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Problem-Solving Aproach in Calculus in Secondary Schools at Grade 12 Level: A Case Study of Selected Secondary Schools in Mansa District, Zambia

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Abstract- A poor essential working in Mathematics is an attribute of poor problem solving processes. The study explored learners' problem solving approach in Calculus at grade 12 level. The objectives were to examine the impact of problem-solving strategies on learners' confidence in tackling calculus problems, evaluate how perseverance in problem-solving influences learners' success in calculus, analyze how problem-solving approaches contribute to a deeper understanding of Calculus concepts and assess the role of collaborative problem-solving in improving learners' comprehension of Calculus. Thirty-two learners and four teachers at four secondary schools in the Mansa district of Luapula province, Zambia, participated. Purposive and stratified random sampling technique was employed. A qualitative study approach, which followed a descriptive case study design, was used. Data was collected using lesson observations, focus group discussions, and semi-structured interviews. Video and audio recordings were used to capture observations and interviews. Thematic analysis was used to analyse data. The four principles of problem solving by Polya namely, understanding the problem, devising a plan, executing the plan and looking back guided the analysis were employed. Although learners' read, re-read and wrote Calculus functions before solving, they experienced difficulties in underlining key important words; writing Calculus formulas; simplifying calculus problems; applying appropriate calculus formulae; and had no reflective skills during and after solving Calculus problems. In view of these findings, it was recommended that teachers should use problem-solving approaches, which assist learners in identifying key words in the problem, devising Calculus formulas, monitoring each step during solving and looking back after solving.

Keywords- Calculus, Problem solving processes, Integration, Derivative

I. INTRODUCTION

Calculus is a fundamental branch of mathematics that plays a pivotal role in the advancement of science, technology, engineering, and various quantitative disciplines. It forms the mathematical foundation for understanding change, motion, and growth, which are core elements in fields such as Physics, Economics, Engineering, Computer Science, and Environmental Science. However, many secondary school learners in Zambia encounter significant challenges when learning Calculus, primarily due to its abstract concepts, lack of contextual application, and the

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absence of structured and learner-cantered problem-solving strategies in the teaching process.

This study aims to investigate the effectiveness of a problem-solving approach in Calculus education, with a focus on promoting critical thinking, enhancing conceptual understanding, and improving academic performance. A problem-solving approach encourages learners to engage with mathematical problems actively, analyze them critically, and apply appropriate strategies to find solutions—thereby shifting the learning process from rote memorization to meaningful understanding.
The Zambian Education Curriculum underwent a major reform in 2013, introducing Calculus into the secondary school Mathematics syllabus for the first time. This move was part of a broader effort to align the curriculum with international standards and prepare learners for tertiary education and professional careers that require strong mathematical skills. The integration of Calculus aimed to bridge the gap between secondary and higher education by providing students with the tools necessary for success in STEM-related fields.

Despite this positive development, national performance in Calculus has remained unsatisfactory. Reports from the Examinations Council of Zambia (ECZ) consistently show low pass rates in mathematics, particularly in calculus-related questions. Common challenges include procedural errors, such as incorrect differentiation or integration techniques, as well as deeper conceptual misunderstandings, such as the inability to interpret the meaning of limits, derivatives, and integrals in real-life contexts. Furthermore, many teachers rely heavily on traditional lecture-based methods, which do not adequately support learners in developing problem-solving skills or in making sense of abstract concepts.
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II. LITERATURE REVIEW

This chapter provides a critical review of existing literature related to problem-solving approaches in calculus education, establishing a theoretical and empirical foundation for the study. It begins by exploring the major theoretical frameworks that support the use of problem-solving strategies in mathematics instruction, including constructivist learning theories, cognitive development models, and inquiry-based learning paradigms. These theories emphasize the role of learners as active participants in constructing knowledge through exploration, reasoning, and reflection principles that are especially pertinent in the context of calculus, where abstract concepts demand higher-order thinking skills.

Theoretical Framework
The study is grounded in two major theories:
Gestalt Theory
Gestalt Theory, as advanced by Wertheimer (1959), posits that meaningful learning is achieved through insight—a cognitive process wherein learners grasp patterns, relationships, and overarching structures, rather than relying on rote memorization or isolated facts. This theory underscores the holistic nature of perception and cognition,

suggesting that individuals learn best when they perceive a problem as a whole rather than as a disconnected series of steps. In the realm of mathematics, and particularly in calculus education, this insight-based learning becomes especially vital due to the abstract and interconnected nature of the subject. When applied to the teaching and learning of Calculus, Gestalt Theory offers a powerful pedagogical lens through which instruction can be designed to promote conceptual understanding over procedural recall. For instance, learners are encouraged to recognize the conceptual links between differentiation and integration—two foundational concepts in calculus that are often taught as separate entities. By understanding how these processes are inverses of each other, and how they are interrelated through the Fundamental Theorem of Calculus, students can develop a more cohesive and flexible understanding of the subject matter.

Furthermore, Gestalt Theory supports the use of structured problem-solving patterns that reflect real-life cognitive processes. When learners are taught to deconstruct complex calculus problems into meaningful sub-patterns such as identifying rates of change, visualizing function behaviour, or interpreting area under curves they are more likely to internalize concepts and apply them creatively in novel situations. This approach contrasts sharply with traditional instructional methods that emphasize algorithmic manipulation and memorization of formulas without fostering understanding of the underlying principles. In practical classroom terms, this means that educators should design lessons that encourage learners to perceive and engage with the “whole structure” of a calculus problem. This might involve the use of visual representations, such as graphs or diagrams, and real-world applications that contextualize abstract concepts, making them more accessible.

Polya’s Problem-Solving Framework

One of the most influential contributions to mathematics education is George Polya’s (1957) four-step problem-solving model, which remains a cornerstone in contemporary pedagogical approaches. Polya outlined a systematic process for tackling mathematical problems that cultivates critical thinking, logical reasoning, and metacognitive awareness. His framework consists of four sequential but flexible stages:

Understanding the Problem – This foundational step involves identifying the key elements, variables, and relationships within the problem. It requires learners to carefully read and interpret the problem statement, discern what is known versus what is being asked, and visualize the mathematical situation—skills particularly crucial in calculus, where comprehension of function behaviour, limits, and rates of change is essential.

Devising a Plan – At this stage, learners select appropriate strategies, formulas, or theorems that are applicable to the problem. In the context of Calculus, this may include deciding whether to apply differentiation, integration, or limit concepts, and choosing methods such as substitution, the chain rule, or area approximation techniques. This phase fosters strategic thinking and encourages learners to draw connections between different areas of mathematical knowledge.

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Executing the Plan – This involves carrying out the chosen strategies while continuously monitoring for accuracy and logical coherence. Calculus problems often involve multi-step calculations and symbolic manipulations, which demand precision and persistence. Polya emphasized the importance of thoughtful execution rather than mechanical computation, encouraging learners to remain flexible and adaptive in the face of difficulties.

Looking Back – The final step emphasizes reflection, prompting learners to evaluate the reasonableness of their solution, verify their results, and consider alternative approaches. This retrospective analysis not only reinforces learning but also cultivates habits of self-assessment and error analysis, which are essential for mastering complex mathematical concepts such as those found in Calculus.

III. METHOD

Research Design

This study adopts a mixed-methods research approach, integrating both quantitative and qualitative methodologies to provide a comprehensive analysis of the effectiveness of problem-solving strategies in calculus education.

Population and Sample Size

Target Population

The study targets Grade 12 learners studying Calculus in Mansa District. Additionally, mathematics teachers and school administrators are included for their perspectives on calculus instruction.

Sample Size and Selection Criteria

A purposive and stratified sampling method is used to ensure a representative selection of learners from different schools. The total sample size is 200 learners from five secondary schools, along with 10 mathematics teachers and 5 school administrators.

Data Collection Methods

Surveys

Structured questionnaires were administered to learners to gather information about their problem-solving experiences, challenges, and perceptions of calculus. Surveys include Likert-scale questions and open-ended responses.

Classroom Observations

Direct classroom observations are conducted to assess teaching methods, learner engagement, and problem-solving interactions. Observations focus on how teachers implement problem-solving strategies in calculus lessons. Key elements recorded include:

- Frequency of problem-solving activities.
- Learner participation levels.
- Use of visual aids and real-life applications in teaching.

In-depth Interviews

One-on-one interviews are conducted with mathematics teachers and school administrators to explore their experiences with calculus instruction, the challenges they face, and their views on problem-solving methodologies. Sample interview questions include:

- How do you integrate problem-solving in calculus lessons?
- What are the main difficulties learners encounter in calculus?
- How do you assess problem-solving skills in your learners?

Focus Group Discussions

Focus group discussions (FGDs) are conducted with learners to gain insights into their problem-solving approaches and challenges in calculus. Each FGD consists of 6-8 learners and discussions are guided by pre-set questions, such as:

- What strategies do you use to solve calculus problems?
- Do you find group problem-solving helpful in understanding calculus?
- What improvements would you suggest for calculus instruction?

Document Analysis

School records and examination results are analysed to track trends in calculus performance before and after implementing problem-solving techniques. Data points examined include:

- Average class scores in calculus over the past five years.
- Frequency of calculus-related failures and their common causes.
- Data Analysis Methods
- Quantitative Data Analysis

Quantitative data from surveys and examination records are analysed using descriptive and inferential statistics. Statistical tools such as Excel are used to:

- Calculate mean, median, and standard deviation for learner performance.
- Conduct t-tests to determine the significance of performance improvements.
- Generate bar charts and line graphs to visualize trends.
- Qualitative Data Analysis

Qualitative data was analysed using thematic analysis

Ethical Considerations

The study ensures adherence to ethical guidelines by:

- Obtaining informed consent from all participants.
- Maintaining confidentiality and anonymity of learner data.
- Seeking approval from the Ministry of Education and participating schools.
- Ensuring participants have the right to withdraw from the study at any time.

IV. RESULTS

Quantitative Data Presentation and Analysis

Learner Performance Before and After Problem-Solving Approach

A key objective of this study was to measure how the implementation of a structured problem-solving approach affected learner performance in calculus. The table below presents average learner scores before and after implementing problem-solving strategies:

Table 4: Learner Performance Before and After Problem-Solving Approach

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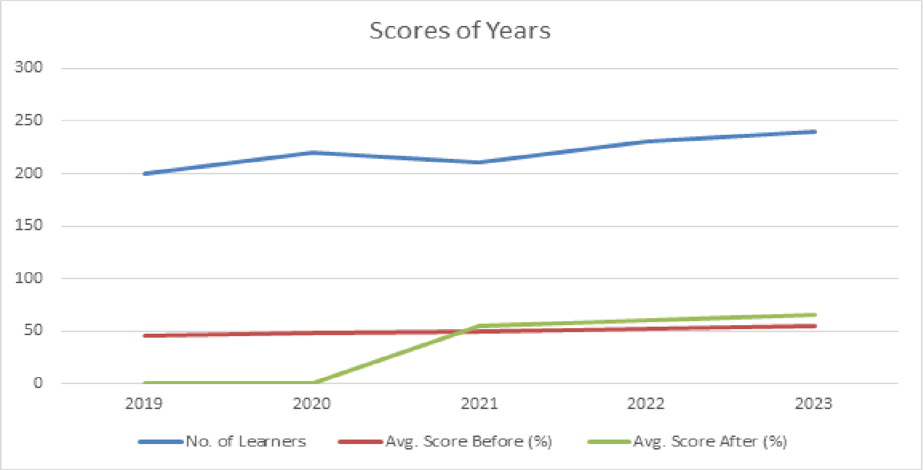
Year	No. of Learners	Avg. Score Before (%)	Avg. Score After (%)
2019	200	45	-
2020	220	48	-
2021	210	50	55
2022	230	52	60
2023	240	55	65

The line graph below illustrates the trend in learner performance before and after the intervention:

Figure 4: Learner Performance Before and After Problem-Solving Approach



Key Observations:

- Before implementing problem-solving strategies, learners' scores remained below 55%.
- After adopting the approach in 2021, learner performance showed a steady increase, reaching 65% in 2023.
- The trend suggests that structured problem-solving positively impacts learners' understanding and application of calculus concepts.
- Learner Confidence in Solving Calculus Problems

A Likert-scale questionnaire was used to assess learners' confidence levels in problem-solving before and after intervention. The responses were classified as:

- Very Low (1-20%)
- Low (21-40%)
- Moderate (41-60%)
- High (61-80%)
- Very High (81-100%)

Table 5: Learner Confidence in Solving Calculus Problems

Confidence Level	Before Problem-Solving (%)	After Problem-Solving (%)
Very Low	40	10
Low	30	15
Moderate	20	30
High	8	30
Very High	2	15

Figure 5: A bar chart comparing learner confidence levels before and after using problem-solving techniques.

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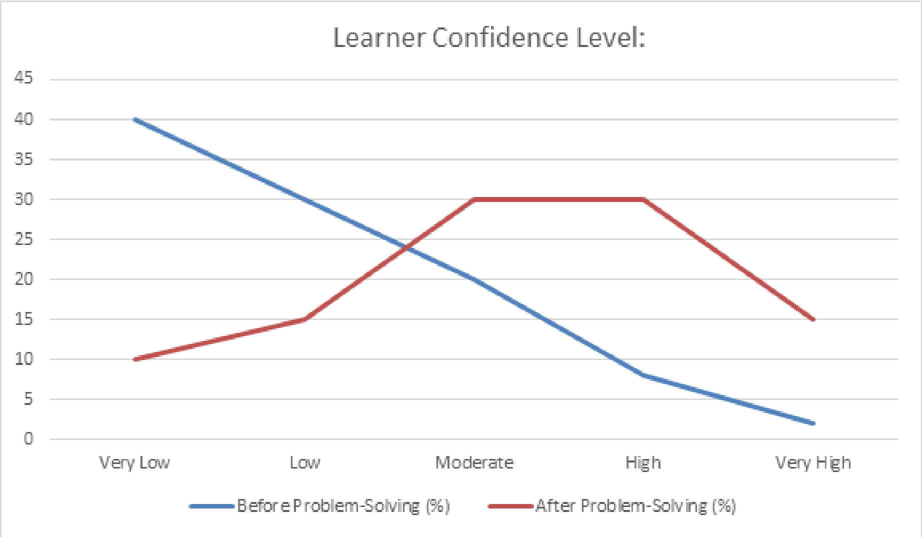

Key Observations:

- 40% of learners had very low confidence in solving calculus problems before intervention, which reduced to 10% after intervention.
- Learners reporting high or very high confidence increased from 10% to 45%, demonstrating improved self-efficacy.

Qualitative Data Analysis

Themes from Classroom Observations

During the classroom observations, key problem-solving behaviours and strategies were systematically recorded, offering valuable insights into the impact of structured problem-solving sessions on learner engagement and conceptual understanding. The observations revealed several recurring themes that shed light on how learners interacted with problem-solving tasks and how these interactions influenced their learning outcomes.

Increased Learner Participation

Engagement in Group Activities: One of the most noticeable behaviours was the increased participation of learners during group problem-solving activities. Initially, some learners appeared passive, but as the lessons progressed, they became more involved in discussions and collaboration. This shift suggests that problem-solving activities provided learners with a platform to actively contribute, exchange ideas, and clarify concepts with their peers.

Peer Discussions and Concept Retention: Peer discussions emerged as a key strategy for improving understanding. Learners who were able to discuss problems with their peers seemed to retain concepts more effectively. This collaborative approach not only enhanced their ability to solve problems but also helped them internalize the calculus concepts better, as they could articulate their reasoning and engage in mutual problem-solving.

Conceptual Understanding over Memorization

- Initial Reliance on Memorization: At the outset, many learners demonstrated a tendency to rely on memorizing formulas and algorithms without fully understanding the underlying principles. This approach, while common in mathematics education, limits the learners' ability to adapt and apply knowledge in unfamiliar problem contexts.
- Shift towards Deeper Understanding: However, after participating in structured problem-solving sessions, a noticeable shift occurred. Learners began to move away from rote memorization and developed a deeper conceptual understanding of key calculus concepts, particularly differentiation and integration. They began to recognize the relationships between different calculus principles and were able to apply them flexibly in problem-solving tasks, demonstrating an ability to understand the logic and reasoning behind the formulas rather than relying on memorization alone.

Error Analysis and Reflection

- Active Error Discussion: One of the most valuable insights from the observations was the learners' approach to error analysis. Learners who initially made mistakes in solving problems did not shy away from their errors; instead, they actively engaged in discussing and correcting them. This reflection process was crucial in solidifying their understanding, as it encouraged them to critically evaluate their thought processes and the steps involved in reaching the solution.
- Encouragement of Multiple Solution Pathways: Another key strategy observed was the teacher's encouragement of exploring multiple solution pathways. Rather than focusing solely on a single correct answer, teachers emphasized the importance of flexible thinking, allowing learners to explore different approaches to solving the same problem. This strategy not only helped learners appreciate the diversity of solutions in mathematics but also fostered a deeper understanding of the problem-solving process itself.

Themes from Focus Group Discussions

Focus group discussions revealed insights into learners' experiences with problem-solving strategies:

Learner 1: "Before, I would just use a formula without thinking about why it worked. Now, I break the problem down and understand each step."

Example:

Before structured problem-solving, a student solving $\int(3x^2 + 2x)\,dx$ would simply apply the power rule without considering why it works. However, with a step-by-step approach, they are now:

Identify each term separately: $\int 3x^2\,dx$ and $\int 2x\,dx$.

Apply the power rule to integrate each term:

- o $\int 3x^2\,dx \rightarrow (3/3)\,x^3 = x^3$
- o $\int 2x\,dx \rightarrow (2/2)\,x^2 = x^2$

Combine results: $x^3 + x^2 + C$.

By understanding the mechanics behind the formula, the learner builds confidence and reduces errors.

Learner 2: “Working in groups helped me see how different people solve the same problem in different ways.”
Example:
In a calculus class, learners were given the problem:
Find the derivative of $f(x) = (x^2 + 1)(x – 3)$ using two different methods.

- **Student A used the product rule:**
  - $f'(x) = (x^2 + 1)'(x – 3) + (x^2 + 1)(x – 3)'$
  - $= (2x)(x – 3) + (x^2 + 1)(1)$
  - $= 2x(x – 3) + x^2 + 1$
- **Student B expanded the function first:**
  - $f(x) = x^3 – 3x^2 + x – 3$
  - **Then derived term by term:**
  - $f'(x) = 3x^2 – 6x + 1$

In a group discussion, students compared both methods, realizing the product rule is useful for quick differentiation, while expansion works well for simpler derivatives. This showed the value of collaborative learning in exploring multiple problem-solving approaches.

Learner 3: “I used to be afraid of calculus, but now I enjoy it because I know how to approach problems systematically.”
Example:
A student struggled with limits, feeling lost when asked to evaluate:
lim⁡x→2x2−4x−2\lim_{x \to 2} \frac{x^2 - 4}{x - 2}x→2limx−2x2−4
Before structured learning, they would get stuck and frustrated. However, with the systematic approach, they now:
Attempt direct substitution: 22−42−2=00\frac{2^2 - 4}{2 - 2} = \frac{0}{0}2−222−4=00 (indeterminate).
Factorize the numerator: (x−2)(x+2)x−2\frac{(x-2)(x+2)}{x-2}x−2(x−2)(x+2).
Cancel common terms: x+2x + 2x+2.
Re-evaluate using substitution: 2+2=42 + 2 = 42+2=4.
By breaking the problem into steps, the student overcomes their fear, realizing calculus is logical and manageable rather than intimidating.

Comparison of Teacher Perceptions on Problem-Solving Methods
Teachers were interviewed to assess their views on traditional teaching methods versus structured problem-solving. The following contrasts were noted:
Table 6: Comparison of Teacher Perceptions on Problem-Solving Methods

Aspect	Traditional Teaching	Problem-Solving Approach
Learner Engagement	Low	High

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Concept Retention	Memorization-based	Understanding-based
Error Correction	Teacher-driven	Learner-driven
Problem-Solving Ability	Weak	Strong

Key Insights:
• Teachers acknowledged that learners were more engaged after the problem-solving approach was introduced.
• Learners became more independent learners, needing less direct instruction over time.

V. DISCUSSION

Quantitative Findings

The statistical analyses of learner performance data confirmed a steady increase in learner scores following the introduction of structured problem-solving strategies. The results from pre- and post-tests demonstrated a marked improvement in learners' ability to solve calculus problems, particularly in areas such as differentiation and integration. These findings were further supported by mean score comparisons and trend analyses, which consistently indicated positive changes in performance across all participating learners. This quantitative evidence underscores the effectiveness of problem-solving approaches in improving learners' academic outcomes in calculus.

Qualitative Findings

Qualitative responses from learners, gathered through interviews, focus group discussions, and classroom observations, highlighted a positive shift in their learning attitudes. Learners reported increased confidence in tackling challenging problems and a greater sense of engagement during lessons. Many expressed that the structured approach to problem-solving not only helped them understand the concepts more deeply but also made learning calculus more enjoyable and accessible. Furthermore, learners noted a reduction in mathematical anxiety, particularly when they were encouraged to explore multiple solution pathways and engage in reflective practices after making errors.

Teacher Perceptions

The teachers’ perceptions of the problem-solving strategies were also overwhelmingly positive. Teachers indicated that the problem-solving approach not only helped students overcome conceptual barriers but also improved their problem-solving skills. They reported that learners were more active and motivated in class, and many

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observed a noticeable improvement in learners' ability to explain and justify their problem-solving steps. Teachers emphasized that providing learners with the opportunity to discuss their reasoning and errors fostered a deeper conceptual understanding of calculus principles.

In a nut shell, the findings from both quantitative and qualitative data provide strong evidence that problem-solving strategies can significantly enhance learner outcomes in calculus. The integration of these strategies not only led to improved academic performance but also positively impacted learner confidence, engagement, and attitudes towards mathematics. Teachers, too, recognized the value of these approaches in improving learners' conceptual understanding and fostering a more collaborative and reflective learning environment.

VI. CONCLUSION

The study demonstrates that structured problem-solving approaches significantly enhance learners' conceptual understanding of calculus. By focusing on active engagement, peer collaboration, and reflective error analysis, learners were able to transition from a rote memorization approach to a more deeply rooted understanding of calculus principles, such as differentiation and integration. This shift was evidenced by both the improvement in learner performance, as seen in the statistical data, and the positive changes in learner attitudes, which were captured through qualitative feedback. Furthermore, the study highlights the importance of teacher facilitation in guiding learners through problem-solving tasks. Teachers who encouraged multiple solution pathways and fostered collaborative learning environments were able to support students in overcoming common difficulties in calculus, such as conceptual misunderstandings and procedural errors. These findings suggest that problem-solving should be viewed not only as a tool for improving academic performance but also as a means of empowering learners to take ownership of their learning.

Implications

The findings of this study hold important implications for both policy and classroom practices in secondary school mathematics education.

For Educators

- Teachers should adopt structured problem-solving approaches by integrating step-by-step explanations into their lessons.
- Peer collaboration and group discussions should be encouraged to help learners exchange ideas and learn from one another.
- Use of real-world examples should be emphasized to connect calculus concepts to practical applications, such as:
- Using rates of change in physics to explain differentiation.
- Explaining area under curves in economics and engineering to demonstrate integration.

For Policymakers

- The Ministry of Education should revise the curriculum to ensure that problem-solving techniques are emphasized in mathematics instruction.
- Workshops and professional development programs should be organized to train teachers on implementing effective problem-solving strategies in calculus instruction.
- The government should provide financial and material support to schools, ensuring access to technology such as graphing calculators and interactive software.
- **For Learners**
- Learners should practice breaking down problems into smaller steps, making it easier to solve complex calculus questions.
- Collaborative learning methods, such as study groups and peer tutoring, should be adopted to improve conceptual understanding.
- Learners should use digital tools and online resources, such as:
- GeoGebra for visualizing calculus problems.
- Khan Academy and Coursera for interactive video lessons.
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