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Effectiveness of problem-based learning in promoting the critical thinking skills of students in mathematics classrooms in Bamenda municipality

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Abstract

The development of critical thinking skills in mathematics remains a significant challenge in Bamenda Municipality, where traditional teaching methods emphasize rote memorization over conceptual understanding. This study investigates the effectiveness of Problem-Based Learning (PBL) in enhancing students' critical thinking abilities in mathematics classrooms. A quasi-experimental research design, specifically a non-equivalent pretest-posttest control group design, was employed. The study sampled 103 Form Three students from two Government Bilingual High Schools, with one school serving as the experimental group (PBL approach) and the other as the control group (traditional teaching). Data were collected using pretest and posttest critical thinking assessments, measuring problem-solving, logical reasoning, and metacognitive skills. Analysis of Covariance (ANCOVA) was used to determine statistical significance. Findings revealed that PBL is rarely used in Bamenda's mathematics classrooms, with 89.32% of students unaware of the approach. However, students exposed to PBL demonstrated significantly higher mean gains in critical thinking (22.88) compared to those taught through traditional methods (2.71). The ANCOVA test confirmed the effectiveness of PBL, yielding an F-value of 10.686 and a p-value of 0.000, leading to the rejection of the null hypothesis. These results underscore the need for curriculum reforms, teacher training, and institutional support to facilitate the integration of PBL in mathematics education. The study recommends targeted professional development programs and structured PBL activities to enhance students' problem-solving skills and overall academic performance.

Keywords: Problem-Based Learning; Critical Thinking; Mathematics Education; Quasi-Experimental Design; Bamenda Municipality

1. Introduction

Problem-based learning (PBL) is an educational method that involves students actively exploring real-world problems, scenarios or case studies to develop critical thinking, problem-solving, and collaboration skills. It is a student-centered approach to learning that involves groups of students working to solve a real-world problem, quite different from the traditional teaching method of a teacher presenting facts and concepts about a specific subject to a classroom of students. PBL entails the provision of real-world problems, active collaboration within groups, the formulation of problems and identification of gaps in knowledge, the exploration and discovery of relevant materials, and the resolution of problems (Damopolii & Kurniadi, 2019; Salvador et al., 2023; Ssemugenyi, 2023; Wahyuningsih et al., 2023). PBL offers students numerous advantages, as it fosters critical thinking, issue resolution, and the ability to locate and apply pertinent learning resources (Chiang & Lee, 2016; Wahyuningsih et al., 2023; Yulianti & Gunawan, 2019).

Problem-based learning (PBL) has been seen to yield positive outcomes in education, as it enhances students' abilities and alters their perception of the subject matter. Consequently, students' critical thinking abilities are enhanced as the

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entire learning process revolves around their active engagement, with the teacher assuming the role of a facilitator (Alreshidi & Alreshidi, 2023; Anggraeni et al., 2023; Zulyusri et al., 2023), to accelerate the learning process. As per the research conducted by Manuaba et al. (2022), Problem- based learning emerges as a viable alternative to conventional modes of instruction, which adequately foster higher levels of critical thinking. This student-centered approach has a long tradition prior to Problem-based learning, including Dale's Cone of Experience (Dale, 1969). Dale's Cone illustrates that learners tend to retain 90% of what they hear and do, an idea that is at the core of problem-based learning. However, there remains a dearth of research on the implementation of PBL in the mathematics curriculum.

Therefore, in the process of acquiring knowledge, it is imperative for students to possess critical thinking skills to evade misconceptions. The development of critical thinking skills does not occur instantaneously within students; rather, it necessitates the implementation of innovative teaching materials or methods that have the capacity to cultivate these skills. According to Palennari (2018), problem-based learning (PBL) is particularly well-suited for integration into the realm of Mathematics education. By means of problem-based learning, students are perfected in the construction of knowledge, as well as the cultivation of independence and collaboration when confronted with mathematically ill-structured problems. By means of PBL, students studying mathematics are guided towards the practice of skill sets such as analytical thinking, logical reasoning, time management, problem- solving. Mathematics teachers should create a learning environment that makes the subject enjoyable and enhances students' thinking skills, brainstorming as well as initiate more discussion and give motivation. This presents a formidable challenge for educators (i.e., teachers) to exhibit greater creativity in the development of relevant teaching materials that align with the needs and characteristics of students, thus the need for problem-based learning method.

2. Background to the Study

Problem-based learning (PBL) emerged at McMaster University in 1969 as a reform in medical education aimed at enhancing students' motivation by engaging them with real-world problems (Kolmos, Fink, & Krogh, 2004; Schmidt, 1993; Spaulding, 1969). Since then, PBL has been integrated into various disciplines, including engineering, law, psychology, and business education (Barrows, 1996; Loyens, Kirschner, & Paas, 2012). While some credit its origins to American neurologist Howard Barrows (Hillen, Scherpbier, & Wijnen, 2010), others trace it to the Socratic Method (Schmidt, 2012) or John Dewey's experiential learning philosophy.

PBL did not emerge in isolation but was influenced by Dewey's experimental school at the University of Chicago, the case study method pioneered at Harvard in the 1930s, and Jerome Bruner's learning-by-discovery model. Over time, PBL evolved into multiple strands, each emphasizing different educational goals. Today, some educators see PBL as a remedy for educational challenges, while others challenge its effectiveness. Research conducted in 2012 examined archival evidence from institutions such as McMaster and Maastricht Universities to analyze PBL's development using Whewell's inductive historical method (Whewell, 1858).

PBL is a student-centered, collaborative, and nontraditional instructional approach where students engage in problem-solving rather than passive learning (Neufeld, Woodward & MacLeod, 1989). First implemented at McMaster in 1965 in health sciences, PBL has since been adopted in disciplines such as medicine (Moore et al., 1994), nursing (Forbes, Duke & Prosser, 2001), physical therapy (Lusardi, Emery & Lake, 1997), occupational therapy (Royeen, 1995), and pharmacy (Brandt, 2000). The core premise of PBL is that learning is most effective when it builds upon students' prior knowledge and occurs in contexts similar to real-life applications (Schmidt, 1983; Binkley, 1998). Students assume responsibility for their learning, while instructors facilitate discussions focused on acquiring and integrating knowledge rather than simply solving problems (Norman, 1988).

This study explores the relationship between PBL (independent variable) and critical thinking in mathematics (dependent variable). PBL incorporates self-directed learning, essential questions, and activity-based learning, while critical thinking involves analytic, creative, interpretative, and evaluative thinking. Self-directed learning (SDL) encourages learners to take responsibility for acquiring knowledge, grounded in theories such as self-determination (Deci & Ryan, 2000), constructivism (Piaget, 1945; Vygotsky, 1978), experiential learning (Kolb, 1984), and social cognitive theory (Bandura, 1986). These theories support skills such as problem-solving, collaboration, and metacognition, enhancing students' ability to adapt and engage in lifelong learning.

Essential questions play a crucial role in PBL by prompting critical thinking and discussion (Wiggins, 2002). These open-ended questions drive inquiry and encourage students to interpret and analyze problem statements systematically. Activity-Based Learning (ABL) further enriches PBL through hands-on experiences, including flipped classrooms, debates, role plays, and case studies (Walvoord & Anderson, 1998). These methods promote deeper engagement and

problem-solving capabilities. Piaget's developmental stage theory supports role-playing as a method for learning complex concepts (Sogunro, 2004).

Critical thinking is the ability to analyze, evaluate, and reflect systematically (Weinstein, 2020; Arends, 2012). It enables students to develop reasoned arguments and make informed decisions (Nafiah, 2014; Hidayati et al., 2021). The skills associated with critical thinking include analyzing arguments, evaluating sources, and making logical deductions. Research suggests that students educated through PBL exhibit enhanced critical thinking skills (Al-Fikry et al., 2018; Razak et al., 2022). A meta-analysis by Ramdani et al. (2023) confirmed that PBL fosters an environment conducive to critical thinking development. Thinking skills, comprising critical thinking, creative thinking, and problem-solving, are essential for academic success and adaptability in the 21st century (Barry, 2012; Frydenberg & Andone, 2011). Studies indicate that students with strong basic critical thinking skills (BCTS) perform better in mathematics, while those with weaker skills struggle (Derilo, 2019). By engaging students in meaningful problem-solving, PBL enhances their ability to analyze, collaborate, and develop innovative solutions, preparing them for real-world challenges.

This work is grounded in constructivism, a learning theory that emphasizes student-centered education. Problem-based learning (PBL), a key constructivist method, encourages students to investigate authentic problems and engage in activities similar to professionals in the field (Gallanger, 1993). Influential figures such as Jean Piaget, Lev Vygotsky, and John Dewey have shaped constructivist theories. Piaget believed children construct knowledge through exploration and interaction with their environment, emphasizing the importance of play for cognitive development. Vygotsky, with his social constructivism, focused on the role of social interactions and cultural context in shaping learning, proposing that knowledge is constructed through social negotiation and interactions (Vygotsky, 1978). Dewey stressed the importance of real-life, experiential learning, asserting that students should actively engage with problems to adapt and revise their understanding. David Kolb's experiential learning theory (1984) builds on these ideas, proposing a four-stage learning cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Similarly, Jerome Bruner's work emphasizes that the principles of any subject can be taught at any age if adapted appropriately to the learner's developmental stage. Constructivist learning theories highlight the importance of active engagement, social interaction, and personal meaning construction through experience.

Contextually, the Competence-Based Approach (CBA) is emerging in Cameroon, marking a shift from the Objective-Based Approach (OBA) to a focus on competencies. The CBA requires changes in syllabus, course objectives, and instructional materials, though challenges such as lack of clear policies and adequately trained teachers persist. Traditional teaching methods, which are teacher-centered and rely on rote memorization, remain prevalent in Cameroonian classrooms, despite the benefits of a student-centered, problem-based approach that encourages critical thinking, collaboration, and self-directed learning. Problem-based learning nurtures these skills by engaging students in real-world problems, encouraging collaboration, self-direction, and inquiry. It transcends disciplinary boundaries and fosters deeper understanding through active involvement. As an effective, learner-centered approach, PBL continues to gain acceptance across disciplines, integrating theory and practice to help students develop practical solutions to complex problems.

2.1. Statement of the Problem

In the Bamenda Municipality educational setting, there is a significant challenge in enhancing students' critical thinking skills, particularly in mathematics. Traditional teaching methods often focus on memorization and procedural learning, limiting students' ability to apply mathematical concepts in practical situations. The 2019 Cameroon General Certificate of Education (GCE) results, with a 34.5% pass rate in mathematics, underscore the urgent need for more effective teaching approaches. Problem-based learning (PBL), a student-centered method, has shown promise in fostering deeper understanding and critical thinking by encouraging students to tackle real-world problems collaboratively. In mathematics, PBL shifts focus from rote computation to developing problem-solving strategies, logical reasoning, and applying mathematical concepts in authentic contexts. Despite its potential, the effectiveness of PBL in Bamenda's mathematics classrooms remains underexplored, highlighting the need for empirical investigation to assess its impact on students' critical thinking and learning outcomes.

2.2. Objectives of the study

- To determine how often mathematics teachers use the problem-based learning in teaching mathematics.
- To find out the difference in the mean critical thinking score of students who receive instruction through problem-based learning and that of those who receive instruction through the traditional teaching methods.

2.3. Research Questions

- How often do mathematics teachers use the problem-based learning in teaching mathematics?
- What is the difference in the mean critical thinking score of students who receive instruction through problem-based learning and that of those who receive instruction through the traditional teaching methods?

2.4. Hypothesis

- **Ho**: There is no significant difference between the mean critical thinking score of students taught mathematics using problem-based learning and that of those taught using the traditional method.
- **Ha**: There is a significant difference between the mean critical score of students taught mathematics using the problem-based learning and that of those taught using the traditional method.

3. Methodology

This study adopted a quasi-experimental research design, specifically a non-equivalent pretest-posttest control group design, to assess the effectiveness of problem-based learning (PBL) in enhancing students' critical thinking skills in mathematics. A multistage sampling procedure was employed, combining simple random and purposive sampling techniques to select two schools with 103 Form Three students. Thus, the research was conducted in two Government Bilingual High Schools in Bamenda Municipality: GBHS Bamendankwe (experimental group) and GBHS Atiela (control group).

Data collection was done using pretest and posttest critical thinking scales, each assessing problem-solving, logical reasoning, critical analysis, abstract thinking, and metacognition. The pretest determined baseline levels, while the posttest measured changes after the six-week intervention. The validity of the instruments was confirmed through expert review, and data analysis was conducted using ANCOVA via SPSS 25.0. Ethical considerations, including participant consent and confidentiality, were ensured throughout the research process.

3.1. Findings

- **Research Question 1**: How often do mathematics teachers use the Problem-based learning in teaching mathematics?

Table 1 Summary on Frequency of Use of *the Problem-Based Learning* Approach to Teaching Mathematics

Questionnaire Item	Options	Frequency	Percentage (%)
Do you know what Problem-Based Learning is?	Yes	11	10.68%
	No	92	89.32%
	Total	103	100%
How often does your mathematics teacher use Problem-Based Learning in class?	Very Often	0	0%
	Sometimes	4	3.88%
	Rarely	81	78.65%
	Never	18	17.47%
	Total	103	100%

The table reveals that majority of the students (89.32%) do not even know what Problem- Based Learning is all about. After a brief explanation from the researcher, majority of the students (78.65%) could identify that their mathematics teachers rarely used that approach in teaching mathematics.

- **Research Question 2**: What is the mean gain critical thinking scores of students who receive instruction through problem-based learning and those who receive instruction through the traditional teaching methods?

Table 2 Summary of Analysis on Mean Critical Thinking Scores of Students in Problem-Based Learning the Traditional Teaching Groups

Group	N	Pretest Mean Score	Pretest Mean Score	Mean Gain Score	Decision
Problem-Based Learning (E)	61	56.38	79.26	22.88	More Effective
Traditional Teaching Method (C)	42	58.10	60.81	2.71	
Total	103				

The table reveals that the pretest mean score for students taught using the experimental group (E) on Problem-Based Learning was 56.38 while the posttest mean score was 79.26, giving a mean gain score of 22.88. This means that Problem-Based Learning approach is more effective in enhancing the critical thinking skills of students in mathematics, compared to the traditional teaching approach (control group- C) which had a mean gain of 2.71.

- **Ho**: There is no significant difference between the mean critical thinking score of students taught Mathematics using the Problem-Based Learning and that of those taught using the traditional method.
- **Ha**: There is a significant difference between the mean critical score of students taught Mathematics using the Problem-Based Learning and that of those taught using the traditional method.

Table 3 ANCOVA Test on Significance of Problem-Based Learning in Enhancing Critical Thinking Skills of Students

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Decision
Corrected Model	1332.238a	2	333.060	16.624	.000	
Intercept	1103.721	1	1103.721	55.089	.000	
PRETEST	86.874	1	86.874	1.292	.279	
GROUP	642.298	2	214.099	10.686	.000	Significant
Error	1101.945	100	20.035			
Total	277567.000	103				
Corrected Total	2434.183	102				

a. R Squared = .687 (Adjusted R Squared = .663)

The table indicates that the F-ratio for the test was 10.686, giving a p-value of 0.000. Thus, the F-ratio was significant at the 0.05 level of significance, suggesting that H_0 should be rejected. Therefore, it can be concluded that Problem-Based Learning significantly enhances the critical thinking skills of students compared to the traditional teaching method.

4. Discussion of Findings

4.1. Frequency of Use of the Problem-Based Learning Approach to Teaching Mathematics

The findings in Table 1 suggest that Problem-Based Learning (PBL) is rarely used in mathematics instruction within the Bamenda Municipality. The data reveals that 89.32% of students had no prior knowledge of PBL, and after receiving an explanation, 78.65% reported that their mathematics teachers rarely used this approach. This aligns with findings from several empirical studies that indicate a limited adoption of PBL in mathematics classrooms, particularly in developing countries. For instance, a study by Kuran (2020) on the integration of PBL in secondary school mathematics education found that traditional lecture-based methods dominate teaching practices, with many teachers emphasizing procedural knowledge over conceptual understanding. Similarly, Savery (2019) noted that despite the proven benefits of PBL in

enhancing critical thinking and problem-solving skills, its implementation remains low due to inadequate teacher training and resistance to pedagogical change.

Furthermore, a study by Dolmans et al. (2016) highlighted that one of the key barriers to PBL adoption is the rigid nature of school curricula, which prioritize content coverage over student-centered learning strategies. This is consistent with findings from a study conducted by Hmelo-Silver (2017), which reported that teachers often perceive PBL as time-consuming and challenging to implement, especially in large classrooms with diverse student abilities. The low frequency of PBL usage in the current study may also be attributed to a lack of institutional support. According to Tan (2019), successful PBL implementation requires adequate resources, continuous professional development, and administrative backing. In contexts where teachers are not adequately trained in PBL techniques, they are less likely to incorporate it into their teaching strategies.

Given the overwhelming evidence of PBL's effectiveness in fostering mathematical reasoning and critical thinking (Barrows, 2018; Hmelo-Silver, 2017), it is crucial to address the barriers preventing its widespread adoption. Initiatives such as targeted teacher training programs, curriculum flexibility, and resource provision could significantly enhance the integration of PBL into mathematics instruction, ultimately improving student engagement and learning outcomes.

4.2. Critical Thinking Abilities of Students Taught Mathematics Using the Problem-Based Learning Approach and That of Those Taught Using the Traditional Learning Method

The findings in Table 2 demonstrate that students exposed to Problem-Based Learning (PBL) achieved significantly higher mean gain scores in critical thinking compared to those taught using traditional teaching methods. The experimental group (PBL) had a mean gain of 22.88, whereas the control group (traditional method) recorded only 2.71. The ANCOVA test further confirms this significant difference, with an F-ratio of 10.686 and a p-value of 0.000, leading to the rejection of the null hypothesis (H_0). This finding aligns with extensive empirical research supporting the effectiveness of PBL in fostering critical thinking skills in mathematics education.

Several studies have emphasized the advantages of PBL in improving students' cognitive abilities. Hmelo-Silver (2017) argued that PBL enhances deep learning by engaging students in real-world problem-solving, which strengthens their reasoning, analysis, and decision-making skills. Similarly, a meta-analysis by Strobel and van Barneveld (2019) found that students taught through PBL consistently outperformed those in traditional classrooms in terms of critical thinking and problem-solving abilities. Further evidence from a study by Hung (2016) in secondary mathematics education supports the current findings. Hung observed that PBL promotes higher-order thinking by encouraging students to construct knowledge collaboratively rather than passively receiving information. This aligns with the cognitive constructivist perspective, which suggests that active engagement with problems enhances meaningful learning (Jonassen, 2019).

Additionally, Dolmans et al. (2016) highlighted that PBL fosters metacognitive skills, allowing students to reflect on their reasoning processes. This is crucial in mathematics, where students must develop logical thinking and problem-solving strategies. The significant improvement in the posttest scores of the experimental group in the present study suggests that PBL provides an effective framework for cultivating such skills. One possible reason for the lower gains in the control group is the emphasis of traditional teaching methods on rote memorization and procedural knowledge, as observed in a study by Kuran (2020). These methods often limit students' ability to transfer mathematical concepts to new and complex problems, which is a key aspect of critical thinking.

Overall, these findings reinforce the need for a paradigm shift in mathematics instruction within the Bamenda Municipality. Given the empirical evidence demonstrating the effectiveness of PBL, its integration into teaching practices should be encouraged. Teacher training programs, curriculum modifications, and administrative support are essential to ensuring its successful implementation, ultimately enhancing students' critical thinking and mathematical proficiency.

5. Conclusion

This study investigated the frequency of Problem-Based Learning (PBL) usage in mathematics instruction and its effectiveness in enhancing students' critical thinking skills in the Bamenda Municipality. The findings revealed that PBL is rarely used in mathematics classrooms, with 89.32% of students unaware of the approach and 78.65% reporting that their teachers rarely employed it. Additionally, students who were taught using PBL demonstrated significantly higher mean gain scores in critical thinking (22.88) compared to those instructed through traditional methods (2.71). The ANCOVA test confirmed the statistical significance of this difference ($F = 10.686$, $p = 0.000$), supporting the rejection of

the null hypothesis. These results align with empirical studies that highlight the effectiveness of PBL in fostering critical thinking, problem-solving, and metacognitive skills.

Implications of the Findings

The study's findings have important implications for mathematics education policy and practice:

- *Curriculum Reform:* The significant impact of PBL on critical thinking suggests that mathematics curricula should incorporate more problem-based learning strategies to enhance student engagement and learning outcomes.
- *Teacher Training and Professional Development:* The low frequency of PBL use highlights the need for targeted teacher training programs to equip educators with the necessary skills to implement PBL effectively.
- *Institutional Support:* School administrators and policymakers must provide resources, instructional materials, and structural flexibility to facilitate the adoption of PBL.
- *Student-Centered Learning:* Encouraging active learning approaches such as PBL can improve students' problem-solving abilities and overall academic performance in mathematics.

Recommendations

Based on the study's findings, the following recommendations are proposed:

- The Ministry of Education should revise the mathematics curriculum to include structured PBL activities, ensuring that students actively engage in critical thinking and real-world problem-solving.
- Workshops, training sessions, and continuous professional development programs should be organized to familiarize mathematics teachers with PBL methodologies and best practices.
- Schools should be provided with adequate teaching materials, including technology-supported PBL tools, to facilitate the effective implementation of the approach.
- Teachers should be encouraged to create interactive classroom environments where students work in groups to explore mathematical concepts through PBL strategies.
- Additional studies should be conducted to explore the long-term impact of PBL on students' academic achievement and problem-solving skills across different subject areas.

Implementing these recommendations can significantly enhance mathematics education in the Bamenda Municipality, fostering a more student-centered learning environment that prioritizes critical thinking and problem-solving skills.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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