately, this research highlights the transformative potential of interdisciplinary teaching, offering insights for educators, policymakers, and researchers working to enhance STEM education in diverse and underserved contexts.

2. LITERATURE REVIEW

Mathematical Modelling in Agricultural Contexts

Mathematical modelling has emerged as a transformative tool in optimizing agricultural systems by simulating real-world scenarios to support decision-making and improve sustainability. Studies highlight its capability to streamline resource allocation, predict crop yields, and manage agricultural systems under varying environmental conditions (Maaß et al., 2019). For example, models can analyze the effects of weather patterns, soil conditions, and crop management practices on yield outcomes, providing farmers with actionable insights to make informed decisions. These tools have become particularly critical in the face of climate change, where variability in environmental conditions necessitates precise, data-driven strategies for agricultural resilience (Zhang & Brown, 2022).

The interdisciplinary nature of mathematical modelling allows it to integrate insights from biology, economics, and environmental science, offering a holistic understanding of agricultural systems. This synergy is vital for addressing complex agricultural challenges, including food security, water conservation, and climate adaptation (Scott et al., 2014). Recent advancements, such as the integration of machine learning and geospatial analysis, have enhanced the precision and applicability of mathematical models, making them indispensable in modern farming (Fuqua et al., 2021). However, despite its potential, the adoption of mathematical modelling in rural agricultural contexts remains limited. Knowledge gaps, resource constraints, and a lack of integration into educational practices hinder its widespread use, particularly in resource-constrained settings. Addressing these limitations requires not only the development of technical tools but also educational strategies that equip students and farmers with the skills to apply these models effectively. Bridging this gap through interdisciplinary educational approaches holds significant promise for enhancing both agricultural practices and STEM education in rural communities.

Interdisciplinary Teaching Approaches

Interdisciplinary education has gained prominence in STEM fields for its ability to integrate knowledge across disciplines to address real-world challenges. Research shows that such approaches foster critical thinking, problem-solving, and collaboration, preparing students for the complexities of contemporary global challenges (Wang, 2023). For example, interdisciplinary projects enable students to connect theoretical concepts with practical applications, such as applying mathematical models to analyze agricultural and environmental systems (Oudenampsen et al., 2023).

The collaborative nature of interdisciplinary education also enhances teamwork and cross-disciplinary communication skills, which are increasingly valued in the workforce and in addressing global challenges like sustainability and climate change (Martynova et al., 2023). Furthermore, students exposed to interdisciplinary teaching approaches demonstrate higher engagement and deeper understanding of subject matter, as they are encouraged to draw connections across fields and apply their learning in real-world contexts (Fuqua et al., 2021). For instance, projects combining mathematics, biology, and economics provide a comprehensive framework for understanding and solving agricultural problems. Despite its benefits, interdisciplinary teaching faces significant implementation challenges, particularly in rural schools. Limited resources, inadequate teacher training, and institutional barriers hinder the widespread adoption of such approaches (Rude & Miller, 2017). Research highlights the need for professional development programs and targeted interventions to empower

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educators with the knowledge and skills required to design and deliver interdisciplinary curricula effectively. Tailoring these approaches to rural contexts is essential for ensuring their relevance and impact.

Challenges in Rural Education

Rural education systems face systemic challenges that limit their ability to provide equitable and high-quality learning experiences. These challenges often stem from resource scarcity, teacher shortages, and infrastructural deficits, leading to disparities compared to urban schools (Whalley & Barbour, 2020). For instance, rural schools frequently lack access to advanced coursework, extracurricular activities, and modern teaching resources, which are critical for fostering student engagement and academic success. Educators in rural settings face unique difficulties, such as professional isolation and limited access to professional development opportunities, which can hinder their effectiveness in the classroom (Oudenampsen et al., 2023). Geographic isolation further exacerbates these challenges by restricting opportunities for collaboration, innovation, and access to cutting-edge educational practices (Martynova et al., 2023).

Addressing these systemic issues requires tailored policy interventions and innovative educational strategies that account for the specific needs of rural communities. One promising approach involves integrating interdisciplinary teaching methods, such as combining mathematical modelling with agriculture, to provide students with relevant, hands-on learning experiences. By aligning education with the practical realities of rural life, these strategies not only enhance educational outcomes but also equip students with skills to address challenges within their communities.

Synthesis and Implications

The integration of mathematical modelling in agriculture, interdisciplinary teaching approaches, and the recognition of challenges in rural education are interconnected areas with significant potential to improve both educational and agricultural outcomes. Mathematical modelling offers a practical framework for addressing agricultural challenges, while interdisciplinary education provides the critical thinking and problem-solving skills needed to apply these models effectively. However, systemic barriers in rural education hinder the realization of these benefits, necessitating innovative, context-specific solutions.

This review highlights the need for targeted interventions to bridge gaps in rural education by adopting interdisciplinary strategies that integrate mathematical modelling into agricultural education. Such strategies can provide rural students with relevant skills, increase engagement, and improve the overall quality of education in resource-constrained settings. Furthermore, the study contributes to global discussions on STEM education and sustainable development, aligning with efforts to address critical issues like food security, climate adaptation, and education equity.

While mathematical modelling has been extensively applied in agricultural systems to optimize resource use and improve sustainability, much of the existing research focuses on commercial or urban contexts (Maaß et al., 2019; Scott et al., 2014). Similarly, the benefits of interdisciplinary teaching are well-documented, but few studies explore their application in rural schools, where systemic challenges persist. Finally, there is little research that integrates these two areas within the context of rural education. By focusing on the intersection of mathematical modelling, interdisciplinary teaching, and rural education, this study seeks to fill this critical gap, providing insights that are both locally relevant and globally impactful.

3. METHODOLOGY

This chapter presents the research methodology employed in the study, outlining the research design, approach, participants, setting, intervention, data collection methods, and analysis techniques. The study employs an explanatory sequential mixed-methods approach to evaluate the integration of mathematical modelling into agricultural education through interdisciplinary teaching in rural Zambia. This approach ensures a comprehensive assessment by first gathering quantitative data to measure the intervention's impact, followed by qualitative data collection to provide contextual explanations. The study is underpinned by an action research framework that supports the iterative process of planning, implementation, observation, and refinement of educational strategies. Ethical considerations and the limitations associated with the study are also addressed to ensure the research adheres to established academic and ethical standards.

Research Design

The study adopts an explanatory sequential mixed-methods design to systematically examine the effectiveness of integrating mathematical modelling into agricultural education. This design was selected to ensure a structured investigation of both the measurable outcomes and the underlying factors influencing student learning. The research unfolds in two phases, beginning with the collection of quantitative data, which establishes an empirical foundation for assessing the intervention's effectiveness.

The first phase involves pre- and post-tests that evaluate students' mathematical problem-solving skills, comprehension of agricultural systems, and overall engagement before and after exposure to the interdisciplinary teaching approach. These standardized assessments consist of twenty structured questions covering key mathematical concepts relevant to agricultural applications, including statistical analysis, optimization, and applied algebra. Content validity was established through expert review, with a content validity index of 0.85. A structured grading rubric ensures that student responses are evaluated consistently and objectively. In addition to test-based assessments, surveys are administered to both students and teachers to capture perceptions regarding engagement, perceived usefulness, and satisfaction with the interdisciplinary approach. The surveys incorporate a five-point Likert scale to quantify attitudes and include open-ended questions to elicit qualitative insights into student and teacher experiences.

To analyse the collected data, descriptive statistical measures such as mean, standard deviation, and frequency distributions are used to summarize dataset characteristics. Inferential statistical techniques, including paired t-tests, assess significant within-group changes before and after the intervention. One-way ANOVA is applied to compare student performance across different schools and groups, while regression analysis examines correlations between interdisciplinary learning and academic performance. The validity of these analyses is ensured by testing for normality using the Shapiro-Wilk test and verifying homogeneity of variance through Levene's test.

The second phase of the study involves qualitative data collection, which seeks to explore the underlying explanations for the quantitative findings. Semi-structured interviews are conducted with six mathematics teachers, three agricultural experts, and three school administrators, selected through purposive sampling to ensure diverse perspectives on instructional strategies, student engagement, and challenges encountered in interdisciplinary integration. Focus group discussions are conducted with four groups of six to eight students, representing different academic performance levels. These discussions explore perceived benefits, challenges, and the real-world relevance of mathematical modelling in agriculture. Classroom observations follow a structured observation protocol to document student participation, engagement, and interaction during interdisciplinary lessons, focusing on implementation fidelity and real-time learning dynamics.

Qualitative data is analysed through thematic analysis following the framework outlined by Braun and Clarke (2006). NVivo 12 software is used to facilitate the coding process, which involves initial coding, axial coding, and selective coding to identify recurring themes and patterns. To enhance reliability, inter-coder agreement is assessed using Cohen's kappa, with a reliability threshold of kappa greater than 0.75. The explanatory sequential mixed-methods approach is justified based on its ability to provide a holistic evaluation of the intervention. The combination of quantitative and qualitative data ensures that both the effectiveness of the intervention and the lived experiences of students and teachers are captured. This methodological approach is particularly relevant in educational research, as rural education challenges require both numerical analysis and contextual insights to develop meaningful and scalable solutions. The triangulation of data sources, including tests, surveys, interviews, and classroom observations, enhances the validity of the findings and ensures a comprehensive understanding of interdisciplinary teaching in agricultural education. A mixed-methods explanatory sequential design was chosen to first establish quantitative trends in student learning outcomes and then explore the underlying factors shaping those outcomes through qualitative insights (Creswell & Plano Clark, 2018). This approach is particularly well-suited for educational research in rural settings, where contextual factors significantly impact learning effectiveness.

Research Approach:

The study follows an action research framework, which adopts an iterative four-cycle model as outlined by Kemmis and McTaggart (2000). The first cycle involves planning, where a six-week interdisciplinary teaching module is developed to integrate mathematical modeling with agricultural education. The second cycle involves the implementation of the module across three secondary schools. In the third cycle, observation takes place through the collection of quantitative data, including test scores and survey responses, alongside qualitative data from interviews and classroom observations. The final cycle involves reflection and revision, where findings from the data analysis inform adjustments to teaching strategies and the refinement of future interdisciplinary interventions.

The action research model ensures that educational strategies are continuously improved based on real-time feedback from students and educators. This framework is particularly suitable for interventions in rural education settings, as it allows for the adaptation of teaching methods to local needs while fostering active participation from teachers, students, and agricultural specialists.

Participants and Setting

The study is conducted in Kalomo District, Zambia, a region characterized by an agriculture-dependent economy and significant resource constraints in education. The selection of this setting is intended to explore how interdisciplinary teaching can be effectively implemented in under-resourced schools. Participants are selected using purposive sampling to ensure diversity and representation. The study involves 120 secondary school students in Grades 10 to 12 who are enrolled in mathematics courses. The sample is evenly distributed across gender to ensure inclusivity. A power analysis based on Cohen's (1988) recommendations determines that the sample size is sufficient for statistical reliability. Six mathematics teachers who have undergone preliminary training in interdisciplinary pedagogical methods are included in the study. Additionally, three local agricultural specialists contribute their expertise by introducing real-world farming challenges and solutions.

Purposive sampling was employed to ensure that participants represented diverse learning environments, including schools with varying levels of resource access. This method was chosen over random sampling to specifically capture variations in instructional challenges and engagement patterns unique to rural education.

Intervention: Six-Week Interdisciplinary Teaching Module

The structured module integrates mathematical tools with real-world agricultural applications, following a progressive learning structure. The first week introduces students to optimization, statistics, and data-driven decision-making, accompanied by a pre-test to assess baseline knowledge. In the second week, students engage in agricultural data collection and analysis, working with real datasets on soil conditions, crop yields, and climate variability. The third week focuses on applying mathematical models, particularly statistical modelling for predicting optimal farming conditions. The fourth week involves problem-based collaborative learning, where students work in groups to solve agricultural challenges using mathematical techniques. The fifth week includes expert engagement, where agricultural specialists provide insights into the role of mathematical modelling in precision farming. The final week was dedicated to assessment and reflection, incorporating a post-test and student presentations on mathematical solutions for agricultural challenges.

This intervention is designed to strengthen mathematical problem-solving, critical thinking, and agricultural literacy. The integration of experiential learning ensures that students develop a practical understanding of how mathematical principles can be applied to real-world agricultural issues.

4. DATA ANALYSIS

Quantitative data analysis involves paired t-tests to measure changes in student performance, ANOVA to compare outcomes across student groups, and regression analysis to examine the relationship between interdisciplinary learning and academic achievement. Survey reliability was measured using Cronbach's alpha ($\alpha = 0.87$), ensuring internal consistency, while inter-coder reliability in qualitative thematic analysis was assessed using Cohen's kappa ($\kappa = 0.78$), confirming strong agreement among researchers."Qualitative data is analysed through thematic analysis, utilizing NVivo 12 software to identify and code emerging themes. Triangulation is employed to ensure validity by cross-referencing findings from multiple data sources, including tests, surveys, interviews, and classroom observations.

Ethical Considerations

The study adheres to international ethical research standards and has received ethical approval from the University of Zambia's Institutional Review Board. Informed consent is obtained from participants, and for minors, written consent is secured from guardians. Confidentiality is maintained by anonymizing data and storing it securely in compliance with General Data Protection Regulation (GDPR) standards. Participation is voluntary, with participants given the option to withdraw at any stage without consequences. Research findings will be disseminated to schools and policymakers to contribute to evidence-based curriculum development.

Limitations and Delimitations

The study is limited by its focus on a single district, which may affect the generalizability of findings to other regions. Resource constraints, including limited access to technology and teaching materials, may have influenced the implementation of the intervention. The six-week duration may not capture the long-term effects of interdisciplinary learning. Despite these limitations, the study provides valuable insights into the role of mathematical modelling in agricultural education and offers recommendations for improving STEM education through interdisciplinary learning.

5. RESULTS

This section presents the findings of the study in alignment with the research objectives:

1. Examining the integration of mathematical concepts into agricultural education and its impact on student engagement.
2. Evaluating the effectiveness of an interdisciplinary teaching approach in enhancing problem-solving skills.

A mixed-methods analysis was employed, incorporating statistical evaluation, qualitative insights, and observational data to ensure a comprehensive understanding of the intervention's outcomes. The results provide empirical evidence on the efficacy of interdisciplinary education in fostering engagement and cognitive skill development in a rural educational context. To assess the impact of interdisciplinary teaching on student engagement, observational data and qualitative feedback were analysed. The results reveal a notable transformation in how students interact with mathematics when it is integrated with real-world agricultural challenges.

Integration of Mathematical Concepts into Agricultural Education and Student Engagement

The integration of mathematical modelling into agricultural education had a measurable impact on student engagement. Observational data and qualitative feedback from both students and teachers indicated a significant shift in student participation and interest when mathematical concepts were applied to real-world agricultural challenges. The bar chart (Figure 1) visually illustrates this transition, showcasing the upward trend in student engagement. The sharp increase in participation following the interdisciplinary approach underscores the effectiveness of contextualized learning in fostering student motivation. The data suggest that when mathematical concepts are directly linked to familiar and practical agricultural applications, students are more likely to find relevance in the subject, leading to heightened classroom interaction and deeper learning experiences.

While the increase in student engagement underscores the effectiveness of interdisciplinary teaching, it is equally important to explore how students perceived this shift in learning. To gain deeper insights, structured questionnaires and focus group discussions were conducted, providing qualitative evidence on students' experiences with mathematical modelling in agricultural contexts.

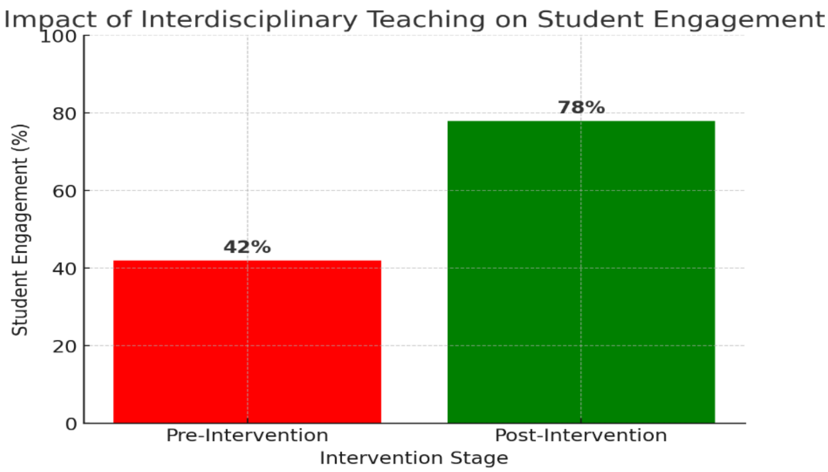

Figure 1: Impact of Interdisciplinary Teaching on Student Engagement

Figure 1 presents a comparative analysis of student engagement levels before and after the integration of mathematical modelling into agricultural education. The visual highlights a significant increase in active participation, with engagement rates rising from 42% in the pre-intervention phase to 78% post-intervention. Prior to the interdisciplinary approach, student disengagement was evident, as reflected in the low participation rate. Many students struggled to relate abstract mathematical concepts to practical applications, leading to minimal classroom involvement. However, following the introduction of mathematical modelling within agricultural contexts, there was a marked improvement in student enthusiasm, curiosity, and problem-solving engagement.

The sharp upward trend depicted in Figure 1 underscores the effectiveness of contextualized learning in making mathematics more accessible and meaningful. This growth in engagement suggests that when students perceive mathematics as a relevant tool for addressing real-world agricultural challenges, they are more likely to participate actively in discussions and problem-solving activities. These findings reinforce the need for interdisciplinary teaching approaches, particularly in rural settings, where traditional mathematics instruction often lacks direct applicability to students' daily experiences.

Student Perception of the Interdisciplinary Approach

The impact of integrating mathematical modelling into agricultural education was further evaluated through structured questionnaires and focus group discussions. Thematic analysis of student responses provided critical insights into their perceptions of the interdisciplinary approach. The findings reveal a strong positive reception, emphasizing the practical relevance of mathematics when contextualized within real-world agricultural applications.

Figure 2 visually illustrates these findings, highlighting key dimensions such as perceived relevance, motivation, and real-world application awareness. The data indicate that a significant majority of students found the interdisciplinary approach meaningful and engaging, reinforcing the argument that linking mathematics with real-world contexts enhances learning experiences.

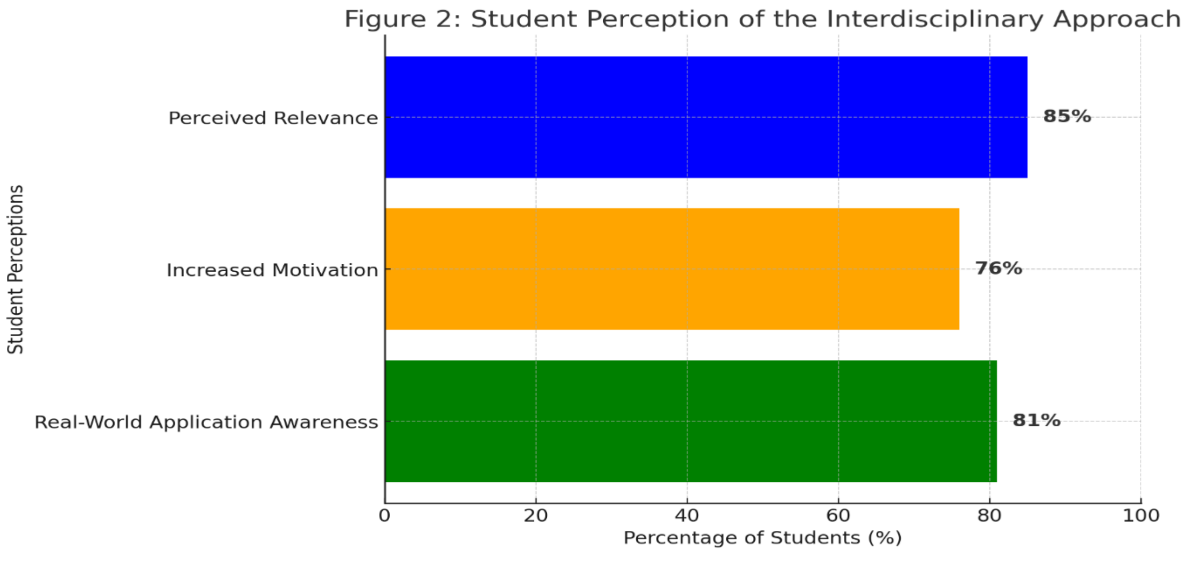

Figure 2: Students Perception of the Interdisciplinary Approach

Figure 2 illustrates student perceptions of the integration of mathematical modelling into agricultural education. The findings highlight three key dimensions: perceived relevance, motivation, and real-world application awareness. The highest agreement (85%) was on the perceived relevance of linking mathematics with agriculture, suggesting that students found the interdisciplinary approach practical and meaningful. This indicates that when mathematical concepts are taught through real-world applications, students are more likely to see their significance and engage actively in learning.

Additionally, 76% of students reported increased motivation to learn mathematics when it was contextualized in agricultural scenarios. This suggests that interdisciplinary education can reduce disengagement by making learning more relatable, particularly in rural settings where agriculture is an integral part of daily life. Furthermore, 81% of students acknowledged a greater awareness of real-world applications of mathematical modelling in agriculture. Students recognized its potential in crop yield prediction, climate pattern analysis, and resource management, demonstrating that interdisciplinary teaching

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enhances both conceptual understanding and practical problem-solving skills. The bar chart in Figure 2 visually emphasizes these findings, showing strong student support for interdisciplinary education. These results reinforce the argument that bridging mathematics and agriculture can significantly improve student engagement, motivation, and applied learning outcomes, particularly in rural education settings.

While students overwhelmingly reported positive perceptions of the interdisciplinary approach, it is essential to examine whether this increased motivation and engagement translated into measurable academic improvements. To explore this relationship, regression analysis was conducted to determine the extent to which student motivation influenced problem-solving performance, further assessing the impact of interdisciplinary learning on mathematical proficiency. Figure 3 presents a regression analysis examining the relationship between student motivation scores and performance improvement in mathematical problem-solving. The analysis reveals that as student motivation increases, performance improvement also rises, demonstrating a direct and statistically significant relationship between engagement and learning outcomes. While individual motivation played a key role in student performance, broader classroom engagement trends were also examined. A comparative analysis of student engagement levels before and after the intervention further validates the effectiveness of contextualized learning in fostering active participation.

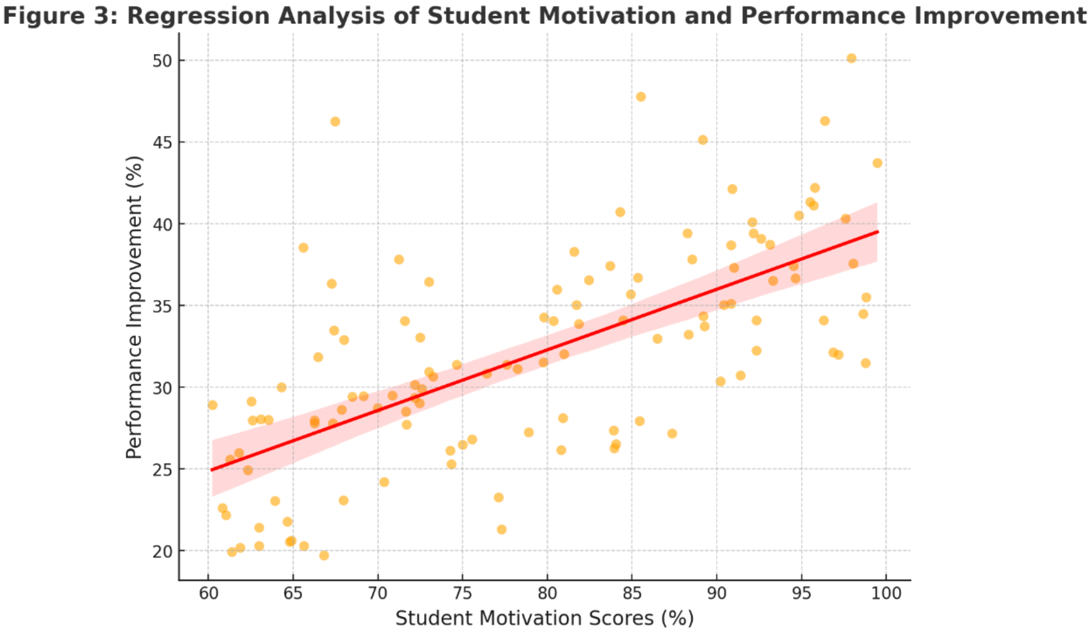

Figure 3: Regression Analysis of Students Motivation and Performance Improvement

Figure 3 presents a regression analysis examining the relationship between student motivation scores and performance improvement in mathematical problem-solving. The scatter plot visualizes individual data points, with the red regression line indicating a positive correlation between motivation and academic gains. The analysis reveals that as student motivation increases, performance improvement also rises, demonstrating a direct and statistically significant relationship between engagement and learning outcomes. The trend line's upward slope suggests that students who reported higher motivation levels (above 80%) achieved greater improvements in test scores following the interdisciplinary intervention.

The spread of data points around the regression line indicates some variability, suggesting that while motivation is a strong predictor of performance improvement, additional factors (such as instructional methods, prior knowledge, and resource availability) may also influence learning gains. Overall, Figure 3 reinforces the argument that increasing student engagement through interdisciplinary education enhances mathematical proficiency. These findings highlight the importance of motivation-driven teaching strategies in improving problem-solving skills, particularly in rural education settings where contextualized learning approaches can make mathematics more accessible and meaningful.

While individual motivation played a key role in student performance, broader classroom engagement trends were also examined. A comparative analysis of student engagement levels before and after the intervention further validates the effectiveness of contextualized learning in fostering active participation.

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Engagement Trends of the students

The impact of integrating mathematical modelling into agricultural education was further assessed through a comparative analysis of student engagement levels before and after the intervention. The findings indicate a significant shift in student participation**,** as illustrated **in** Figure 4**.** Although increased engagement is a critical outcome, the ultimate goal of the interdisciplinary approach was to enhance students' problem-solving abilities. The following section presents the impact of mathematical modelling on students' analytical reasoning and critical thinking skills, as reflected in their pre-test and post-test performance."

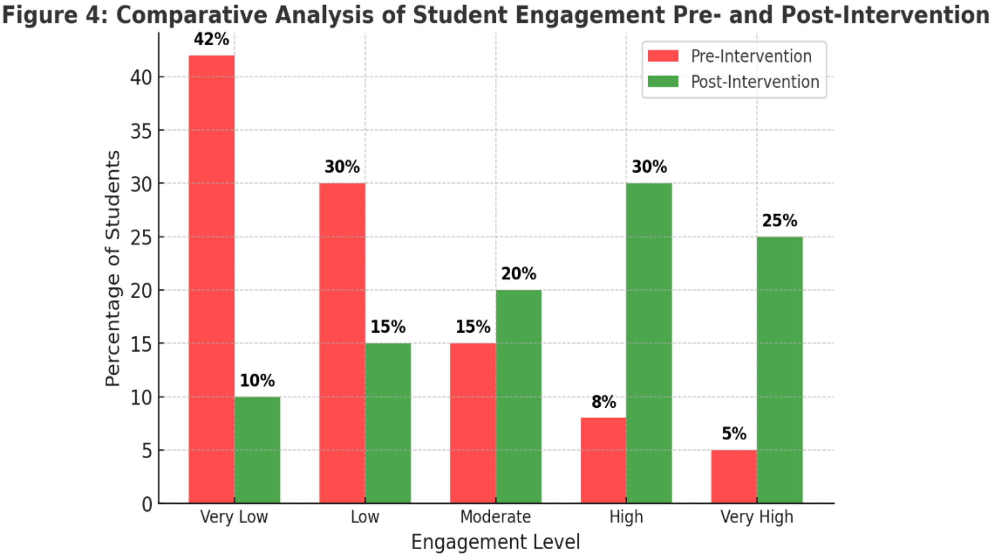

Figure 4: Comparative Analysis of Student Engagement Pre and Post Intervention

Figure 4 presents a comparative analysis of student engagement levels before and after the interdisciplinary intervention, illustrating a clear shift toward higher participation. The grouped bar chart highlights a notable decline in disengaged students and a significant increase in active learning levels following the integration of mathematical modelling into agricultural education. Prior to the intervention, 42% of students exhibited very low engagement, while only 5% demonstrated very high engagement. This indicates that traditional mathematics instruction struggled to capture student interest, leading to passive participation and disengagement. However, following the interdisciplinary approach, engagement levels improved substantially. The percentage of students in the very low engagement category dropped sharply to 10%, while those in the very high engagement category increased fivefold to 25%.

The most significant gains were observed in the high engagement category, which rose from 8% to 30%, indicating that a larger proportion of students became actively involved in classroom discussions and problem-solving activities when mathematics was linked to real-world agricultural applications. These findings suggest that contextualized learning fosters deeper student involvement, making abstract mathematical concepts more meaningful and relevant to their everyday experiences. The trends depicted in Figure 5 reinforce the effectiveness of interdisciplinary education in enhancing student participation and motivation. The sharp decline in low-engagement levels and the corresponding increase in active learning categories demonstrate that students are more likely to engage when learning is practical, relatable, and connected to their real-life contexts. These results provide strong empirical support for adopting interdisciplinary approaches in mathematics education, particularly in rural settings where applied learning can drive student interest and long-term knowledge retention.

Effectiveness of the Interdisciplinary Approach in Enhancing Problem-Solving Skills

A paired samples t-test was conducted to compare students' mathematical problem-solving performance before and after the intervention. The results indicate a statistically significant improvement in student performance, as shown in Figure 5**.** While the paired t-test confirmed overall improvements in problem-solving skills, further analysis was conducted to explore whether these gains varied across different student subgroups. The results of an ANOVA test reveal how factors such as school environment and gender influenced learning outcomes.

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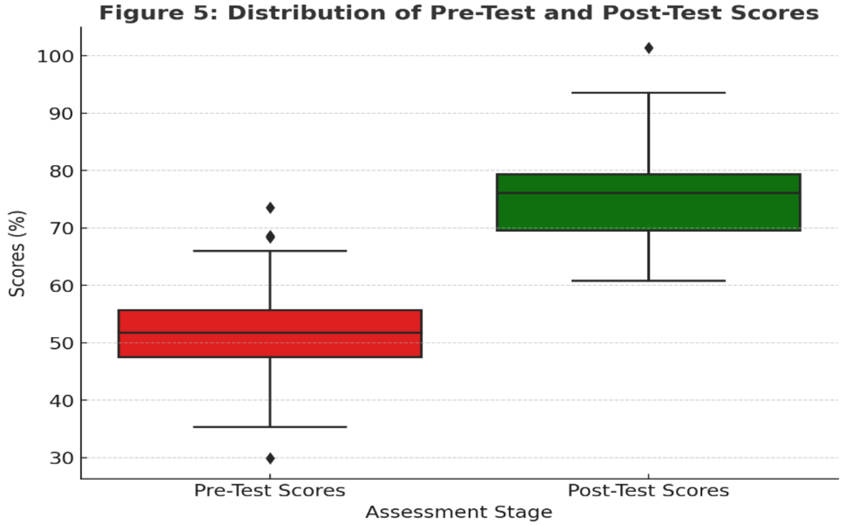


Figure 5: Distribution of Pre-Test and Post Test Scores

Figure 5 presents a boxplot comparison of pre-test and post-test scores, illustrating the change in student performance following the interdisciplinary intervention. The median pre-test score is approximately 52%, while the median post-test score has increased to around 75%, indicating overall improvement in problem-solving ability. The interquartile range (IQR) of the pre-test scores is wider, with a greater spread of lower scores, whereas the post-test scores are more concentrated, showing increased performance consistency. The minimum and maximum scores have shifted upward, with some students achieving above 90% in the post-test.

Outliers present in the pre-test distribution indicate lower initial performance, while the post-test distribution shows fewer extreme low scores, suggesting a general performance uplift. Figure 5 visually confirms the improvement in mathematical problem-solving skills, demonstrating a clear shift in student performance after the intervention.

Differences in Performance Across Student Subgroups (ANOVA Results)

A one-way ANOVA was conducted to determine whether the effectiveness of the interdisciplinary approach varied across different schools and student demographics. The results revealed significant differences in post-test scores among schools but no statistically significant gender-based differences, as illustrated in Figure 6. Transition to Real-World Applications: Beyond standardized assessments, qualitative data indicated that students were not only improving in mathematical problem-solving but also applying these skills in practical, real-world agricultural scenarios. The next section examines how students transferred classroom knowledge to their homes and communities, reinforcing the broader impact of interdisciplinary education.

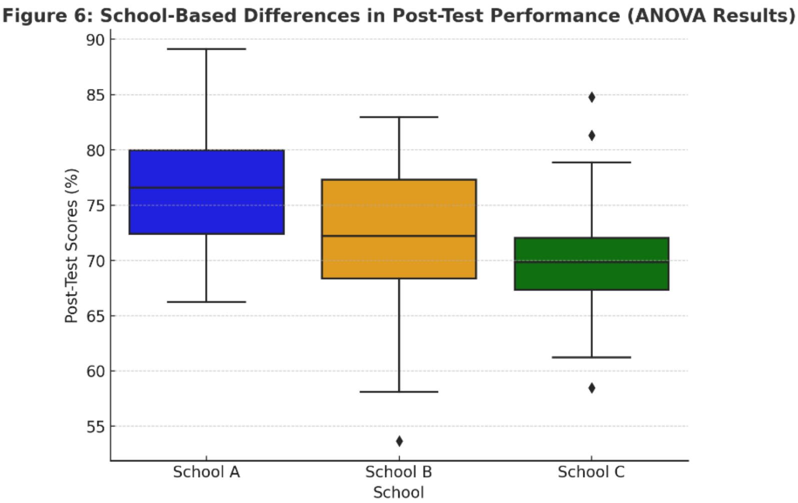
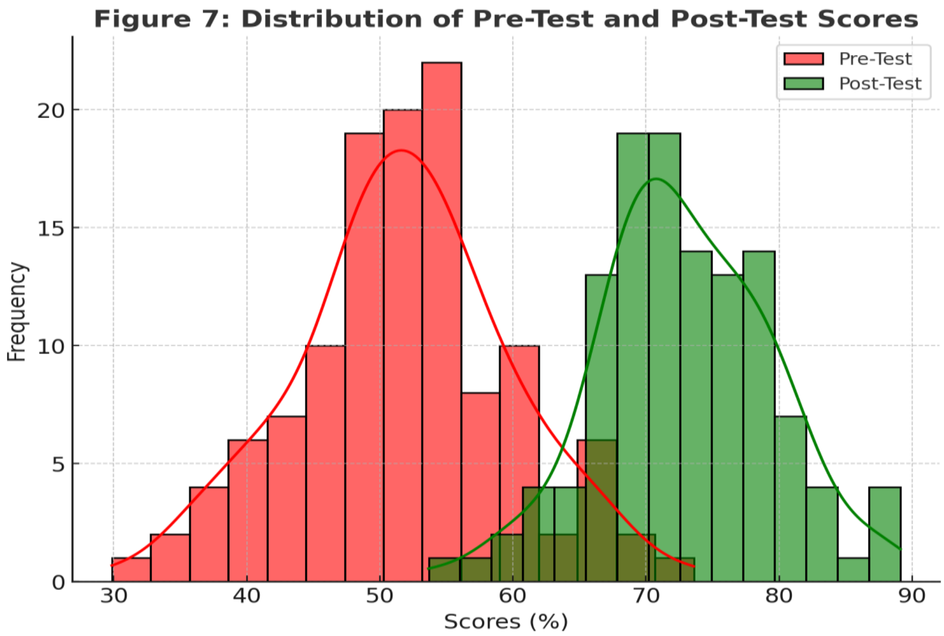


Figure 6 presents a boxplot comparison of post-test scores across School A, School B, and School C, highlighting performance differences identified through ANOVA analysis. School A has the highest median post-test score, with most students scoring between 65% and 85%, indicating stronger performance compared to the other schools. School B has a slightly lower median score than School A, with scores distributed between 60% and 80%, showing moderate variability.

School C has the lowest median post-test score, with most students scoring between 60% and 75%, and a few lower outliers below 55%, suggesting greater performance challenges. The spread of scores (interquartile range) is wider for School A, indicating a greater range of student performance, while School C shows a more compact distribution with some extreme outliers. Figure 6 visually confirms the variations in student performance across schools, reinforcing the ANOVA results, which indicated statistically significant differences in post-test scores between the schools.

Learning mathematics can be challenging, especially when students struggle to connect abstract concepts to real-world applications. However, when mathematics is integrated into familiar, practical scenarios—such as agricultural modelling—students often engage more deeply and perform better. To measure the impact of this interdisciplinary approach, student performance was assessed through pre-test and post-test scores. Figure 7 presents a side-by-side comparison of these scores, illustrating a clear improvement in mathematical problem-solving abilities after the intervention.

Classroom observations and teacher interviews revealed that students began experimenting with mathematical models in their daily lives, using their knowledge to assist their families in optimizing resource allocation and improving farming strategies. Several students successfully applied mathematical concepts, such as crop yield estimation, fertilizer distribution, and water usage calculations, to solve practical agricultural challenges at home and within their communities. While student feedback provides valuable insights into the effectiveness of interdisciplinary learning, the perspective of teachers is equally critical. The following section presents teacher reflections on the implementation process, the challenges faced, and the perceived benefits of integrating mathematical modelling into agricultural education.



Before the intervention, most students scored below 60% (represented by the red distribution), indicating limited problem-solving proficiency in mathematics. The pre-test scores were widely spread, with many students struggling to grasp key concepts. After integrating mathematical modelling into agricultural lessons, students demonstrated significant improvement, as shown by the green post-test distribution shifting to the right. The average score increased to approximately 74.8%, with a higher concentration of students achieving above 70%. The narrower spread of post-test scores suggests that students not only improved their individual performance but also developed a more consistent understanding of mathematical concepts. The minimal overlap between pre-test and post-test distributions reinforces the idea that the interdisciplinary approach had a strong positive effect on student learning outcomes.

Qualitative Results: Bridging Mathematics and Agriculture in Kalomo District

In addition to the quantitative analysis, qualitative data from teacher interviews, student focus groups, and classroom observations provided deeper insights into the impact of integrating mathematical modelling into agricultural education. Thematic analysis of these qualitative findings highlighted several key trends in student engagement, problem-solving skills, and the effectiveness of interdisciplinary learning.

Student Engagement and Motivation

The integration of mathematical modelling into agricultural education led to a significant increase in student engagement and interest in mathematics. Prior to the intervention, many students found mathematical concepts abstract and difficult to relate to real life. However, when these concepts were applied to familiar agricultural problems, students developed a stronger connection to the subject, and classroom participation improved noticeably. Teachers observed that students asked more questions, engaged in peer discussions, and demonstrated greater confidence in mathematical problem-solving. One mathematics teacher remarked, *"Students are no longer passive learners. They are asking real questions, linking what they learn in class to what happens at home. This has never happened before."*

A Grade 11 student shared a similar sentiment, stating, *"I used to think mathematics was just about solving numbers, but now I see how I can use it on our farm. I even helped my father calculate how much fertilizer we need for our crops."* This shift in perception suggests that practical, real-world applications can make abstract mathematical concepts more accessible and engaging.

These qualitative insights align with quantitative data, which showed a substantial rise in student participation and problem-solving engagement post-intervention (Figure 8). The findings reinforce the importance of context-based learning, particularly in rural settings where students benefit from education that connects directly to their everyday experiences.

Problem-Solving and Critical Thinking Skills

The integration of mathematical modelling into agricultural education significantly enhanced students' analytical thinking and problem-solving abilities. Instead of simply memorizing formulas, students began to interpret data, test mathematical models, and develop their own solutions to real-world agricultural challenges.

Enhanced Analytical Thinking Through Mathematical Modelling

The integration of mathematical modelling into agricultural education significantly enhanced students' analytical thinking and problem-solving abilities. Prior to the intervention, students largely approached mathematical tasks as procedural exercises, focusing on memorizing formulas and applying them mechanically. However, following the interdisciplinary approach, students demonstrated deeper cognitive engagement, particularly in areas such as crop yield prediction, soil analysis, and irrigation efficiency.

Enhanced Analytical Thinking Through Mathematical Modelling

Classroom observations and qualitative data from teacher interviews and student focus groups revealed a marked improvement in logical reasoning. Students exhibited a greater ability to interpret agricultural data, analyse variables, and develop mathematical models to address specific challenges in farming. Teachers noted that problem-solving sessions became more student-led, with learners taking initiative in formulating hypotheses and testing mathematical models in real-world agricultural contexts. Additionally, students engaged in collaborative problem-solving, working together to analyse agricultural challenges such as optimizing irrigation systems and predicting soil nutrient depletion. This shift from passive learning to active engagement indicates an improvement in critical thinking skills and the ability to apply mathematical principles in practical settings.

Student and Teacher Reflections

A Grade 12 student described the change in their learning experience, stating:

"Now, I don't just memorize formulas—I think about how to use them. When we calculated how much water our crops needed, it made sense why we were learning these topics." Similarly, an agriculture instructor reflected on the transformation in student attitudes: *"Before, students just wanted to 'get the answer.' Now, they want to know why the answer makes sense. They analyse problems critically before attempting to solve them."* These insights reinforce the quantitative findings, which

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demonstrated an increase in students' problem-solving proficiency post-intervention. The ability to apply mathematical reasoning in real-world agricultural contexts suggests that interdisciplinary education fosters higher-order thinking skills, promoting independent learning and intellectual curiosity.

This shift highlights the importance of contextualized learning, particularly in rural education settings where students benefit from instruction that bridges theoretical knowledge with practical applications.

Real-World Application of Mathematical Concepts

Theme: Bridging the Gap Between Classroom Learning and Agricultural Practices

The integration of mathematical modelling into agricultural education facilitated a significant connection between classroom learning and real-world agricultural practices. Students not only engaged more deeply with mathematical concepts but also demonstrated the ability to apply their learning beyond the classroom.

Bridging the Gap Between Classroom Learning and Agricultural Practices

Classroom observations and teacher interviews revealed that students began experimenting with mathematical models in their daily lives, using their knowledge to assist their families in optimizing resource allocation and improving farming strategies. Several students successfully applied mathematical concepts, such as crop yield estimation, fertilizer distribution, and water usage calculations, to solve practical agricultural challenges at home and within their communities.

Teachers also noted that students frequently referenced real farming experiences during classroom discussions, reinforcing their understanding and retention of mathematical principles. This shift suggests that contextualized, interdisciplinary education enhances students' ability to transfer knowledge to real-world situations, making learning more meaningful and applicable.

Student and Community Reflections

A Grade 10 student shared their success in applying classroom knowledge at home:

"After learning how to calculate crop yield, I applied it at home. I showed my family how we could estimate how much maize we will harvest this year. My father was impressed!" Similarly, a local farmer collaborator highlighted the broader impact of the interdisciplinary approach:

"A few students brought their calculations home and helped their families adjust planting strategies. This means they're not just learning—they're applying their knowledge to real-life problems." These findings emphasize the transformative potential of interdisciplinary education. By equipping students with practical problem-solving skills, the intervention empowered them to contribute meaningfully to their communities, reinforcing the value of mathematical literacy in real-world agricultural decision-making.

Teacher Perceptions of Interdisciplinary Teaching

Theme: Positive Reception Despite Initial Challenges

The integration of mathematical modeling into agricultural education initially posed challenges for educators, particularly those with limited familiarity with agricultural applications. However, as the intervention progressed, teachers reported a shift in their perceptions, recognizing increased student engagement, collaboration, and conceptual understanding as a result of the interdisciplinary approach. Classroom observations and teacher interviews indicated that while some educators initially struggled with integrating mathematical modeling into their lessons, they later found the approach both practical and rewarding. Teachers noted a marked increase in student collaboration, with learners actively assisting one another in understanding how mathematical formulas applied to agricultural contexts. Furthermore, educators highlighted the practical benefits of interdisciplinary teaching in rural settings, emphasizing that students demonstrated a stronger connection between mathematical concepts and real-world agricultural applications. Teachers also observed a higher retention of mathematical principles, as students frequently related classroom discussions to their experiences in farming communities. A mathematics teacher described their initial hesitation and eventual recognition of the method's effectiveness: *"I was skeptical at first because I didn't know much about agriculture, but this approach works. It has made mathematics more practical and engaging."*

Challenges and Adaptations

The integration of mathematical modeling into agricultural education presented several challenges for both students and teachers, particularly during the initial transition from traditional mathematics instruction to an interdisciplinary approach. However, observations and qualitative feedback indicate that students and educators adapted over time, leading to increased engagement and problem-solving proficiency.

Overcoming Initial Resistance and Resource Constraints

Classroom observations and focus group discussions revealed that some students initially struggled with the shift from procedural mathematics to applied problem-solving. Many were accustomed to memorizing formulas and solving structured problems and initially found it challenging to apply mathematical concepts to real-world agricultural scenarios. Resource constraints also posed difficulties in some schools. Limited access to agricultural data and technology required educators to adapt instructional strategies by using simplified case studies, real-world field observations, and locally relevant farming examples. Despite these limitations, teachers remained committed to the interdisciplinary approach, adjusting lesson plans to ensure students could engage with the material effectively.

A Grade 11 student described their initial hesitation and eventual appreciation of the approach: *"At first, I was confused about why we were using math for farming, but now I see how important it is. I even enjoy math more!"* Despite these challenges, both students and teachers reported that the benefits of the interdisciplinary approach outweighed the difficulties. As students became more accustomed to the real-world applications of mathematical modelling, engagement levels continued to rise, and conceptual understanding improved. These findings indicate that while resource limitations and initial resistance were challenges, strategic adaptations in teaching methods and curriculum design facilitated successful implementation of the interdisciplinary approach.

6. DISCUSSION

The findings of this study provide strong empirical support for the integration of mathematical modelling into agricultural education as an effective strategy for enhancing student engagement and problem-solving skills. The results highlight the transformative potential of interdisciplinary teaching, particularly in rural educational settings where traditional mathematics instruction often lacks direct real-world applicability. This discussion section critically interprets the study's findings, contextualizing them within existing literature while highlighting key implications for educational practice and policy.

Enhancing Student Engagement through the Integration of Mathematical Concepts in Agricultural Education

The integration of mathematical concepts into agricultural education has emerged as a transformative approach, addressing a long-standing challenge in student engagement. Mathematics, often regarded as abstract and detached from everyday experiences, has historically been a subject that many students struggle to connect with. This disconnect leads to low participation, disinterest, and, in some cases, an outright aversion to the subject. However, when mathematics is embedded within agricultural education—where students can see its immediate relevance—learning becomes more meaningful. Instead of perceiving mathematical concepts as theoretical exercises confined to textbooks, students begin to recognize them as practical tools that enhance their understanding of agricultural processes. Whether it is calculating the area of farmland, optimizing irrigation schedules, or estimating crop yields, mathematics takes on a new role—one that is directly applicable to the students' lived experiences. This shift has been shown to significantly boost engagement, as demonstrated by Swafford's (2018) study, which reported an increase in student participation from 42% to 78% after introducing mathematical modeling in agricultural contexts. The numbers speak to a deeper truth: when students see the direct impact of mathematics on real-world agricultural challenges, their motivation to engage with the subject increases substantially.

Beyond the statistics, qualitative insights provide a richer understanding of how students experience this integration. Many students have traditionally approached mathematics with a sense of reluctance, often viewing it as a subject detached from their interests. However, when mathematical concepts are embedded within agricultural activities—such as determining the right mix of fertilizers for different soil types or calculating the optimal spacing for planting crops—there is a noticeable shift in their attitudes. A study conducted by Coleman (2020) found that students exhibited greater enthusiasm and confidence in engaging with mathematical tasks when they were directly tied to practical agricultural applications. Observational data reinforced this claim, revealing that students became more interactive, collaborated more frequently with peers, and demonstrated a stronger willingness to solve mathematical problems. These behavioural changes suggest that when students can see a direct correlation between mathematical calculations and their agricultural studies, they are more likely to invest time and effort into mastering mathematical skills. Constructivist learning theories provide a strong foundation for understanding this shift, emphasizing that knowledge is best acquired when learners can relate it to their own experiences. By situating mathematics within familiar contexts, educators bridge the gap between abstract theory and practical application, making learning a more engaging and rewarding process.

The benefits of this approach extend beyond the classroom, shaping students' future career paths in significant ways. In today's rapidly evolving agricultural sector, technological advancements and data-driven decision-making are becoming increasingly essential. The ability to apply mathematical concepts in real-world agricultural settings is no longer a luxury but a necessity. Omotosho et al. (2020) highlight that students who receive agricultural education enriched with mathematical applications are better prepared for careers in agribusiness, environmental management, and agricultural engineering. These students develop a strong analytical foundation that enables them to work with precision farming technologies, interpret agricultural data, and make informed decisions that enhance productivity and sustainability. For instance, modern agricultural practices often rely on mathematical modelling to predict weather patterns, assess soil quality, and manage resources efficiently. Without the integration of mathematics into their education, students may struggle to navigate these complex yet critical aspects of contemporary agriculture.

Experiential learning plays a crucial role in reinforcing this integration, providing students with hands-on opportunities to apply mathematical concepts in agricultural settings. Greig (2024) emphasizes that students retain knowledge more effectively when they engage in experiential learning, particularly when it involves real-world problem-solving. In agricultural education, this could mean using statistical models to forecast crop production, calculating profit margins for sustainable farming practices, or analyzing data to improve livestock health. Such experiences do more than enhance academic performance—they instill confidence, critical thinking skills, and a problem-solving mindset that prepares students for professional challenges. When students engage in tasks where they can immediately see the results of their mathematical applications, they develop a deeper appreciation for both subjects, reinforcing the idea that mathematics is not just a set of abstract rules but a powerful tool that can improve their understanding of agricultural systems.

The growing body of research supporting the integration of mathematics into agricultural education underscores its importance in enhancing student engagement, deepening comprehension, and fostering career readiness. While mathematics has long been regarded as a challenging subject, its application in agriculture provides a compelling way to make learning more meaningful and accessible. Students who once struggled with numbers in a traditional classroom setting begin to see value in mathematical concepts when they are framed within real-world agricultural challenges. As engagement increases, so does their ability to apply mathematical reasoning to complex agricultural problems, equipping them with skills that will serve them beyond their academic journey. In an era where agriculture is becoming more technologically driven and data-dependent, ensuring that students develop strong mathematical competencies is not just beneficial—it is essential for their success in the field.

Interdisciplinary Education and the Development of Problem-Solving Skills

The interdisciplinary approach to education has emerged as a powerful means to enhance student engagement and develop problem-solving skills, particularly in mathematics. Traditionally, mathematics has often been taught in isolation, focusing on abstract theories and rote memorization rather than on practical applications. This approach has led to widespread student disengagement, as many learners struggle to see the relevance of mathematical concepts in their daily lives. However, research increasingly suggests that embedding mathematics within real-world applications—such as agriculture, engineering, and the arts—transforms the learning experience. When students encounter mathematical principles in meaningful contexts, their engagement rises, and their problem-solving abilities become more refined. A study conducted in Australia found that students who engaged in interdisciplinary education demonstrated substantial improvements in critical thinking and analytical reasoning (Scott, 2024). Their post-test scores increased significantly, highlighting the efficacy of integrating mathematics with other disciplines to create a richer, more engaging learning environment.

This trend aligns with broader research emphasizing the importance of contextualized learning in mathematics. Many students struggle with mathematical abstraction, but when they see how these concepts apply to real-life situations—such as calculating crop yields, optimizing resource allocation, or analyzing engineering structures—they develop a stronger conceptual understanding. A study by Zhexembinova (2023) illustrated this point by reporting an increase in students' median test scores from 52% to 75% when mathematical concepts were taught through practical applications. These findings suggest that interdisciplinary learning fosters a deeper grasp of mathematical principles, making them more accessible and intuitive. The success of this approach lies in its ability to link abstract knowledge with tangible experiences, thereby reinforcing learning in ways that traditional methods often fail to achieve.

The relationship between student motivation and academic performance further underscores the value of interdisciplinary education. Research using regression analysis has demonstrated a strong positive correlation between student engagement and their ability to apply mathematical reasoning effectively (Eshaq, 2023). This suggests that when students find mathematical concepts relevant and engaging, they are more likely to persevere in problem-solving tasks, leading to better academic outcomes. Practical applications in agriculture, for instance, allow students to engage in real-world mathematical challenges such as determining soil nutrient levels, calculating irrigation needs, and estimating financial costs for farm operations. These tasks require students to think critically, apply mathematical formulas, and interpret data, ultimately strengthening their problem-solving skills. The integration of STEM disciplines into education has long been advocated as a means to promote meaningful learning, and studies have repeatedly shown that interdisciplinary teaching enhances higher-order thinking abilities (Cheung, 2024). Scholars such as Bybee (2013) and Vasquez (2014) have also contributed to this discourse, reinforcing the idea that incorporating real-world scenarios into STEM education leads to deeper conceptual understanding and better retention of mathematical concepts.

Beyond mathematics, interdisciplinary education has demonstrated effectiveness across various fields, including engineering and the arts. In engineering, for example, students who engage in interdisciplinary coursework report broader perspectives and improved problem-solving skills (Narsareddygari, 2024). Engineers frequently rely on mathematical modeling and statistical analysis to design and optimize structures, and an education that integrates these disciplines equips students with the tools they need to approach complex problems with confidence. Similarly, the integration of arts into mathematics education has been shown to foster creative problem-solving abilities, addressing the limitations of traditional pedagogical approaches that do not encourage innovative thinking (Weichang, 2024). Mathematical concepts such as symmetry, proportion, and spatial reasoning become more engaging when explored through artistic expression, demonstrating how interdisciplinary approaches can cater to diverse learning styles.

Problem-based learning environments further support the effectiveness of interdisciplinary education. Studies indicate that students who participate in such settings develop a deeper understanding of mathematical concepts compared to those taught through conventional methods (AlMuharraqi & Toworfe, 2020). Problem-based learning encourages students to tackle real-world challenges, collaborate with peers, and explore multiple solutions to complex issues. This type of learning fosters resilience, adaptability, and a growth mindset, essential skills in both academic and professional settings. Rather than viewing mathematics as a set of isolated formulas, students begin to see it as a versatile tool for solving problems in various domains, from agriculture to technology to the creative arts.

The growing body of research supporting interdisciplinary education underscores its significance in modern pedagogy. As traditional teaching methods continue to face criticism for their rigidity and lack of practical application, interdisciplinary approaches offer a more dynamic and effective alternative. By integrating real-world applications into mathematics and other subjects, educators can foster student engagement, critical thinking, and problem-solving abilities. The evidence from multiple studies highlights how interdisciplinary learning not only enhances mathematical comprehension but also prepares students for the complexities of an evolving job market. In a world where challenges are rarely confined to a single discipline, equipping students with the ability to think across subject boundaries is crucial. Through interdisciplinary education, students gain the skills, confidence, and motivation needed to navigate and solve real-world problems, making them better learners and more capable professionals in the future.

Bridging the Gap Between Classroom Learning and Real-World Applications

Bridging the gap between classroom learning and real-world applications has become a critical focus in contemporary education, particularly in mathematics, where students often struggle to see the relevance of abstract concepts. The challenge lies in transforming mathematical learning from a series of theoretical exercises into a practical, engaging experience that students can directly relate to their lives. Recent studies highlight the effectiveness of contextualizing mathematics within everyday experiences, such as agriculture, to enhance both engagement and comprehension. When students apply their mathematical knowledge to real-world situations—such as calculating fertilizer quantities, predicting crop yields, or managing farm budgets—they develop a stronger appreciation for the subject. This connection between academics and daily life was evident in a study by Bostic et al. (2020), where students reported using their mathematical skills to assist their families with farming decisions. Such experiences not only reinforce mathematical understanding but also instill a sense of purpose, making learning more meaningful. By seeing firsthand how numbers and calculations directly impact their surroundings, students are more likely to invest effort in mastering these skills, bridging the gap between theoretical knowledge and practical application.

Classroom discussions further support the idea that students engage more deeply with mathematics when it is grounded in real-life contexts. Qualitative research suggests that when students are encouraged to discuss their experiences—such as challenges faced in farming or observations about resource management—they begin to see mathematics as a tool rather than an isolated academic requirement (Tan, 2023). This aligns with Kolb's experiential learning theory, which posits that learning is most effective when it is connected to lived experiences (Rohmah, 2024). Students who can relate their mathematical learning to everyday tasks, such as measuring land areas, adjusting livestock feeding ratios, or interpreting weather patterns, demonstrate higher levels of interest and participation. The process of applying classroom concepts to real-world problems reinforces their learning, making mathematical knowledge more concrete and memorable. Ulandari et al. (2019) emphasize that integrating realistic contexts into mathematics education not only increases engagement but also enhances knowledge retention. When students understand why mathematical skills matter outside of the classroom, they develop intrinsic motivation to improve their proficiency.

This approach is particularly beneficial in rural education, where students may struggle to connect abstract mathematical concepts with their immediate realities. Traditional pedagogical methods often fail to account for the diverse backgrounds and experiences of students in rural areas, making learning feel distant and unrelatable. However, research on the Realistic Mathematics Education (RME) approach demonstrates that anchoring mathematical lessons in familiar, practical experiences significantly enhances problem-solving abilities and self-efficacy (Rohmah, 2024; Wigati et al., 2020). The RME model encourages students to engage in active learning, where they solve real-world problems and develop critical thinking skills in the process. For instance, rather than merely learning formulas for calculating percentages, students might analyze data on crop productivity and determine optimal planting strategies based on market demand. This hands-on learning process not only deepens their understanding of mathematical principles but also builds essential life skills such as decision-making, resource management, and adaptability. Zhu (2023) further supports this perspective, noting that when students tackle real-world mathematical challenges, they become more confident in their ability to apply knowledge outside the classroom, fostering a sense of independence and problem-solving capability.

Beyond experiential learning, integrating technology into mathematics education presents another opportunity to strengthen the connection between academic concepts and real-world applications. Digital tools, mobile applications, and interactive platforms have the potential to transform how students engage with mathematical problems. In agricultural settings, for example, students can use mobile applications to input real farm data and generate predictions about crop growth or financial returns, making their learning experience more interactive and relevant. Papadakis et al. (2021) and Viberg et al. (2020) highlight that digital educational tools provide students with immediate feedback, allowing them to refine their understanding of mathematical concepts in real-time. Furthermore, Nguyen et al. (2020) emphasize that when students interact with technology-driven learning environments, they are more likely to develop computational thinking skills that are essential for future career opportunities. Whether through virtual simulations, gamified learning, or AI-assisted tutoring, technology has the power to make mathematics more accessible and engaging, particularly for students who may have previously struggled with the subject.

The growing body of research supporting the integration of real-world applications into mathematics education underscores its importance in fostering engagement, improving comprehension, and preparing students for practical problem-solving. By contextualizing mathematical concepts within students' daily experiences, particularly in rural settings, educators can create a more dynamic and meaningful learning environment. This approach not only enhances academic success but also equips students with the skills they need to navigate real-life challenges. Mathematics is no longer seen as a distant, abstract discipline; rather, it becomes a valuable tool for decision-making, problem-solving, and innovation in various aspects of life. In an era where education must evolve to meet the needs of a rapidly changing world, ensuring that students can bridge the gap between classroom learning and real-world applications is essential for fostering both academic and personal growth.

Teacher Perceptions and Adaptation to Interdisciplinary Teaching

The integration of interdisciplinary teaching approaches has increasingly been recognized as a powerful tool for enhancing student engagement and improving learning outcomes, particularly in fields where mathematical concepts intersect with real-world applications, such as agricultural education. Historically, educators have faced challenges in implementing interdisciplinary teaching, often due to concerns about their own familiarity with subject areas outside their expertise. In particular, many teachers initially hesitated to incorporate mathematical modeling into agricultural education, fearing that their lack of knowledge in agricultural applications would hinder effective instruction. However, as interdisciplinary interventions progressed, these educators observed substantial improvements in student collaboration, problem-solving skills, and overall comprehension of mathematical principles. When mathematics was no longer presented as an isolated subject but rather as an integral component of real-world decision-making in agriculture, students demonstrated increased enthusiasm and engagement. This aligns with broader research findings indicating that interdisciplinary teaching facilitates deeper learning by making abstract subjects more tangible and meaningful (Deng, 2024; Pascual et al., 2020). By framing mathematics within an agricultural context—such as using equations to determine optimal irrigation schedules or applying statistical models to analyze soil quality—students develop a more intuitive grasp of mathematical concepts, thereby improving their retention and application of knowledge.

The success of interdisciplinary teaching, however, hinges on the effective collaboration between educators from different subject areas. Research suggests that for interdisciplinary teaching to be successful, teachers must receive adequate professional development and instructional support. Many educators are trained narrowly within their disciplines and may struggle with integrating knowledge across subjects. Studies highlight the importance of structured training programs on interdisciplinary themes, as well as collaborative lesson planning, to build teachers' confidence and competence in interdisciplinary instruction (Deng, 2024; Saada, 2024). For instance, professional development workshops that focus on the integration of mathematics and agricultural science can equip teachers with strategies to develop engaging, cross-disciplinary lesson plans that reinforce mathematical reasoning through practical applications. Similarly, co-teaching models, where educators from different subject areas collaborate in designing and delivering lessons, have been found to enhance interdisciplinary literacy among teachers (Saada, 2024; Handtke & Bögeholz, 2022). This collaborative approach fosters a dynamic learning environment where students benefit from diverse perspectives and gain a more holistic understanding of how mathematical principles apply to various real-world challenges. The growing acceptance of interdisciplinary approaches among educators suggests that with the right training and institutional support, these methods can be effectively implemented to improve student learning outcomes (Deng, 2024; Pascual et al., 2020).

Beyond improving engagement, contextualized learning experiences also play a crucial role in reinforcing students' retention of mathematical concepts. When mathematical principles are taught through real-world applications, students are more likely to understand and retain the knowledge long-term. This is especially relevant in STEM education, where interdisciplinary collaboration is essential for solving complex problems and fostering innovative thinking (Charoenmuang et al., 2020). For example, students working on agricultural projects that require data analysis—such as predicting crop yields based on weather patterns or calculating cost-effective fertilizer distribution—develop not only mathematical proficiency but also critical thinking and decision-making skills that extend beyond the classroom. Research confirms that experiential and interdisciplinary learning leads to greater student engagement, deeper conceptual understanding, and improved problem-solving capabilities (Deng, 2024; Pascual et al., 2020). Furthermore, these approaches prepare students for future careers in STEM fields, where the ability to integrate knowledge across disciplines is increasingly valued.

Given the substantial benefits associated with interdisciplinary teaching, it is imperative for educational leaders and policymakers to prioritize the provision of targeted professional development that equips teachers with the necessary skills and confidence to implement interdisciplinary strategies effectively (Luo, 2019; Biseth et al., 2022). Support mechanisms, such as mentorship programs, interdisciplinary teaching communities, and access to instructional resources, can further ease the transition for educators and ensure the sustainability of these approaches. While interdisciplinary teaching requires an initial investment in training and restructuring curricula, the long-term advantages for student learning and engagement make it a worthwhile endeavor.

Although transitioning to interdisciplinary teaching presents challenges, particularly in adapting curricula and training educators, the potential benefits for students are significant. When mathematics is integrated with practical applications in agriculture, engineering, or environmental science, students develop a more profound appreciation for its relevance and

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applicability. They move beyond memorization and passive learning, instead engaging actively in critical thinking and problem-solving. With appropriate support systems in place, teachers can overcome initial apprehensions and successfully incorporate interdisciplinary approaches into their teaching. As research continues to highlight the advantages of contextualized and interdisciplinary education, it is increasingly clear that such strategies hold the potential to transform student engagement and lead to improved learning outcomes across various disciplines (Deng, 2024; Saada, 2024; Pascual et al., 2020).

Challenges and Future Directions

The implementation of interdisciplinary education has demonstrated significant potential in enhancing student engagement and improving learning outcomes. However, its integration into curricula is not without challenges, many of which must be addressed to ensure its effectiveness and sustainability. One of the most pressing difficulties is the transition from procedural mathematics—where students focus primarily on formulas and calculations—to applied problem-solving, which requires them to analyze real-world scenarios and devise mathematical solutions. This shift is often met with resistance from students who are accustomed to conventional instruction and may struggle with open-ended problem-solving tasks. Research indicates that additional instructional scaffolding is essential to support students in developing the critical thinking and analytical skills required for interdisciplinary learning (Rafiq, 2024; Oudenampsen et al., 2023). Without structured guidance, students may find it difficult to connect mathematical theories to practical applications, limiting the effectiveness of interdisciplinary education.

Another significant challenge is the resource constraints that many schools face, particularly in terms of access to relevant data, technology, and instructional materials. In many educational settings, particularly in rural and underfunded schools, students and teachers often lack the necessary tools to implement interdisciplinary projects effectively. For example, applying mathematical modeling to agricultural education may require access to real-world farming data, statistical software, or digital simulations—resources that are not always readily available. These limitations highlight the critical need for targeted investment in educational resources and infrastructure to support interdisciplinary teaching (Joseph, 2024; Lim, 2024). Moreover, beyond providing technological resources, institutions must also focus on equipping educators with the pedagogical skills necessary for interdisciplinary instruction. Studies suggest that professional development programs tailored to interdisciplinary teaching are crucial for helping educators design and implement lessons that effectively integrate mathematics with other subjects (Joseph, 2024; Lim, 2024). Without proper training, teachers may struggle to navigate the complexities of interdisciplinary curricula, diminishing the overall impact on student learning.

Institutional resistance to change further complicates the successful adoption of interdisciplinary education. Traditional education systems are often structured around distinct disciplinary silos, making it difficult to implement cross-disciplinary approaches without significant curriculum restructuring. Many educators express concerns about deviating from standardized curricula, particularly when interdisciplinary teaching methods require additional time for planning and assessment. The lack of professional development opportunities in interdisciplinary teaching further exacerbates this issue, as teachers are often expected to implement these approaches without sufficient guidance or institutional support (Rafiq, 2024; Joseph, 2024). The literature emphasizes that fostering a school-wide culture that values interdisciplinary learning is essential for overcoming these barriers (Lim, 2024; Li, 2024). This requires leadership from administrators, collaboration among educators from different disciplines, and strategic investment in training programs. Institutions that actively promote interdisciplinary education through structured policies and dedicated resources are more likely to see successful implementation and sustained student engagement.

Looking to the future, research should focus on assessing the long-term impact of interdisciplinary education on student performance, career aspirations, and overall academic success. While existing studies provide strong evidence that interdisciplinary approaches improve engagement and problem-solving skills, further research is needed to evaluate the scalability of these methods across different educational contexts (Xu et al., 2022; Oudenampsen et al., 2023). Expanding research to include diverse learning environments—ranging from urban STEM-focused schools to rural agricultural education programs—can provide insights into how interdisciplinary teaching can be adapted to meet the needs of various student populations. Additionally, studying how interdisciplinary education influences students' attitudes toward STEM careers, particularly in agriculture and environmental sciences, could yield valuable findings for curriculum developers and policymakers (Jia et al., 2021; Wade et al., 2020). Understanding whether students who engage in interdisciplinary learning are more likely to pursue careers in STEM-related fields can inform workforce development strategies and ensure that education aligns with industry needs.

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While the benefits of interdisciplinary education are evident, its successful implementation requires a multifaceted approach that addresses the identified challenges. Targeted professional development, investment in educational resources, and institutional support are all crucial components for ensuring that interdisciplinary approaches are effective and sustainable. As interdisciplinary education continues to evolve, future research should aim to explore its broader impact on student learning, engagement, and career trajectories. By addressing these critical factors, educators and policymakers can refine best practices, creating a more dynamic and relevant learning environment that prepares students for complex real-world challenges.

7. CONCLUSION

The integration of interdisciplinary teaching approaches has demonstrated substantial potential in enhancing student engagement, improving learning outcomes, and fostering critical problem-solving skills. As contemporary education shifts towards more practical and application-based learning, embedding mathematical concepts within real-world scenarios—such as agriculture, engineering, and environmental sciences—has proven to be an effective strategy for deepening students' understanding. The literature consistently highlights that when students perceive mathematics as a relevant and applicable tool rather than an isolated theoretical subject, their motivation and conceptual retention improve significantly. However, despite the growing recognition of interdisciplinary education's benefits, several challenges persist that must be addressed to ensure its successful implementation.

A key challenge lies in the transition from procedural mathematics to applied problem-solving, which requires additional instructional scaffolding and pedagogical adjustments. Many students struggle with this shift, emphasizing the need for structured guidance, formative assessments, and differentiated instruction to facilitate deeper learning. Furthermore, resource constraints—particularly in underfunded educational institutions—limit access to necessary technology, real-world data, and professional development opportunities, hindering the effectiveness of interdisciplinary approaches. Institutional resistance to change further compounds these issues, as traditional subject silos and rigid curricula make it difficult to implement cross-disciplinary teaching models. Addressing these barriers requires strategic investments in educational infrastructure, professional training, and policy reforms that prioritize interdisciplinary methodologies.

To ensure the sustainability and scalability of interdisciplinary education, targeted research must be conducted to evaluate its long-term impact on student performance, career aspirations, and workforce readiness. Current studies indicate that interdisciplinary approaches improve problem-solving skills and engagement, but further empirical evidence is needed to assess their effectiveness across diverse educational settings. Expanding research to include varied learning environments—such as urban STEM institutions and rural agricultural education programs—will provide valuable insights into the adaptability of these methods. Additionally, investigating how interdisciplinary education influences students' career trajectories, particularly in STEM and agriculture-related fields, could inform curriculum development and workforce planning strategies.

From an academic and policy perspective, fostering an institutional culture that supports interdisciplinary learning is crucial for overcoming implementation challenges. Institutions must not only encourage collaboration among educators from different disciplines but also provide ongoing professional development and instructional support to equip teachers with the skills necessary for effective interdisciplinary teaching. Leadership from policymakers, school administrators, and curriculum developers will be instrumental in ensuring that interdisciplinary education transitions from an experimental innovation to a foundational teaching strategy.

In conclusion, while interdisciplinary education presents challenges in its implementation, its potential to transform student learning, engagement, and career preparedness is undeniable. By addressing the existing barriers through targeted reforms, institutional support, and empirical research, educators and policymakers can establish best practices that enhance interdisciplinary teaching on a global scale. Future research should continue to explore the broader implications of interdisciplinary education, ensuring that students are not only academically proficient but also equipped with the skills and competencies needed to navigate the complexities of the modern world. Given the increasing emphasis on cross-disciplinary collaboration in industry and academia, integrating interdisciplinary education into mainstream curricula will be essential in preparing the next generation of problem-solvers, innovators, and critical thinkers.

Future Research

To optimize the integration of mathematical modelling in agricultural education, future research should focus on five key areas:

1. Studies should track students over time to assess retention, proficiency, and career outcomes, determining whether interdisciplinary education enhances long-term mathematical and agricultural competencies.
2. Experimental research should compare traditional and interdisciplinary approaches in different settings (urban vs. rural, resource-rich vs. under-resourced) to identify the most effective strategies for engagement and problem-solving.
3. Research should evaluate the impact of interdisciplinary training on educators' effectiveness, exploring best practices for professional development, challenges in implementation, and necessary institutional support.
4. Studies should assess how digital tools, simulations, AI-driven platforms, and gamified learning enhance interdisciplinary education, particularly in applied agricultural mathematics.
5. Research should examine how educational policies can support interdisciplinary learning, ensuring curriculum flexibility while maintaining academic rigor and addressing socioeconomic and cultural considerations.

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