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Mathematics Education in South African Schools (Grades 1-12): A Systems Dynamics Approach from an Engineering Education Perspective

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Abstract

Teaching mathematics in South Africa's educational system continues to face difficulties, especially for students in grades 1 through 12. This research explored these issues using systems dynamics modeling as a cutting-edge analytical technique and seeing them through the perspective of engineering education. The debate about South African school learners' challenges with mathematics achievement has sparked a critical analysis of the necessity for systemic changes within the educational environment. This study investigated how systems dynamics modeling could offer new perspectives on the complex network of variables affecting mathematics education results for students. From the engineering education perspective, there is an acknowledgment of the critical role of mathematics as a fundamental ability for aspiring engineers and innovators. The research aimed to understand the intricate relationships between numerous factors contributing to poor school mathematics performance. The factors are curriculum design, teacher quality, socioeconomic inequities, and student engagement. The idea was to provide a thorough understanding of the difficulties experienced by students from early schooling through high school. Additionally, the study investigated the potential repercussions of a paradigm shift in education that emphasizes cutting-edge teaching strategies, interdisciplinary thinking, and improved teacher preparation at all grade levels. The study shed light on the potential implications of systemic changes in mathematics instruction for South African school learners using systems dynamics modeling. The strategies and interventions may enable decision-makers to be more educated, change the educational system, and alter society's perceptions of innovation.

Keywords
Systems Dynamics Modeling, Mathematics Education, Engineering Education, South African Schools, Educational System

1. Introduction
This research is motivated by the acknowledgment that various urgent concerns influence mathematics instruction in South African schools. These factors encompass the ongoing inequalities in educational achievements, the necessity for changes in the curriculum, the urgent requirement to improve the quality of teachers, and the desire to inspire a deep interest in mathematics among students. At the heart of this endeavor lies a more encompassing aspiration - to equip South African students with the information and abilities needed to flourish in an ever-changing global environment Furthermore, this research is motivated by a dedication to actively participate in the ongoing discourse around education reform in South Africa. This research is a response to the request for creative solutions that can effectively tackle the long-standing disparities and structural obstacles that still impact students in the present. The driving question is: How can mathematics teaching be revolutionized in South African schools to guarantee that it is not only easily accessible but also empowering, not just a mere topic but a catalyst for creativity and advancement? Despite substantial endeavors to reform and allocate resources towards STEM education in the aftermath of apartheid,

the field of mathematics education in South Africa persists in confronting obstacles stemming from historical disparities and curriculum requirements (Maarman and Klopper 2017). Consequently, this has resulted in a subpar performance in both national and international assessments, underscoring the imperative for focused research and interventions.

The history (Roberts, 2018) of mathematics education in South Africa is characterized by segregation during the apartheid era and subsequent reforms such as the Curriculum and Assessment Policy Statement (CAPS). This journey is intricate as it seeks to address historical legacies and socioeconomic inequalities to enhance the quality of education for all. A comprehensive comprehension of the South African education system, namely its grading framework, is necessary to situate conversations on mathematics instruction within its appropriate context. The educational framework is structured into three distinct stages: the Foundation Phase, encompassing Grades 1-3; the Intermediate Phase, encompassing Grades 4-6; and the Senior Phase, encompassing Grades 7-9, culminating in the Further Education and Training (FET) phase, which encompasses Grades 10-12. The design of each phase is intended to further develop the information and abilities obtained in the preceding phase, with a notable focus on mathematics starting from the early grades. The objective of this framework is to equip students with the necessary skills and knowledge not only for matriculation examinations but also for pursuing further education and jobs that play a crucial role in the advancement of the nation (Jojo 2019).

A country's educational system must have a strong foundation in mathematics education since it promotes societal advancement and personal empowerment (Reddy and Taylor 2017). Teaching and studying mathematics are still essential for promoting educational justice, a culture of creativity, and engineering excellence in South Africa, a country that has experienced significant change since the end of apartheid (Letseka et al. 2012). Nonetheless, there have been ongoing obstacles and inequalities in the South African educational system regarding offering pupils in grades 1 through 12 a high-quality mathematics education (Reddy and Taylor 2017). Despite the country's dedication to providing high-quality education, South African students have encountered significant obstacles in pursuing mathematical competency. These problems have several facets and include a variety of outside-the-classroom influences. Mathematical education outcomes for children across grade levels are hampered by a complex web of issues, including curriculum design, teacher quality, socioeconomic disparities, and student involvement (Letseka et al. 2012).

Moreover, mathematical competency is fundamental for future engineers and innovators and goes beyond scholastic achievement (Felder and Silverman, 1988). To guarantee that South Africa's future engineers and innovators have the requisite mathematical capabilities; the deficiencies in mathematics education must be addressed within the larger framework of engineering education (Felder and Silverman 1988). This project uses insights from engineering education in conjunction with a systems dynamics modeling method to fully address the complexities of mathematics instruction in South African schools (Forrester 1961; Kuenzi 2008). A dynamic and comprehensive lens through which to examine the interrelated factors influencing the results of mathematics education is provided by systems dynamics modeling. It makes it possible to investigate how modifications to one area of the educational system can also affect other areas (Forrester 1961).

Research has shown how important it is to investigate novel strategies for resolving the enduring problems in South African mathematics education. Studies conducted in 2010 by Hudson and colleagues demonstrated how technology-assisted learning interventions can improve students' competency in mathematics. Furthermore, the influence of early childhood mathematics instruction on long-term learning results was highlighted by Björklund et al. in 2020. These results highlight the complexity of South Africa's mathematics education system and the demand for all-encompassing approaches. The debate about reforming mathematics education in South Africa has gotten more traction in recent years. The study conducted by Shahrill et al. (2016) explores the possible advantages of using a problem-based learning strategy in educational settings. Future Nations School in South Africa has successfully implemented the project-based learning (PBL) strategy, and the school is seeing excellent outcomes from it. The 2023 Matric learners attained a 100% passing percentage. Additionally, the impact of teacher professional development programs on improving mathematics education was investigated by Ramos-Rodríguez et al. in 2022. These revelations have added to the current conversation about innovative teaching strategies and methods for supporting teachers that have the potential to enhance the results of mathematics education.

Several problem statements arise within the intricate terrain of mathematics education in South Africa (Jojo 2019 and Centre for Development and Enterprise (CDE) 2013):

- **Disparities in Educational Outcomes:** Despite the country's dedication to providing fair education, significant mathematical achievement discrepancies persist among South African learners. These gaps are frequently based on socioeconomic issues, whereby students from underprivileged households encounter more substantial obstacles, such as lack of support.
- **Curriculum Design Challenges:** The existing curriculum design may need to correspond adequately with the varied requirements of South African learners. It is crucial to investigate curricula with several dimensions and improve the significance and involvement of mathematics education.
- **Educator Quality:** The expertise of educators is intimately linked to the quality of mathematics education. It is crucial to tackle the difficulties in teacher training and professional development to enhance the quality of mathematics instruction.
- **Learner Engagement:** Promoting learner engagement is crucial for cultivating a fervor for mathematics among South African students. Comprehending the elements that impact student engagement and participation is essential for improving mathematics instruction.

Considering the abovementioned issues, this research will investigate sustainable and applicable alternatives that can revolutionize mathematics education in South African schools. It utilizes a diverse methodology, incorporating systems dynamics modeling and knowledge from engineering education, to address these intricate difficulties directly. This study explores various aspects of mathematics education in South Africa, including research methodology and suggesting comprehensive frameworks for long-lasting development. This paper aims to delve into the following key dimensions:

- **Complexity of Mathematics Education:** A comprehensive analysis of the complex nature of mathematics education in South African schools, considering the interaction between socioeconomic variables, curriculum design, teacher expertise, and student participation.
- **Engineering Education Perspective:** To highlight the importance of mathematics in engineering education and creativity and stress the consequences for future engineers and innovators of South Africa.
- **Systems Dynamics Modeling:** Introduces systems dynamics as a state-of-the-art analytical method for examining and comprehending the dynamic relationships within the educational ecosystem.

1.1 Objectives

- **Contribution to Education Initiatives:** To contribute significantly to ongoing educational initiatives in South Africa by proposing innovative and sustainable solutions for improving mathematics education
- **Empowerment of South African Students:** To empower South African students with a mathematics education that equips them with essential skills, critical thinking abilities, and problem-solving capabilities necessary for their future success.
- **Preparation for a Successful Future:** To ensure that South African learners are well-prepared for future opportunities, including careers in engineering, innovation, and technology, by enhancing the quality and relevance of mathematics education.
- **Positive Impact on Society:** To foster a positive and transformative effect on South African society by addressing disparities in educational outcomes and promoting equitable access to quality mathematics education

2. Methodology

The research in question utilizes a combination of qualitative and quantitative research methodologies along with systems dynamics modeling. The study used a contemporaneous mixed methods methodology, which involves the simultaneous collection and analysis of qualitative and quantitative data. This integrated approach aims to provide a thorough knowledge of the intricate nature of mathematics instruction in South African schools. The decision is driven by the study's goals to measure the magnitude of educational inequalities and accomplishments in mathematics education, as well as to comprehend the intricate experiences of students, teachers, and policymakers in this setting. By simultaneously utilizing both techniques, our objective is to attain a more thorough comprehension of the present condition of mathematics education, enabling a more in-depth study that can guide more focused and efficient solutions.

Below are the details of the methodology seen in Figure 1.

A. **Data Collection:** This study largely centers on presenting the data analysis of mathematics performance, whereas other datasets will be examined in separate publications. The objective was to offer a thorough comprehension of the complex dynamics of mathematics education. The data analyzed was shared by Marketplace Academy (MPA), and it is 2023 June mathematics results (grade 8 to 12) for seven schools.
B. **Systems Dynamics:** The core of this research revolves around utilizing systems dynamics modeling, a methodology that enables the representation and simulation of the dynamic interactions within the educational ecosystem. The modeling technique will show causal loop diagrams, visually illustrating the interconnections and feedback loops among elements that impact mathematics education outcomes. The approach will also provide a conceptual framework solution that policymakers will be utilize for decision-making and the iterative nature of improving mathematics through systems dynamics.
C. **Qualitative and Quantitative Data Collection:** This sub-process entails collecting qualitative and quantitative data. Qualitative data is characterized by its abundance of contextual information and subjective viewpoints, whereas quantitative data offers numerical observations and analysis. These two forms of data enhance each other, providing a holistic perspective of the educational ecology**.**
D. **Stakeholder Inputs:** The modeling approach integrates stakeholder contributions. The contributions encompass viewpoints from educators, students, and other stakeholders engaged in the education system. They offer valuable perspectives and enhance the precision of the models.
E. **Scenario Analysis:** Analyses is performed using the dynamic simulation models generated during the systems dynamics modeling phase. Scenarios replicate alterations in diverse variables, such as curriculum configuration, instructor instruction, and resource distribution. This step facilitates the examination of prospective policy interventions. In this case in this research, a framework is designed that emphasizes the interconnectedness of curriculum design and support mechanisms, recognizing that both are essential components of a sustainable solution for mathematics education.

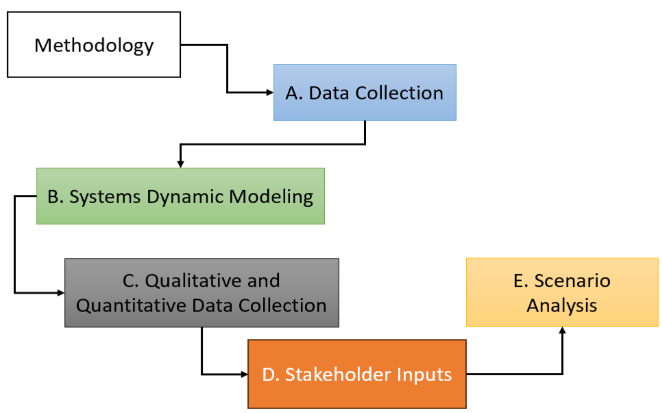

Figure 1. Methodology Conceptual Framework Diagram

3. Results and Discussion

This section provides a comprehensive analysis of the academic performance in mathematics of Grade 8 to 12 learners across seven schools, focusing on their performance in June 2023. The study is centered on critical metrics such as mean scores, standard deviation, and the percentage of learners scoring above and below 50%, as well as those achieving distinctions, as detailed in Tables 1 – 5. A critical finding is the significant disparity in academic performance among the schools. The rationale behind employing a 50% pass mark as a substantial benchmark for evaluating learner achievement in mathematics in this research is based on a deliberate endeavor to conform to international educational norms and anticipations, specifically within the realm of STEM domains. The selection of this barrier, while recognizing South Africa's official lower pass score, aims to cultivate a more demanding academic atmosphere that promotes exceptional performance and equips learners for advanced study and competitive professions in mathematics, engineering, and technology.

This benchmark represents the degree of competency required for pupils to be deemed sufficiently equipped to tackle the intricacies and difficulties of mathematics in higher education and professional settings. School A is highlighted for its exemplary performance, consistently achieving higher mean scores and lower standard deviations across all grades. This denotes a uniform and superior level of mathematical understanding among its learners. Other schools exhibit concerning trends. They are characterized by lower mean scores and higher standard deviations, suggesting not only a lower overall performance in mathematics but also a broader range of academic achievement among learners. Particularly worrying is the performance of Grade 8 learners in these schools, marked by low mean scores, high standard deviations, and a significant proportion of students scoring below 50%. The percentage of learners achieving distinction is generally modest across all schools, with School A leading in most instances. This disparity in academic outcomes necessitates a thorough investigation into the underlying factors and the implementation of targeted strategic interventions, especially for schools requiring urgent support.

In summary, this analysis underscores the need for a holistic and detailed examination of these schools' educational practices and challenges. Such efforts are essential to address the disparities and enhance the overall quality of mathematics education in these schools. Moreover, one significant aspect of this research will involve a thorough examination of test results within schools. This examination will uncover the root causes of the substantial deviations observed in mathematics performance. It has become evident from data analysis that there are significant disparities in student outcomes, highlighting a potential gap in peer-to-peer support. While high standard deviations in mathematics marks can indeed suggest such a gap, it is essential to recognize that a variety of factors can influence this phenomenon. These factors include differences in individual abilities, study habits, access to resources, and the level of peer support. Moreover, further investigation will be conducted in-depth analysis of the schools themselves to determine the presence and extent of gaps in peer-to-peer support. To achieve this, gathering additional data and considering various factors is needed. These factors include:

- **Student Feedback:** Engaging with students to gain insights into their experiences and perceptions regarding the support they receive from their peers.
- **Observation:** Actively observing classroom dynamics and interactions among students to assess whether disparities exist in collaboration and help-seeking behaviour.
- **Peer Tutoring Programs:** Evaluating the effectiveness and prevalence of peer tutoring programs or study groups within the schools under examination.
- **Resource Availability:** Assessing the accessibility and adequacy of all students' resources such as textbooks, study materials, and online resources.
- **Teacher Involvement:** Investigating the role of teachers in facilitating peer support and determining whether they encourage and enable collaboration among students.

Figures 2 and 3 highlight some factors that affect students' performance in the education system. The provided causal loop diagram (CLD) elucidates the current situation of the education system in schools located in both urban and rural areas. Several variables may or may not be pertinent to either the state or the region. The CLD linkages exhibit either a positive or negative polarity. The positive polarity signifies a direct correlation, where an increase in the base variable corresponds to an increase in the variable at the arrowhead. The negative polarity illustrates an inverse relationship, where a rise in the base variable leads to a drop in the variable at the arrowhead. The red and purple links pertain to the teacher elements that are relevant to the quality of teaching and the economic dimension of the education system. The grey links: The grey linkages in the model represent the factors related to a learner's academic achievement and their contribution to the human capital index, based on poverty and school infrastructure/resources. The orange links: The orange links pertain to the social dimension of the education system as it relates to learners. The social dimension of the model holds significance for learners residing in both urban and rural settings, as it pertains to the physiological growth of learners and its impact on their learning outcomes. By the puberty paradigm, it is possible for puberty to either diminish or enhance the rate of learning. The green links: Parental support is typically influenced by the economic condition of the parents, in accordance with the model of parental support.

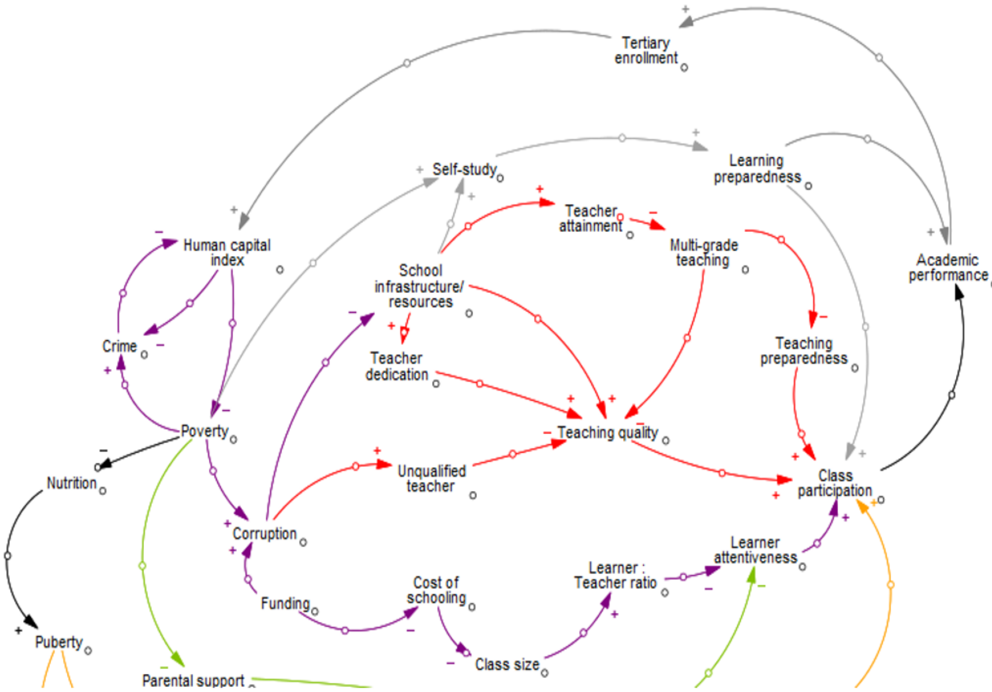

Figure 2. South African basic education system CLD – 1 [Adapted from the Manuscript (Chaba and Ngwenya, 2023)]

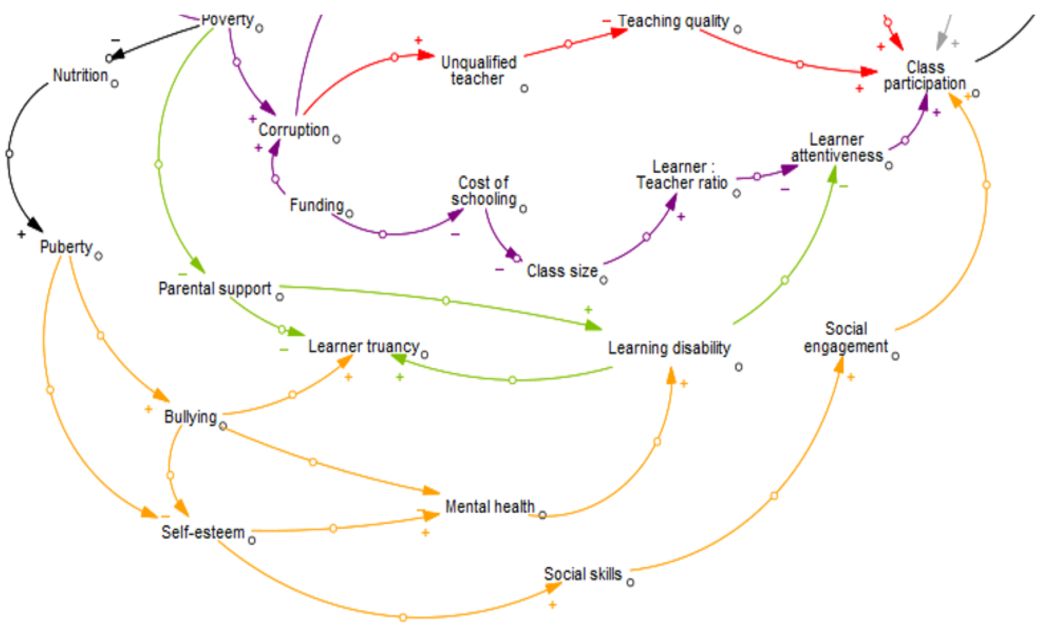

Figure 3. South African basic education system CLD – 2 [Adapted from the Manuscript (Chaba and Ngwenya, 2023)]

Table 1. Grade 8 academic performance for mathematics June results 2023

Grade 8 June 2023 Results	School A (333 Learners)	School B (446 Learners)	School C (425 Learners)	School D (410 Learners)	School E (500 Learners)	School F (448 Learners)	School G (446 Learners)
Mean	57.25%	53.92%	32.28%	33.12%	36.03%	37.12%	35.50%
Standard Deviation	14.89949	15.58966	13.43209	14.07871	16.25958	18.38864	13.97329
Greater than or equal to 50%	103 Learners 67.27%	251 Learners 55.90%,	41 Learn ers 9.65% ,	48 Learners 11.71%	111 Learner s 22.2%	108 Learner s 24.11%	54 Learners 12.11%,
Less than 50%	109 Learners 32.73%	198 Learners 44.10%	384 Learn ers 90.35 %	362 Learners 88.29%	389 Learner s 77.80%	340 Learner s 75.89%	392 Learners 87.89%
Distinction	33 Learners 9.91%	20 Learners 4.45%	0%	0%	0%	6 Learners 1.33%	3 Learners 0.67%

Table 2. Grade 9 academic performance for mathematics June results 2023

Grade 9 June 2023 Results	School A (289 Learners)	School B (421 Learners)	School C (359 Learners)	School D (388 Learners)	School E (379 Learners)	School F (316 Learners)	School G (416 Learners)
Mean	41.03%	60.07%	35.28%	34.04%	40.53%	37.84%	30.66%
Standard Deviation	20.85505	17.30061	15.92169	13.78436	14.75787	15.97492	15.94863
Greater than or equal to 50%	75 Learners 29.95%	306 Learners 72.68%	57 Learners 15.88%	43 Learners 11.08%	88 Learners 23.22%	75 Learners 27.73%	54 Learners 12.98%
Less than 50%	214 Learners 74.05%	115 Learners 27.32%	302 Learners 84.12%	345 Learners 88.92%	291 Learners 76.78%	241 Learners 72.27%	362 Learners 87.02%
Distinction	22 Learners 7.61%	60 Learners 14.25%	3 Learners 0.00836%	0%	5 Learners 1.32%	5 Learners 1.58%	3 Learners 0.72%

Table 3. Grade 10 academic performance for mathematics June results 2023

Grade 10 June 2023 Results	School A (119 Learners)	School B (166 Learners)	School C (221 Learners)	School D (86 Learners)	School E (67 Learners)	School F (0 Learners)	School G (155 Learners)
Mean	40.24%	45.87%	14.14%	16.71%	28.33%	-	34.19%
Standard Deviation	17.31217	17.60907	12.69992	17.8087	18.26272	-	21.9429
Greater than or equal to 50%	29 Learners 24.37%	69 Learners 45.57%	5 Learners 2.26%	6 Learners 6.98%	9 Learners 13.43%	-	33 Learners 21.29%
Less than 50%	90 Learners 75.63%	97 Learners 54.43%	216 Learners 97.74%	80 Learners 93.02%	58 Learners 86.57%	-	122 Learners 78.71%
Distinction	5 Learners 4.20%	5 Learners 3.01%	0%	0%	0%	-	9 Learners 5.81%

Table 4. Grade 11 academic performance for mathematics June results 2023

Grade 11 June 2023 Results	School A (187 Learners)	School B (59 Learners)	School C (148 Learners)	School D (41 Learners)	School E (80 Learners)	School F (133 Learners)	School G (97 Learners)
Mean	23.26%	49.27%	26.47%	26.41%	38.27%	22.56%	32.58%
Standard Deviation	21.28653	14.65915	20.71624	16.07634	20.29215	17.92848	19.0169
Greater than or equal to 50%	23 Learners 12.30%	30 Learners 50.85%	20 Learners 13.51%	3 Learners 7.32%	22 Learners 27.50%	15 Learners 11.28%	18 Learners 18.56%
Less than 50%	164 Learners 87.70%	29 Learners 49.15%	128 Learners 86.49%	38 Learners 92.68%	58 Learners 72.50%	118 Learners 88.72%	79 Learners 81.44%
Distinction	4 Learners 2.14%	1 Learner 1.69%	2 Learners 1.35%	0%	2 Learners	1 Learner 0.75%	3 Learners 3.09%

Table 5. Grade 12 academic performance for mathematics June results 2023

Grade 12 June 2023 Results	School A (118 Learners)	School B (38 Learners)	School C (133 Learners)	School D (43 Learners)	School E (50 Learners)	School F (77 Learners)	School G (102 Learners)
Mean	32.43%	55.39%	31.53%	33.16	27.46%	35.42%	27.02%
Standard Deviation	17.73281	21.50366	20.36841	20.70419	17.61749	19.22536	17.09147
Greater than or equal to 50%	16 Learners 13.56%	22 Learners 57.88%	25 Learners 18.80%	9 Learners 20.93%	5 Learners 10%	14 Learners 18.18%	8 Learners 7.84%
Less than 50%	102 Learners 86.44%	16 Learners 42.12%	108 Learners 81.20%	34 Learners 79.07%	45 Learners 90%	63 Learners 81.82%	94 Learners 92.16%
Distinction	2 Learners 1.69%	6 Learners 15.79%	4 Learners 3%	0%	1 Learner 2%	2 Learners 1.13%	2 Learners 1.96%

4. Strategic Intervention in Pilots

This section outlines the strategic interventions executed in pilot programs to tackle specific difficulties in mathematics education and evaluate their influence. These initiatives are essential experimental platforms for improving the designed comprehensive frameworks and creating future educational tactics.

4.1 Complexity of Mathematics Education: Integrated Curriculum Design and Holistic Support

This conceptual diagram (Figure 4) illustrates the comprehensive strategy for addressing the intricacies of mathematics education in South African schools. **Curriculum Design:** The left branch signifies the necessity for a comprehensive curriculum that adjusts to the varied requirements of students. The subject involves the practical use of mathematical concepts, logical reasoning, and the incorporation of traditional knowledge systems. This strategy seeks to improve the pertinence and involvement of students. **Holistic Support:** The right branch emphasizes the need for a support system that addresses all aspects of a person's well-being. This method encompasses customized treatments designed for students from underprivileged backgrounds, mentorship initiatives, and community engagement. The goal is establishing a conducive learning environment where students receive essential assistance beyond academic teaching.

In this research, a significant emphasis is placed on providing holistic support. The commitment to understanding the comprehensive view of CLDs (Figures 2 and 3) underscores the importance of support in enabling students to achieve their optimal potential. Throughout the journey of mentorship within entities like Keep That Goal Shining (KTG), Own and Manage (OM), Marketplace Academy (MPA), and the University of Pretoria (UP), numerous success stories have emerged, highlighting the transformative impact of holistic support. These stories chronicle the progress of students who received mentorship not only during their school years but also throughout their university education and beyond. This holistic support approach has cultivated a profound sense of community, characterized by unwavering support, and has provided the fertile ground for students to flourish. As depicted in Figure 5, the holistic, lifelong mentorship approach has proven to be practical and sustainable when students are consistently offered support throughout their educational and professional journeys.

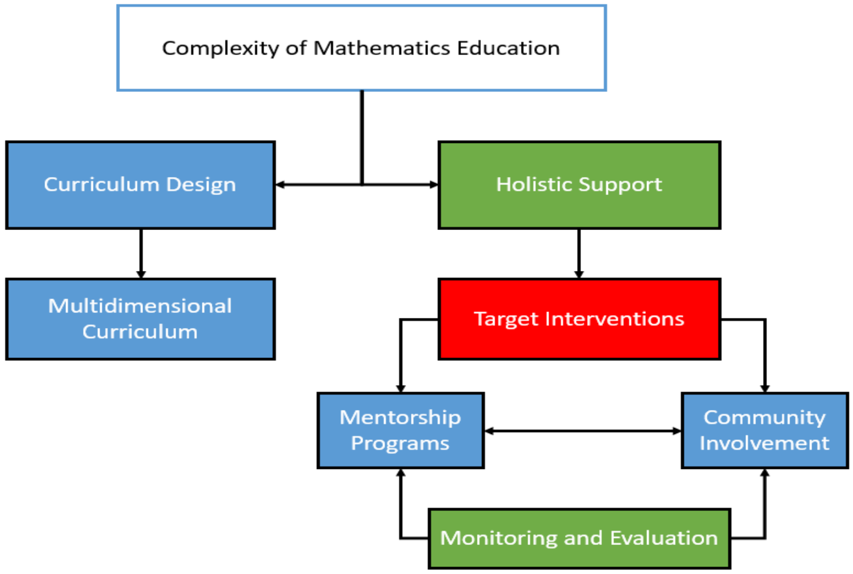

Figure 4. This conceptual diagram illustrates the integrated approach to addressing the complexity of mathematics education

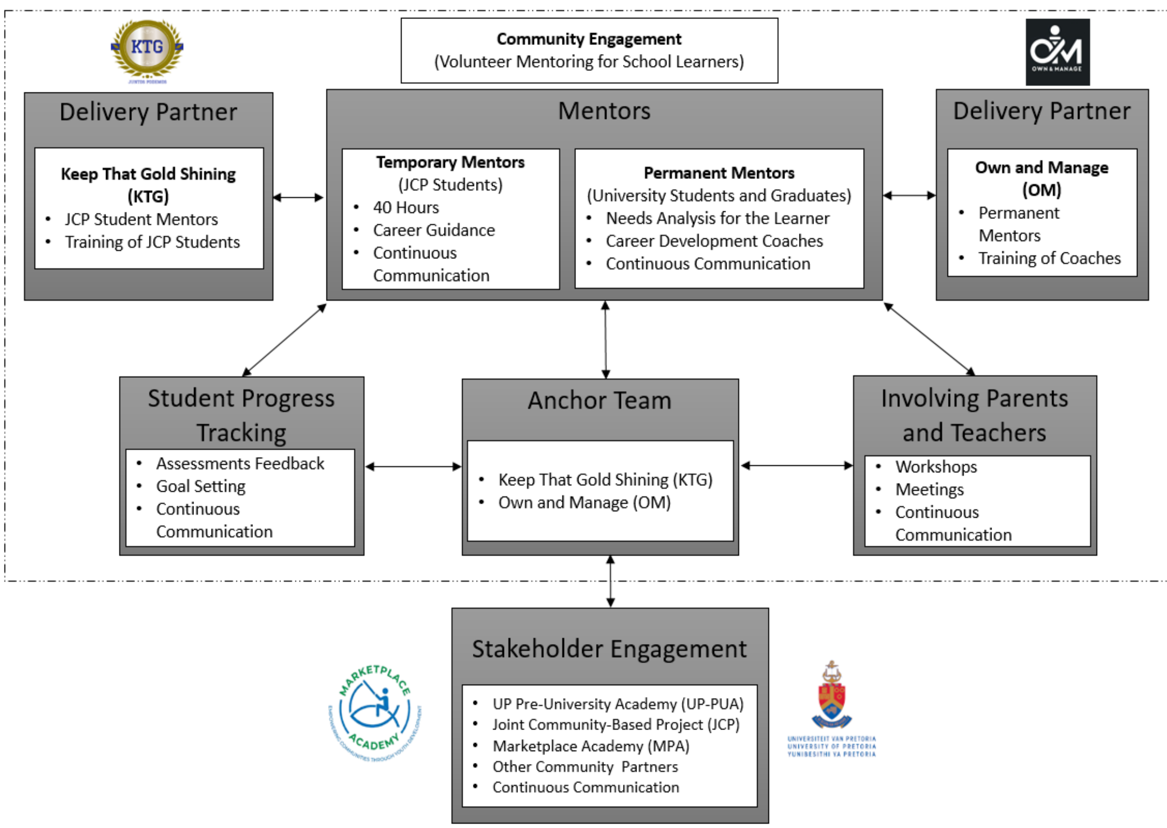

Figure 5. Holistic Integrated Mentorship

4.2 Engineering Education Perspective: STEAM and STEM Integration and Early Exposure

This conceptual framework (Figure 6) illustrates the elements of promoting mathematics in engineering education and fostering early STEAM and STEM exposure. The framework highlights the crucial significance of mathematics in engineering education and creativity from an engineering education perspective. It also emphasizes the cultivation of future engineers and innovators in South Africa. The integration of STEM/STEAM courses is crucial within this complete framework. This integration entails the creation of curricular modules that not only instruct mathematics but also demonstrate its practical applications in engineering and technology domains, thus closing the divide between theoretical understanding and real-world problem-solving. Concurrently, the right branch of this framework greatly emphasizes early introduction to STEM/STEAM subjects. This involves introducing STEM/STEAM concepts from primary school through various enrichment programs, and extracurricular activities, and developing STEM/STEAM clubs. The aim is to cultivate a strong interest and enthusiasm for these disciplines from a young age. Specialized training for mathematics and science educators is essential in providing them with the required abilities to motivate pupils and effectively communicate the practical importance of mathematics in engineering and creativity.

Moreover, cultivating alliances with the industry is crucial within this framework, providing mentorship, internships, and experimental projects that showcase the concrete utilization of mathematics in engineering. Ultimately, this paradigm prioritizes the establishment of an innovation ecosystem that connects educational institutions, communities, research organizations, and industry. This ecosystem fosters entrepreneurship and innovation among students, empowering them to utilize mathematical concepts in practical problem-solving situations. Essentially, this comprehensive framework takes a comprehensive and interconnected approach to engineering education. It starts by introducing STEM/STEAM concepts at an early stage and applying them in practical ways. It also emphasizes the importance of collaborating with industry partners to create strong connections. Finally, it aims to create an innovation ecosystem that will support and promote engineering and innovation in South Africa in the future.

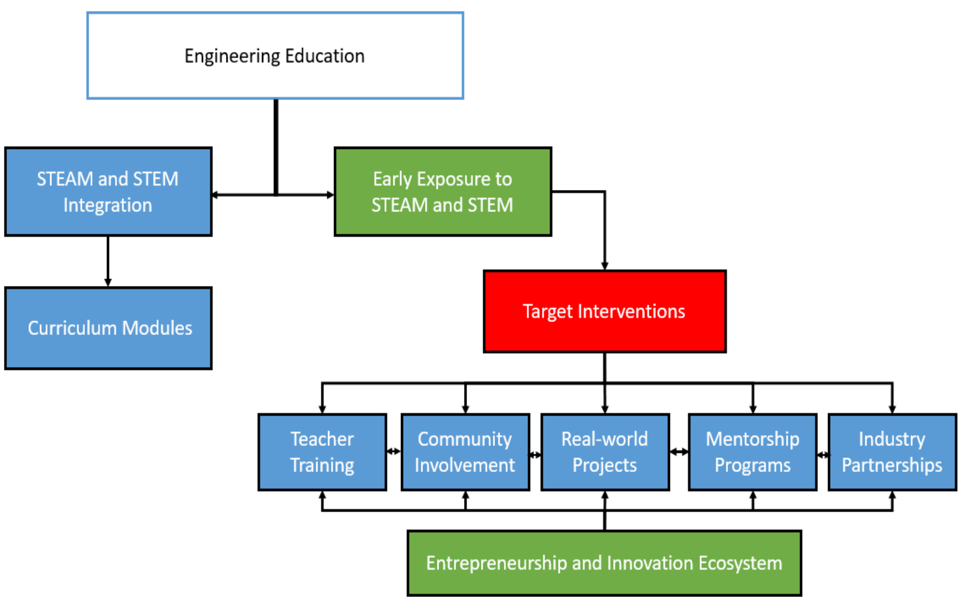

Figure 6. This conceptual diagram illustrates the elements of promoting mathematics in engineering education and fostering early STEAM and STEM exposure

4.3 Systems Dynamics Modeling: Data-Driven Decision-Making and Continuous Improvement

This conceptual diagram (Figure 7) demonstrates the components of a data-driven approach using systems dynamics modeling. The framework for systems dynamics modeling emphasizes the data-driven approach fundamental to comprehending and improving mathematics teaching in South African schools. At the beginning of this process, thorough data collection becomes crucial, covering a range of educational factors, including student performance, curriculum effectiveness, and teacher quality. Dynamic systems models are carefully constructed to illustrate the intricate connections, feedback loops, and interdependencies within the educational ecosystem, enabling the identification of specific areas that require strategic intervention. These models allow stakeholders to conduct scenario analysis, allowing them to realistically replicate various interventions and policy changes to anticipate future outcomes and assess their impact on mathematics education. Based on the knowledge gained from the models and scenario assessments, evidence-based policies are carefully developed to address the underlying factors contributing to mathematics education issues. Notably, the framework emphasizes the ongoing process of monitoring and evaluating the success of established policies and actions, promoting a dedication to constant development. This comprehensive conceptual framework emphasizes the importance of using data to make decisions and highlights the iterative process of improving mathematics education. It utilizes systems dynamics modeling to provide stakeholders with robust tools to transform mathematics education in South African schools.

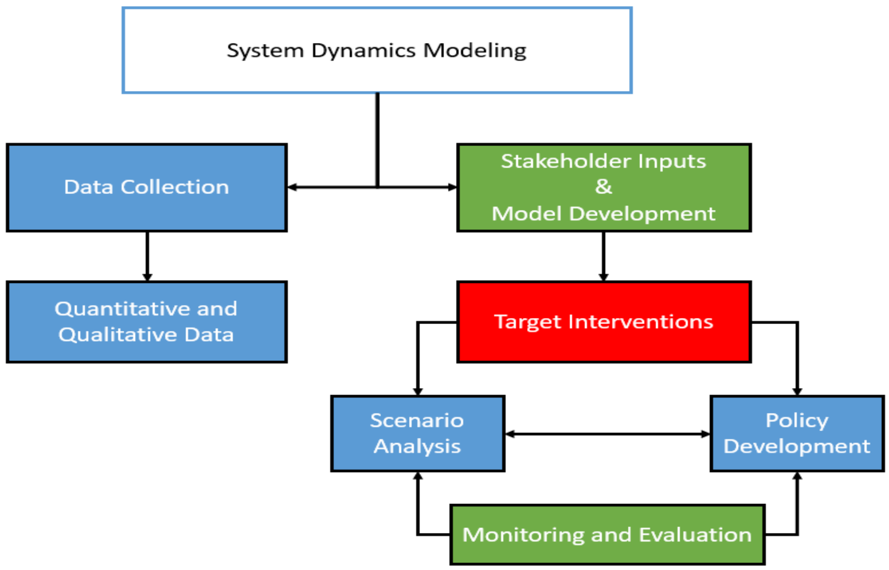

Figure 7. This conceptual diagram demonstrates the components of a data-driven approach using systems dynamics modeling

5. Conclusion

In conclusion, this research paper has thoroughly explored the complex terrain of mathematics education in South African schools, utilizing a comprehensive strategy that includes the integration of STEM/STEAM, early introduction, specialized teacher education, collaborations with industry, and cultivating an environment conducive to innovation. Data-driven systems dynamics modeling, which forms the basis of conceptual frameworks, presents a practical and revolutionary approach to improving mathematics teaching in South Africa. By acknowledging the crucial significance of mathematics in engineering and innovation and highlighting the necessity for comprehensive, lifelong guidance, there is a vision of a future where South African students achieve exceptional results in mathematics and become agents for innovation and transformation. The interrelated elements of the frameworks emphasize the significance of cooperation among educational institutions, industry, communities, and research organizations, creating an environment that enables students to utilize mathematical principles in solving real-life problems. In the future, the research will focus on collecting further data on the pilot initiatives and thoroughly reviewing their effects. This approach will enhance the strategies and create well-founded suggestions for expanding practical activities. And there will be active collaboration with educators, students, and stakeholders. The pursuit of a more promising future commences with the acquisition of mathematical knowledge. This research paper acts as a guiding instrument, directing policymakers towards that optimistic vista. Through continuous endeavors to collect additional data and assess the current approaches, the aim is to improve mathematics education in South Africa further.

References

Björklund, C., van den Heuvel-Panhuizen, M. & Kullberg, A. Research on early childhood mathematics teaching and learning. *ZDM Mathematics Education* **52**, 607–619. https://doi.org/10.1007/s11858-020-01177-3, 2020.

Centre for Development and Enterprise (CDE). Mathematics Outcomes in South African Schools: What are the facts? What should be done? Johannesburg: The Centre for Development and Enterprise. http://www.cde.org.za , 2013.

Chaba, P.E & Ngwenya, T. Using Systems Dynamics to Model the Gaps in Education Service between Rural and Urban Education. Manuscript, 2023.

Felder, R. M., & Silverman, L. K. Learning, and teaching styles in engineering education. Engineering education, 78(7), 674-681, 1988.

Forrester, J. W. Industrial dynamics. Management Science, 7(1), 1-40, 1961.

Hudson, S., Kadan, S., Lavin, K., & Vasquez, T. Improving Basic Math Skills Using Technology. https://files.eric.ed.gov/fulltext/ED512698.pdf, 2010.

Jojo, Z. Mathematics Education System in South Africa. In: Mathematics Education System in South Africa. 1st ed. Pretoria: University of South Africa (UNISA), pp.1-11. http://dx.doi.org/10.5772/intechopen.85325, 2019.

Kuenzi, J. J. Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action. Congressional Research Service, 2008.

Letseka, M., Bantwini, B. & King-McKenzie, E. Public-Union Sector Politics, and the Crisis of Education in South Africa. *Creative Education, 3,* 1197-1204. doi: 10.4236/ce.2012.37178, 2012.

Maarman, G.J. and Klopper, H. A review of challenges in South African education and possible ways to improve educational outcomes as suggested by decades of research. Africa Education Review, 14(3-4), pp.134-155, 2017.

Ramos-Rodríguez, E.; Fernández-Ahumada, E.; Morales-Soto, A. Effective Teacher Professional Development Programs. A Case Study Focusing on the Development of Mathematical Modeling Skills. *Educ. Sci.*, *12*, 2. https://doi.org/10.3390/educsci12010002, 2022.

Reddy, V., & Taylor, S. Trends in International Mathematics and Science Study (TIMSS) 2015: South African Highlights Report. Human Sciences Research Council (HSRC), 2017.

Roberts, N. A Historical and Sociopolitical Perspective on Mathematics Education in South Africa. In: A Historical and Sociopolitical Perspective on Mathematics Education in South Africa. https://www.researchgate.net/publication/322632434 , 2018.

Shahrill, M., Mahalle, S., Matzin, R., Hamid, M. H. S., & Mundia, L. A comparison of learning styles and study strategies used by low and high math achieving Brunei secondary school students: Implications for teaching. International Education Studies, 6(10), 39-46. DOI:10.5539/ies.v9n2p51, 2013.

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