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# The Impact of Flipped Teaching on Students' Critical Thinking, Collaboration, and Mathematics Retention in Southwest Cameroon

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**Abstract**

Lecture-based mathematics instruction often struggles to build higher-order thinking or lasting knowledge in secondary schools. To tackle this, the present study employed an explanatory sequential mixed-methods design to test the flipped classroom approach with 120 Form Two students in Buea, Cameroon. The design consisted of a 2x2x2 factorial quasi-experiment, crossing instructional method, gender, and socioeconomic status, followed by a qualitative phase. Grounded in Vygotsky's social constructivism, the flipped group (n = 65) experienced ten weeks of pre-class videos and digital handouts, while the control group (n = 55) stayed with traditional lectures. Critical thinking was measured using an adapted California Critical Thinking Skills Test, collaboration through self-reports and teacher ratings, and retention with a delayed test twenty weeks after the intervention. The ANCOVA results, adjusted for pretest scores, showed clear benefits for the flipped group. Critical thinking rose sharply ($F = 41.500$, $p < .001$, $\eta_p^2 = .262$). Collaboration improved modestly ($F = 4.081$, $p = .046$, $\eta_p^2 = .034$). Retention showed the strongest effect ($F = 174.877$, $p < .001$, $\eta_p^2 = .493$). Gender did not moderate outcomes, but socioeconomic status did. Numbers alone don't capture the full picture. To explain the findings, we interviewed fifteen students from the flipped group, representing varied achievement levels, genders, and economic backgrounds. In semi-structured conversations, they described how pre-class videos shaped problem-solving, how peer discussions unfolded, and how replaying lessons weeks later helped recall content. Reflexive thematic analysis revealed the cognitive, social, and structural mechanisms behind the statistical results.

**Keywords:** Flipped Teaching, Critical Thinking, Collaboration, Long-Term Retention, Socioeconomic Status, Gender Moderation

## Introduction

The fundamental purpose of classroom mathematics instruction is to equip students with the cognitive skills they need to solve real-life problems and navigate daily socio-economic challenges (Nkepah & Feli, 2025) [20]. Effective mathematics education must therefore enable learners to apply abstract concepts meaningfully when addressing societal issues (Bethell, 2016) [6]. To achieve this utility, students must demonstrate deep mastery of classroom concepts, analyze complex problems logically, collaborate productively with peers on challenging tasks, and successfully retrieve knowledge weeks or months after initial exposure. Often, this is reflected in high test scores. Regrettably, mathematics achievement remains a persistent global challenge, with a vast majority of students struggling to attain proficiency. Many learners demonstrate disengagement and impatience, finding it difficult to devote the cognitive effort required to break down foundational mathematical structures. Furthermore, students frequently exhibit difficulties working collaboratively with peers or retaining basic concepts taught only hours or days prior. While multiple systemic factors contribute to these pedagogical deficits, variables such as gender and socioeconomic status (SES) play an undeniable role in shaping student learning trajectories in the contemporary world (Justice & Itankan, 2025) [13]. Consequently, an enduring disconnect remains between passive classroom setups and daily life realities, where individuals are urgently required to deploy critical thinking, exercise collaborative skills, and recall durable knowledge to resolve localized problems.

According to Alvarez-Tinajero *et al*. (2026) [3], critical thinking in the context of mathematics learning, represents the capacity

to analyze complex problems logically rather than relying on rote formulas. Concurrently, collaboration fosters peer-to-peer mathematical communication and joint problem-solving, which deepens conceptual understanding. Ultimately, long-term retention ensures that these internalized mathematical mental frameworks remain stable, durable, and retrievable for future academic pursuits and real-world application.

Although numerous curricular reforms have been enacted to improve instructional delivery, empirical evidence demonstrate that classroom practices in Cameroon frequently deviate from recommended standards (Ekobina, 2021; Nsangong, 2023) [7, 21]. While reforms at the basic and secondary education level heavily emphasize learner-centered strategies and the integration of ICTs, interactive and time-saving approaches such as the flipped classroom have received little attention within the Cameroonian primary and secondary school contexts. In a flipped teaching approach, students study lesson content independently before class time, and then engage in interactive, problem-solving, and higher-order activities during classroom time under the guidance of the teacher.

The flipped teaching method has consistently demonstrated positive and significant effects on students' attitudes and achievement in mathematics. Yet, despite these promising international indicators, only a handful of studies in Cameroon have explored its execution or mapped its impact on both narrow and broad learning outcomes (Nkepah, 2018; Nkepah, 2023) [18, 19]. These pioneer local studies revealed large effect sizes in both attitudes and performance when experimental groups were exposed to electronic video lessons (via DVDs) prior to class sessions.

However, these regional studies heavily prioritized short-term academic achievement scores while neglecting broader learning outcomes like critical thinking, collaboration, and long-term retention which are important tools for an increasingly tech-driven world. Critical thinking, collaboration, and long-term retention are survival tools for navigating, complexity, innovation and constant change (Rusmin *et al*. 2024) [23]. Moreover, several critical gaps persist in the existing Cameroonian literature. The potential moderating role of gender has been overlooked and flipped related interventions have typically been restricted to brief windows of four to six weeks, limiting insights regarding long-term instructional sustainability. Prior research has unrealistically assumed uninterrupted access to electricity and high-end ICT infrastructure, ignoring prevailing digital divide issues and the potential for low-tech flipped alternatives, such as printed summary packages and basic mobile phone delivery. Also, assessment tools have relied heavily on psychometric reliability without triangulating qualitative data.

The present study is crucial since integrating flipped teaching within the Cameroonian educational landscape is a critical endeavor that aligns with the national transition toward the Competency-Based Approach (CBA). By shifting the focus from rote memorization to active knowledge application, this pedagogical model directly cultivates the critical thinking skills essential for modern problem-solving. In the context of the South West Region, where large class sizes often dictate teacher-centric lectures, the flipped model reclaims classroom time for peer collaboration. This fosters social negotiation and teamwork, soft skills vital for success in the multicultural Cameroonian labor market.

Furthermore, evaluating long-term retention is paramount for improving student outcomes in high-stakes national examinations, such as the GCE and Baccalauréat, where deep conceptual understanding is required over short-term recall. As the Ministry of Secondary Education (MINESEC) continues to prioritize ICT integration, this study serves as a localized test of digital resilience, assessing whether such frameworks can bridge the digital divide while building learner autonomy. Ultimately, by fostering independent inquiry and cognitive engagement, flipped teaching offers a robust, flexible framework capable of maintaining educational continuity and narrowing gender gaps in STEM, ensuring that Cameroonian graduates are both academically proficient and globally competitive. The problem addressed in the present study therefore is a lack of empirical evidence regarding the impact of a contextualized flipped teaching strategy on students' critical thinking abilities, collaboration, and long-term retention as well as the interaction effect of gender and socioeconomic status on this relationship in Anglophone Cameroon.

**Objectives**

The purpose of the study is to;

- Assess the critical thinking skills of students taught mathematics using the flipped teaching method and those taught using the lecture method.
- Assess the collaboration skills of students taught mathematics using the flipped teaching method and those taught using the lecture method.
- Assess the long-term retention of students taught mathematics using the flipped teaching method and those thought using the lecture method.
- Examine whether the differences in mathematics learning outcomes between students taught using the flipped method and those taught using the lecture method vary by gender.
- Examine whether the differences in mathematics learning outcomes between students taught using the flipped method and those taught using the lecture method vary by socioeconomic status.

**Research Questions**

The study was guided by the following research questions;

1. What is the difference in the mean critical thinking skills score of students taught mathematics using the flipped teaching method and those thought using the lecture method?
2. What is the difference in the mean collaboration score of students taught mathematics using the flipped teaching method and those taught using the lecture method?
3. What is the mean long-term retention score of students taught mathematics using the flipped teaching method and those taught using the lecture method?
4. What is the main and interaction effect of gender on the mean learning outcome scores of students taught mathematics using the flipped teaching method and those taught using the lecture method?
5. What is the main and interaction effect of socioeconomic status on the mean learning outcome

scores of students taught mathematics using the flipped teaching method and those taught using the lecture method?

**Hypotheses**

The following hypotheses are to be tested at 0.05 significant level;

There is no significant difference in the mean critical thinking skills score of students taught mathematics using the flipped teaching method and those taught using the lecture method.

There is no significant difference in the mean collaboration score of students taught mathematics using the flipped teaching method and those taught using the lecture method.

There is no significant difference in the mean long-term retention score of students taught mathematics using the flipped teaching method and those taught using the lecture method.

There is no significant interaction effect of gender and instructional method (flipped teaching vs. pure lecture) on students' mathematical learning outcomes.

There is no significant interaction effect of socioeconomic status and instructional method (flipped teaching vs. pure lecture) on students' mathematical learning outcomes.

**Operational Definition of Terms**

**Critical Thinking:** In this study, critical thinking refers to a students' score on a mathematics achievement test specifically consisting of items that require the learner to analyze mathematical concepts, demonstrate logical problem-solving steps, provide supporting calculations or diagrams, justify their methodological choices, and evaluate alternative solution path.

**Collaboration:** In this study, collaboration is operationally defined as an aggregated composite score derived from two sources: (a) students' performance scores on cooperative mathematics tasks, and (b) students' self-reported responses to a 5-point Likert-scale questionnaire. These instruments collectively assess students' capacity to communicate mathematically, share tasks, and problem-solve effectively within pairs or small groups.

**Long-Term Retention:** In this study, long-term retention refers to a student's score on a delayed mathematics achievement test administered 20 weeks (five months) post-intervention. This parameter is measured using a parallel-form test, consisting of different but structurally equivalent items to the immediate post-test, evaluating the capacity to recall and apply knowledge over time.

**Flipped teaching method:** In this study, the flipped teaching method refers to an instructional intervention where students are exposed to primary mathematical content via audio-visual and print formats delivered through mobile phones three (3) days prior to class. Face-to-face class sessions are subsequently dedicated to collaborative problem-solving, analytical tasks, and concept application under the teacher's guidance.

**Lecture method:** In this study, the lecture method refers to a teacher-centered instructional approach where the educator delivers mathematical content primarily through direct verbal explanation and board work. Students are structurally positioned as listeners and note-takers, with classroom interaction limited to teacher-directed question-and-answer routines.

**Gender:** In this study, gender refers to the classification of students as male or female based on their biological sex, as recorded in school enrolment registers.

**Socioeconomic Status (SES):** In this study, socioeconomic status refers to the relative economic standing of students' households, measured through self-reported parental income scale. For analytical purposes, SES is operationalized as a dummy variable with two categories: Low SES (monthly household income strictly less than 200,000 XAF) and High SES (monthly household income equal to or greater than 200,000 XAF).

**Significance of the Study**

This study holds multifaceted significance for the advancement of mathematics education reform regarding the delivery of instruction within the Cameroon educational system. For students, it could demonstrate how a contextualized flipped teaching framework can cultivate advanced critical thinking, cooperative collaboration, and long-term cognitive retention, effectively shifting the learning paradigm away from traditional rote memorization. For educators, the findings could provide empirical evidence of a robust, learner-centered pedagogy that enhances classroom interaction and fosters active engagement, even within logistically challenging environments. For policymakers, the timing is relevant. MINESEC is already committed to ICT integration and the Competency-Based Approach. This study could offer evidence that indicate that those commitments can be joined rather than pursued separately. Flipped teaching is one way to satisfy CBA objectives while actually improving examination outcomes, provided the implementation accounts for who has access to technology outside school. Finally, for teacher education programs, the study could underscore the critical necessity of equipping pre-service teachers with competencies in instructional technology integration and equitable flipped design, ultimately providing a sustainable blueprint for modernizing mathematics instruction across the national territory.

**Review of Related Literature**

**Theoretical Review**

Theoretically, the study is anchored in the theory of social constructivism propounded by Vygotsky (1978) [25]. According to this theory, learning occurs most effectively through social interaction, where students develop higher-order thinking skills within the Zone of Proximal Development by collaborating with peers and receiving guidance from teachers. The flipped teaching method can be meaningfully explained through Vygotsky's Social Constructivist Theory, which emphasizes the importance of social interaction and guided learning in developing higher-order thinking skills. By engaging with instructional materials before class, students enter the classroom prepared to analyze problems more deeply, fostering critical thinking. During class, the collaborative environment aligns with Vygotsky's concept of the Zone of Proximal Development, where learners achieve more through peer interaction and teacher guidance than they could independently. This active engagement and repeated application of knowledge in group discussions and problem-solving tasks also strengthen long-term retention, as students move beyond rote memorization to meaningful understanding. Thus, the flipped teaching method creates conditions that directly support critical thinking, collaboration, and durable

knowledge retention, making Social Constructivist Theory a strong framework for explaining its impact in mathematics classrooms.

**Conceptual Review**

Conceptually, the flipped teaching method in the teaching of mathematics reverses the conventional classroom: students watch short video lessons or read materials at home before class, then use class time for active problem-solving with the teacher as a guide (Francisco, 2021) [10]. Specifically, students are exposed to various explanations of knowledge on a particular concept. This involve watching videos one at a time, reading notes in digital print format and then actively taking part in solving problems in class with the teacher's help, and teacher coaches 1-on-1 while students work (Elhilal, 2025) [8]. The benefits of flipped teaching in math learning are manifold. Students can pause, and re-watch tricky parts of the video at their own pace, class time focuses on understanding instead of just listening, and Teachers can spot mistakes quickly and give immediate feedback (Wang *et al*., 2025) [27].

Critical thinking, collaboration, and long-term retention are often collectively referred to as higher-order learning competencies. While these mathematical abilities go beyond rote memorization, researchers categorize them in different ways. Critical thinking represents the analytical dimension, while collaboration reflects the social-interactive side, and long-term retention captures memory sustainability (Gradini *et al*., 2025; Wang & Abdullah, 2024) [12, 26]. Together, they form a triad of skills that help students apply mathematical concepts to real-world situations. For instance, Nkepah and Feli (2025) [20] described these abilities as "cognitive and socio-emotional competencies" necessary for lifelong learning. Other recent research by Al Moray (2024) [1] frames them as "integrated 21st-century skills" or essential components for building sustainable mathematical literacy. To build these competencies, teachers must design math lessons that demand deep thinking, shared problem-solving, and weekly reviews.

Practically, these three competencies can be developed during a mathematics lesson through deliberate teaching choices: Critical thinking for instance is strengthened when students analyze, question, and justify their reasoning rather than just memorizing steps to a mathematics problem. Teachers can promote this by using open-ended mathematical tasks with multiple solution paths, which encourage students to take risks and examine problems through different strategies. Collaboration can be developed when teachers design teamwork activities that require students to share ideas and solve problems together (Magdalan, 2025) [16]. Such tasks are usually those that cannot be completed effectively by one student alone. Strategies such as Think-Pair-Share or asking students to "convince a friend or a skeptic" help ensure that all voices are heard. Finally, long-term retention requires intentional instructional practices that strengthen memory. This is achieved when students regularly revisit mathematical concepts and connect them to prior knowledge. Rather than introducing a topic once and moving on, teachers should space the material over time, use weekly mini-quizzes to encourage active recall, and close lessons with summary discussions that help anchor learning more securely.

**Empirical Review**

Empirically, few experimental or quasi-experimental studies have jointly examined flipped teaching, critical thinking, collaboration, retention, and moderation by both gender and SES in one design. Most papers either study flipped teaching outcomes without moderation analysis, or test gender/SES effects in related learning contexts rather than flipped mathematics specifically. Recent experimental and quasi-experimental studies show that flipped teaching improves higher-order learning outcomes such as critical thinking and retention, but direct evidence on whether these effects vary by gender or socioeconomic status remains limited. Where moderation has been tested, gender and SES sometimes show differential effects, although findings are inconsistent across contexts (Kasmini *et al*., 2024 [14]; Kutigi *et al*., 2022). Maryami *et al*. (2025) [17] conducted a cluster-randomized experiment with 87 sixth-semester nursing undergraduates to assess the effects of the flipped classroom on critical thinking, self-esteem, and retention. The intervention group (n = 45) completed preclass preparation and in-class collaborative problem-solving, while the control group (n = 42) received conventional lectures. The flipped group showed significant gains in critical thinking, self-esteem, and retention, with large effect sizes. The relationship was neither moderated by gender nor SES.

Using a quasi-experimental design, Salhoobi (2021) [24] conducted a study to examine whether the flipped classroom approach, in conjunction with gender, influences high school students' psychological needs (autonomy, competence, relatedness) and chemistry achievement. The sample included 90 diverse students split evenly between flipped and traditional classrooms, taught by experienced chemistry teachers. ANCOVA analyses showed no significant differences in autonomy, competence, or relatedness based on instructional approach or gender. However, students in the flipped classroom scored significantly higher on post-assessments than those in traditional classrooms, indicating improved achievement. Gender did not moderate the relationship between instructional approach and psychological needs, but instructional approach itself moderated achievement outcomes, flipped learning enhanced performance regardless of gender.

Atwa *et al*. (2022) [5] utilised a quasi-experimental pretest–posttest design to examine the impact of flipped classroom instruction on Grade 9 students across four public schools. The sample included 385 students, with classes assigned to experimental and control conditions. The flipped group showed significant improvements in critical thinking, reduced psychological stress, and higher mathematics achievement, although effects on Science, IT, and English were not significant. Almodaires *et al*. (2019) [2] conducted a quasi-experimental study in pre-service teacher education to examine the effects of flipped learning in an educational technology course. The experimental group included 128 students, and the control group included 67. The flipped group performed better academically and reported positive

attitudes toward the method, indicating its instructional value despite some implementation constraints.

## Research Methodology

### Research Design

This study adopted an Explanatory Sequential Mixed-Methods Design (QUANT followed by qual). The investigation commenced with a primary quantitative phase employing a quasi-experimental, pretest–posttest nonequivalent control group design with a 2x2x2 factorial structure (N = 120). Due to administrative and ethical constraints within the participating secondary schools, random assignment of individual learners to conditions was not feasible; consequently, pre-existing intact classrooms were assigned to either an experimental group taught via flipped instruction (n = 65) or a control group taught via traditional lecture (n = 55). To examine critical moderation dynamics, specifically whether gender and socioeconomic status influenced the impact of the flipped method, the factorial structure simultaneously crossed three independent variables: instructional method (flipped vs. lecture), gender (male vs. female), and socioeconomic status (high vs. low). This enabled the study to evaluate main effects across critical thinking, collaboration, and long-term retention, as well as demographic interaction effects. To triangulate and explain the quantitative findings, a secondary qualitative phase utilizing a qualitative descriptive design was subsequently conducted. Semi-structured post-intervention interviews were administered to students in the flipped intervention group. The resulting qualitative data were analyzed using reflexive thematic analysis to elucidate the cognitive and social mechanisms driving the statistical ANCOVA results.

Both groups completed a pretest to establish baseline equivalence in critical thinking, collaboration, and long-term retention. A structured ten-week intervention exposed the experimental group to flipped teaching while the control group continued with lectures. At the end of ten weeks, both groups completed a posttest measuring critical thinking and collaboration. To isolate durable cognitive outcomes from short-term assessment cramming, long-term retention was assessed 20 weeks later to evaluate students' ability to recall knowledge after the intervention. The groups were nonequivalent in terms of gender distribution and the number of students represented in each group.

### Population and Sample

The study's population comprised 60,970 secondary school students in the Buea Sub-division of Cameroon. Enrolment statistics for the 2025/2026 academic year indicate 29,284 boys and 31,686 girls (Regional Delegation of Secondary Education, 2026) [22]. Public schools accounted for 32% of this population, denominational schools 10%, and lay private schools 58%. The target population consisted of 50,605 first-cycle students, representing over 83% of the total, with 24,305 boys and 26,300 girls. Specifically, Form Two students were targeted for the intervention. The accessible population comprised 798 Form Two students in Buea, including 383 boys and 415 girls. From this, a sample of 120 students was drawn from two candidate schools, one public and one lay private. The sample included 65 students in the experimental group and 55 in the control group, with 70 girls and 50 boys across both groups.

### Sampling

Multistage sampling was employed to select the study's sample. To ensure methodological rigor in the quantitative phase, a two-stage stratified random sampling procedure was used. First, candidate schools within the Buea Sub-division were stratified by school type (public, denominational, and lay private). Within each stratum, intact Form Two classes were administered a baseline pretest measuring critical thinking, collaboration, and long-term retention. Schools whose classes demonstrated no statistically significant baseline differences ($p > .05$) across these measures were flagged as equivalent and eligible for inclusion. From the accessible pool of four candidate schools that achieved baseline equivalence, two schools, one public and one lay private, were randomly selected. Within these selected schools, intact classes were assigned to either the experimental flipped instruction group (n = 65) or the control traditional lecture group (n = 55), yielding a total quantitative sample of N = 120. Following the completion of the six-week intervention and quantitative post-testing, a qualitative sampling procedure was executed to select participants for the exploratory phase. A purposive subsample of n = 15 students was selected exclusively from the experimental flipped instruction group (n = 65). To ensure maximum variation and rich qualitative data, participants were selected to reflect diverse academic performance levels, socioeconomic backgrounds, and genders. This purposive selection enabled the qualitative phase to explore how varying student demographics experienced the flipped model, illuminating the specific cognitive, social, and structural mechanisms underlying the quantitative ANCOVA outcomes.

### Treatment

Regarding the treatment, the control group received traditional mathematics instruction for ten weeks consisting of teacher-led lectures, note-copying, and limited student interaction. On the other hand, the flipped group worked from the same curriculum but in a different sequence. Before each class, the teacher sent short video lectures and printable notes through a school WhatsApp group. Students watched and read at home, then arrived with baseline familiarity. Class time was reserved for what the videos could not provide and the students worked through problems in pairs and small groups while the teacher circulated, correcting misconceptions and pressing for deeper reasoning rather than delivering content from the board. No distinction was drawn between sub-types of flipped instruction; all experimental classrooms followed this single unified format.

### Instruments

Separate instruments were employed to measure each higher-order skill. Critical thinking was assessed using an adapted version of the California Critical Thinking Skills Test (CCTST) to ensure broader coverage of analytical and evaluative abilities. Within the framework of the CCTST, tasks administered to students were designed to measures five core skills consisting of analysis, interpretation, inference, evaluation, explanation & self-regulation. Collaboration was measured through a combination of tools: a 5-point Likert-scale student-report questionnaire, which evaluated students' perceived interaction ability in structured group problem-solving activities, and the

Mathematics Learning Collaboration Inventory (MLCI), a 5-point Likert-scale teacher-report questionnaire assessing peer interaction during paired discussions, group projects, and cooperative tasks. The MLCI was designed to allow teachers measure how well students collaborate on task by assessing their ability to communicate, joint reasoning, problem-solving process, and reflection. Students were individually rated by the teacher on a scale from 1 = weak, 2 -3 = moderate, 4-5 = strong following their participation in their groups on communication, joint reasoning, problem-solving, and self-assessment abilities. Long-term retention was measured using a Standardised Delayed Achievement Test (SDAT), administered after a set interval to determine recall and application of previously learned material. To strengthen validity, the SDAT included both multiple-choice items and short constructed-response questions, providing a more nuanced picture of memory sustainability. To explain the cognitive and social processes driving these quantitative results, semi-structured qualitative interviews were conducted with a subsample of flipped-classroom students using an interview protocol that explored how pre-class procedural video viewing influenced in-class problem solving, how collaborative group dynamics unfolded among diverse peers, and how video re-watchability supported retention prior to the delayed test.

**Validation and Reliability**

Two experts, senior mathematics teachers from the regional delegation of Education reviewed the CCTST and the MLCI to ensure content validation and that all dimensions of critical thinking were covered, and all observable aspects of peer-interaction during task were covered respectively. Construct validity of the CCTST was determined through the calculation of the difficulty and discriminant indices of the test items. Calculated difficulty and discriminant index for the pretest were 0.52 and 0.45 respectively. The difficulty index (ρ) being the proportion of students who get an item right is considered valid for an item if it lies between 0.3 and 0.7, while the discrimination index (d) which measures if high-scorers on the total test also get a specific item right is considered high if $d > 0.40$, and good if $d > 0.25$. The reliability of the CCTST was ascertained through the calculation of the interrater reliability. Inter-rater reliability was employed to minimize subjectivity and bias in scoring, with at least three experienced mathematics teachers independently evaluating the scoring of items assessing each core skill (analysis, interpretation, inference, evaluation, explanation & self-regulation).

**Experimental Procedure**

Data were collected from both experimental and control groups at three points: pretest, posttest, and delayed posttest. The immediate posttest measured short-term learning, while the delayed posttest assessed retention. Using both was essential: the first test established mastery, and the second showed sustained mastery. Importantly, the posttest itself strengthened memory through the testing effect, so delayed performance reflected both natural forgetting and reinforcement from retrieval practice.

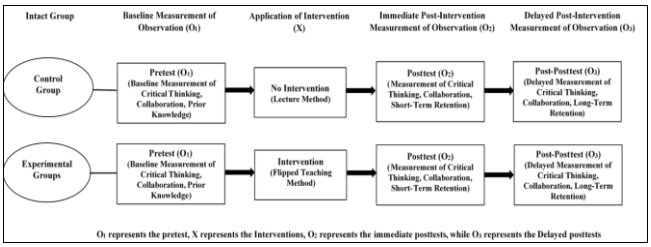


**Fig 1:** Experimental Procedure Model Illustrating Group Allocation, Instructional Treatments, and Observation Sequences

**Data Analyses**

Quantitative data were analyzed using descriptive and inferential statistics. Pretest scores were compared to confirm baseline equivalence between groups. Posttest and delayed posttest scores were analyzed to determine the effect of flipped teaching on critical thinking, collaboration, and retention. Independent samples t-tests and ANCOVA were employed to assess differences between groups, controlling for baseline scores. Observational data were triangulated with test results to provide a richer understanding of classroom interaction patterns and collaborative behaviors. Gender distribution and group size differences were noted as nonequivalent factors but statistically controlled during analysis.

Internal validity concerns in this study primarily stemmed from the use of intact classes, which made random assignment impossible and introduced risks of group nonequivalence in gender distribution and class size. To overcome these threats, a multistage stratified random sampling procedure was employed, ensuring that candidate schools were first stratified by type and then pretested to establish baseline equivalence in critical thinking, collaboration, and retention. Only schools whose classes showed no significant differences ($p > 0.05$) at baseline were included, thereby reducing selection bias. Additionally, extraneous variables such as pretest sensitization, Hawthorne effect, and contamination were systematically monitored, while triangulation through multiple instruments and embedded observations strengthened construct validity. Statistical controls (ANCOVA) were further applied during analysis to adjust for residual group differences, thereby enhancing the internal validity of the findings.

**Findings**

The findings of this study are organized according to the specific research questions. For each objective, Analysis of Covariance (ANCOVA) results are reported, including pretest baseline comparisons, tests of homogeneity of regression slopes, adjusted post-intervention means (*Madj*) with standard errors (*SE*), *F*-statistics, degrees of freedom (*df*), *p*-values, and partial eta squared ($\eta_p^2$) effect sizes.

**Research Question 1:** What is the difference in the mean critical thinking skills score of students taught mathematics using the flipped teaching method and those taught using the traditional lecture method?

Prior to the main analysis, preliminary assumption testing was conducted. Independent samples *t* -tests indicated no statistically significant baseline differences between the

pretest scores of participants in the control group ($M$ = 11.47, $SD$ = 4.10) and the flipped teaching group ($M$ = 11.01, $SD$ = 3.80), $t(118) = 2.412$, $p = .081$, $d = 0.15$. The homogeneity-of-regression assumption was also tenable, $F(1, 116) = 0.183$, $p = .670$.

**Table 1:** ANCOVA Results for Post-Intervention Critical Thinking Scores by Instruction Group (Controlling for Pretest Scores)

| Source | SS | df | MS | $F$ | $p$ | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| **Pretest (Critical Thinking)** | 453.007 | 1 | 453.007 | 35.622 | < .001 | .233 |
| **Group (Flipped Teaching)** | 527.733 | 1 | 527.733 | 41.500 | < .001 | .262 |
| **Error** | 1487.832 | 117 | 12.716 | | | |
| **Corrected Total** | 2468.572 | 119 | | | | |

*Note.* SS = sum of squares; MS = mean square; $\eta_p^2$= partial eta squared, N = 120 ($n_1$ = 65, $n_2$ = 55).

A one-way ANCOVA was conducted to evaluate the effect of the flipped teaching strategy on students' critical thinking skills in mathematics while controlling for pre-intervention scores. As shown in Table 1, the results revealed a statistically significant difference in adjusted post-test critical thinking scores between the control and flipped teaching groups, $F(1, 117) = 41.500$, $p < .001$, $\eta_p^2 = .262$. Consequently, the null hypothesis ($H01$) was rejected. Participants in the flipped instruction group demonstrated significantly higher adjusted post-intervention scores ($M_{adj}$ = 15.15, SE = 0.44) than those in the lecture-based control group ($M_{adj}$ = 10.96, SE = 0.48). The flipped teaching intervention accounted for 26.2% of the variance in students' critical thinking skills in mathematics.

**Research Question 2:** What is the difference in the mean collaboration scores of students taught mathematics using the flipped teaching method and those taught using the lecture method?

Evaluation of baseline equivalence revealed no significant difference between the pretest collaboration scores of the control group ($M$ = 11.39, $SD$ = 4.10) and the flipped teaching group ($M$ = 11.00, $SD$ = 2.75), $t(118) = 2.312$, $p$ = .071, $d$ = 0.18. The test of the homogeneity of regression slopes assumption was also non-significant, $F(1, 116)$ = 1.464, $p = .229$, validating the use of ANCOVA.

**Table 2:** ANCOVA Results for Post-Intervention Collaboration Scores by Instruction Group (Controlling for Pretest Scores)

| Source | SS | df | MS | $F$ | $p$ | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| Pretest (Collaboration) | 701.120 | 1 | 701.120 | 67.971 | < .001 | .367 |
| Groups (Flipped Teaching) | 42.098 | 1 | 42.098 | 4.081 | .046 | .034 |
| Error | 1206.802 | 117 | 10.872 | | | |
| Total | 13329.000 | 119 | | | | |

The one-way ANCOVA comparing post-intervention collaboration ratings while adjusting for pretest baseline scores revealed a statistically significant difference between the instruction groups, F(1, 117) = 4.081, p < .05, $\eta_p^2 = .034$. Consequently, the null hypothesis ($H_{02}$) was rejected. Students taught via the flipped teaching strategy showed significantly higher adjusted mean collaboration scores ($M_{adj}$ = 10.54, SE = 0.40) relative to the lecture group ($M_{adj}$ = 9.29, SE = 0.43). The flipped teaching intervention explained 3.4% of the variance in students' collaboration skills in mathematics.

**Research Question 3:** What is the mean long-term retention score of students taught mathematics using the flipped teaching method compared to those taught using the lecture method?

Baseline assessments indicated no statistically significant difference in pretest long-term retention scores between the control ($M$ = 12.32, $SD$ = 4.22) and intervention groups ($M$ = 11.99, $SD$ = 3.80), $t(118) = 2.513$, $p = .077$, $d = 0.11$. Furthermore, the test for homogeneity of regression slopes between pretest scores and instructional groups yielded a non-significant result, $F(1,116) = 1.762$, $p = .428$.

**Table 3:** ANCOVA Results for Post-Intervention Long-Term Retention Scores by Instruction Group (Controlling for Pretest Scores)

| Source | SS | df | MS | $F$ | $p$ | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| **Pretest (Retention)** | 243.822 | 1 | 243.822 | 32.008 | < .001 | .467 |
| **Group (Flipped Teaching)** | 1332.121 | 1 | 1332.121 | 174.877 | < .001 | .493 |
| **Error** | 891.243 | 117 | 7.617 | | | |
| **Corrected Total** | 2467.186 | 119 | | | | |

A one-way ANCOVA evaluated the impact of instructional strategy on long-term retention in mathematics while controlling for initial pretest retention scores. The test yielded a statistically significant difference between groups, $F(1, 117) = 174.877$, $p < .001$, $\eta_p^2$= .493. Consequently, the null hypothesis ($H_{03}$) was rejected. Participants in the flipped teaching condition demonstrated significantly higher adjusted retention scores ($M_{adj}$ = 15.21, SE = 0.35) than their counterparts in the control group ($M_{adj}$ = 12.42, SE = 0.38). The flipped classroom model explained 49.3% of the variance in students' delayed post-test long-term retention scores in mathematics.

**Research Question 4:** What is the main and interaction effect of gender on the mean learning outcome scores of students taught mathematics using the flipped teaching method and those taught using the lecture method?

A composite learning outcome score was computed as the sum of students' critical thinking, collaboration, and long-term retention scores. Prior to the main analysis, preliminary assumption testing was conducted. Independent samples $t$ -tests indicated no statistically significant baseline differences between the pretest composite scores of participants in the control group ($M$=35.22, $SD$=8.45) and the flipped teaching group ($M$ = 33.98, $SD$ = 8.15), $t(118)$ = 2.080, $p$ = .084, $d$ = 0.15. Additionally, the assumption of homogeneity of regression slopes between pretest composite scores and the treatment groups was satisfied, $F(1,116)$ = 0.240, $p = .625$.

**Table 4:** Two-Way ANCOVA Results for Post-Intervention Composite Learning Outcome Scores by Instruction Group and Gender (Controlling for Pretest Scores)

| Source | SS | df | MS | $F$ | $p$ | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| Pretest (Composite) | 1250.000 | 1 | 1250.000 | 67.971 | < .001 | .371 |
| Group (Teaching Method) | 1380.000 | 1 | 1380.000 | 75.041 | < .001 | .395 |
| Gender | 11.000 | 1 | 11.000 | 0.598 | .441 | .005 |
| Group × Gender | 7.000 | 1 | 7.000 | 0.381 | .538 | .003 |
| Error | 2151.626 | 115 | 18.389 | | | |
| **Corrected Total** | 4799.626 | 119 | | | | |

A two-way ANCOVA was conducted to evaluate the main and interaction effects of instructional strategy and gender

on students' composite learning outcome scores while controlling for pre-intervention composite scores. As shown in Table 4, the results revealed a statistically significant main effect of teaching method, $F(1,115) = 74.041$, $p < .001$, $\eta_p^2 = .395$. Consequently, the null hypothesis for the main effect of teaching method ($H_{04a}$) was rejected. Participants in the flipped instruction group demonstrated significantly higher adjusted post-intervention composite scores ($M_{adj} = 40.89$, SE = 0.53) than those in the lecture control group ($M_{adj} = 32.71$, SE = 0.58). The flipped teaching intervention accounted for 39.5% of the variance in students' composite learning outcomes.

However, the main effect of gender was not statistically significant, $F(1,115) = 0.598$, $p = .441$, $\eta_p^2 = .005$. Consequently, the null hypothesis for the main effect of gender ($H_{04b}$) was not rejected. Similarly, the Group × Gender interaction was not statistically significant, $F(1,115) = .381$, $p = .538$, $\eta_p^2 = .003$. Consequently, the null hypothesis for the interaction effect ($H_{04c}$) was not rejected. Inspection of the adjusted cell means indicated that male students in the flipped group obtained scores ($M_{adj} = 40.82$, $SE = .75$) comparable to female students in the flipped group ($M_{adj} = 40.96$, $SE = .73$), and this parallel pattern held in the lecture group (Male: $M_{adj} = 32.64$, $SE = .76$; Female: $M_{adj} = 32.78$, $SE = .78$). These findings indicate that gender did not moderate the relationship between flipped teaching and students' composite learning outcomes.

**Research Question 5:** What is the main and interaction effect of socioeconomic status on the mean learning outcome scores of students taught mathematics using the flipped teaching method and those taught using the lecture method?

Independent samples *t* -tests indicated no statistically significant baseline differences between the pretest composite scores of participants in the control group ($M = 35.15$, $SD = 8.30$) and the flipped teaching group ($M = 34.05$, $SD = 8.20$), $t(118) = 2.120$, $p = .079$, $d = .13$. The assumption of homogeneity of regression slopes between pretest composite scores and the treatment groups was satisfied, $F(1,116) = .310$, $p = .580$.

**Table 5:** Two-Way ANCOVA Results for Post-Intervention Composite Learning Outcome Scores by Flipped Teaching Group and Socioeconomic Status (Controlling for Pretest Scores)

| Source | SS | df | MS | *F* | *p* | $\eta_p^2$ |
|---|---|---|---|---|---|---|
| Pretest (Composite) | 1200.000 | 1 | 1200.000 | 64.860 | < .001 | .361 |
| Group (Flipped Teaching Method) | 950.000 | 1 | 950.000 | 51.350 | < .001 | .309 |
| Socioeconomic Status (SES) | 220.000 | 1 | 220.000 | 11.890 | .001 | .094 |
| Group × SES | 175.000 | 1 | 175.000 | 9.460 | .003 | .076 |
| Error | 2127.500 | 115 | 18.500 | | | |
| **Corrected Total** | 4672.500 | 119 | | | | |

A two-way ANCOVA was conducted to evaluate the main and interaction effects of instructional strategy and socioeconomic status on students' composite learning outcome scores while controlling for pre-intervention composite scores. As shown in Table 5, the results revealed a statistically significant main effect of the flipped teaching method, $F(1,115) = 51.350$, $p < .001$, $\eta_p^2 = .309$. Consequently, the null hypothesis for the main effect of teaching method ($H_{05a}$) was rejected. The main effect of socioeconomic status was also statistically significant, $F(1,115) = 11.890$, $p = .001$, $\eta_p^2 = .094$, indicating that students from higher-SES backgrounds obtained significantly higher adjusted composite scores ($M_{adj} = 38.25$, $SE = .58$) than students from lower-SES backgrounds ($M_{adj} = 35.00$, $SE = .55$).

Crucially, the Group × SES interaction was statistically significant, $F(1,115) = 9.460$, $p = .003$, $\eta_p^2 = .076$. Consequently, the null hypothesis for the interaction effect ($H_{05b}$) was rejected. Inspection of the adjusted cell means revealed that the flipped teaching advantage was larger for high-SES students (Flipped-High SES: $M_{adj} = 41.85$, $SE = .78$; Lecture-High SES: $M_{adj} = 30.55$, $SE = .85$; Difference = +11.30) than for low-SES students (Flipped-Low SES: $M_{adj} = 39.45$, $SE = .72$; Lecture-Low SES: $M_{adj} = 34.65$, $SE = .82$; Difference = +4.80). The flipped teaching intervention explained 30.9% of the variance in overall composite learning outcomes, with the significant interaction suggesting that the magnitude of this effect depended on students' socioeconomic background.

To examine the source of the significant interaction, follow-up simple effects analyses were conducted for each learning outcome subscale. The Group × SES interaction was not significant for critical thinking skills, $F(1,115)= 1.756$, $p = .188$, $\eta_p^2 = .015$. However, the interaction was statistically significant for collaboration, $F(1,115) = 8.214$, $p = .005$, $\eta_p^2 = .067$, and long-term retention, $F(1,115) = 11.453$, $p = .001$, $\eta_p^2 = .091$. For collaboration, high-SES students in the flipped teaching group demonstrated significantly higher adjusted scores than their lecture counterparts, whereas the group difference was attenuated among low-SES students. Similarly, for long-term retention, the flipped teaching advantage was pronounced among high-SES students and comparatively modest among low-SES students. These findings indicate that socioeconomic status moderated the relationship between flipped teaching and students' learning outcomes, particularly in the domains of collaboration and long-term retention.

To triangulate and enhance the validity of the quantitative findings, a qualitative follow-up was conducted with students in the flipped intervention group to explore how pre-class procedural video exposure, in-class collaborative participation, and resource accessibility impacted their learning outcomes. The thematic analysis of the interview data revealed three primary themes that directly elucidate the ANCOVA results. First, regarding critical thinking, students reported that previewing procedural video lectures at home offloaded basic cognitive demands, leaving in-class time free for higher-order problem-solving and deeper conceptual analysis alongside teacher guidance ($F = 41.500$, $p < .001$, $\eta_p^2 = .262$). Second, while students noted that peer collaboration enhanced their problem-solving confidence, their participation effectiveness was strongly influenced by whether group members had completed the pre-class preparation; high-SES students frequently led group discussions while underprepared peers created slight friction, providing a qualitative rationale for the statistically significant yet modest effect size in collaboration ($F = 4.081$, $p = .046$, $\eta_p^2 = .034$) as well as the significant Group × SES interaction ($F = 9.460$, $p = .003$). Finally, for long-term retention, participants emphasized that the ability to rewind and re-watch lesson videos prior to delayed assessments, combined with active in-class retrieval practice, converted temporary memorization into durable conceptual

understanding, explaining the robust, substantial variance accounted for in the delayed post-test scores ($F = 174.877$, $p < .001$, $\eta_p^2 = .493$).

## Discussion

The findings from this quasi-experimental study revealed that flipped teaching considerably boosts students' critical thinking, teamwork, and long-term memory retention in mathematics. This supports previous evidence that flipped instruction enhances higher-order learning outcomes. The substantial effect size noted for critical thinking ($\eta_p^2 = .262$) aligns with recent quasi-experimental studies: Atwa *et al.* (2022) [5] found notable improvements in critical thinking among Grade 9 students in flipped mathematics classes, and Maryami *et al.* (2025) [17] observed large effect sizes for critical thinking in flipped nursing education. By combining these statistical improvements with qualitative feedback from students, the cognitive mechanism becomes clearer: participants indicated that viewing procedural videos at home before class reduced basic cognitive load, allowing more class time and mental resources for advanced problem-solving and in-depth conceptual analysis with direct teacher support.

Even though the impact on collaboration was minor ($\eta_p^2 = .034$), it still aligns with qualitative findings from flipped mathematics studies, indicating that organized in-class tasks encourage peer interaction and collaborative problem-solving. From a qualitative perspective, students mentioned that engaging with peers increased their confidence in solving problems, but the success of group interactions largely depended on whether peers had completed the pre-class work. Often, discussions were dominated by prepared, high-SES students, while those who were not prepared caused social tension, offering a practical explanation for the smaller statistical effect size seen in collaboration.

The most notable finding was the significant impact on long-term retention ($\eta_p^2 = .493$), which not only supports but also greatly surpasses the considerable retention effects documented by Asanre *et al.* (2025) [4] in a comparable quasi-experimental study ($\eta_p^2 = .249$). The qualitative data shed light on the reasons behind this pronounced effect: students emphasized that the capability to pause, rewind, and repeatedly watch video lessons before delayed assessments, alongside active retrieval practice in class, converted short-term memorization into lasting conceptual comprehension. Collectively, these results are consistent with meta-analytic evidence showing that flipped instruction leads to medium-to-large positive outcomes in mathematics achievement and enduring learning (Sopamena *et al.*, 2023), and they bolster the conclusion of Almodaires *et al.* (2019) [2] that flipped learning results in better academic performance compared to traditional lectures.

While gender did not moderate these learning outcomes, indicating that the flipped framework functioned with equal effectiveness across male and female students, socioeconomic status emerged as a significant moderator, with the flipped teaching advantage being more pronounced for students from higher socioeconomic backgrounds, particularly in collaboration and long-term retention.

## Conclusion

This study confirms that flipped teaching raises critical thinking, peer collaboration, and retention in secondary school mathematics within the Southwest Region of Cameroon. The pattern fits Vygotsky's (1978) [25] social constructivism: students first encountered concepts alone through video, then refined them through guided interaction in class. Interviews explained why this worked. Watching lectures at home offloaded basic recall, so class time could be spent on argument and problem-solving. Being able to pause and rewind meant concepts stuck. The retention effect was the largest of the three outcomes ($\eta_p^2 = .493$), and that matters for Cameroon specifically. GCE Ordinary and Advanced Level examinations, along with the Baccalauréat, do not reward last-minute cramming. They demand that students hold onto mathematical reasoning months after first encountering it. A method that produces this level of durable learning is worth taking seriously at the policy level.

Gender did not moderate any outcome. Boys and girls gained roughly the same amount, which aligns with MINESEC's stated commitment to equity in STEM classrooms. Socioeconomic status did moderate results, and student interviews made the mechanism plain. Group discussions worked well when everyone had watched the video. When a peer arrived unprepared, usually because they lacked internet, electricity, or a quiet space, the dynamic collapsed. Prepared students, typically from wealthier homes, took over. Underprepared peers withdrew. The gap widened. As MINESEC rolls out the Competency-Based Approach and expands ICT infrastructure, flipped learning offers a viable framework. But viability depends on whether schools close the preparation gap. That means offline options, USB drives, printed worksheets, dedicated morning or afternoon lab hours, so that a student's address does not determine whether they arrive ready to participate. Without those supports, flipped teaching becomes another advantage for the already advantaged. With them, it can be a national strategy.

## Recommendations

The quantitative results, read alongside student interview accounts, point to several concrete steps for policy, practice, and further inquiry. Firstly, MINESEC should formalize flipped teaching within the national Competency-Based Approach curriculum for secondary mathematics. This means more than adding the method to a list of approved strategies. It requires implementation frameworks that explicitly distinguish between content suited for pre-class video delivery and content that deman ds live classroom interaction, thereby protecting contact hours for higher-order reasoning and teacher-guided problem solving rather than allowing them to drift back into lecture format.

Teacher training institutions, including ENS, and regional in-service programs must expand their focus beyond subject-matter expertise to include the technical and pedagogical skills that flipped instruction actually requires. Educators need guidance on producing concise pre-class materials that manage cognitive load without overwhelming students, but they also need strategies for facilitating cooperative learning in ways that distribute participation across the room. When peer-accountability protocols are built into group tasks from the start, discussions are less likely to default to the handful of students who arrived fully prepared.

Closing the socioeconomic gap demands infrastructure that does not assume universal home connectivity. Schools should distribute pre-loaded USB drives, maintain local

offline media servers, and provide printed guided worksheets as parallel pathways to the same content. Administrators might also open computer labs before and after the school day, creating dedicated windows when resource-constrained students can view pre-class materials on campus and enter the classroom on equal footing with their peers.

Assessment practices require similar realignment. Internal evaluations currently lean heavily on short-term surface measures that contradict the very retention strengths the flipped model demonstrated. Department heads should instead incorporate spaced cumulative items and application tasks that revisit concepts after intervals of weeks rather than days, a shift that would simultaneously prepare students for the conceptual demands of the GCE and Baccalauréat examinations and reinforce the habit of sustained independent study.

For future research, the priority is to open the black box of socioeconomic mediation. The present study establishes that SES moderates flipped learning outcomes in secondary mathematics, but it does not isolate which specific resource channels carry that effect. Subsequent work should examine whether household digital access, parental academic support, or the physical conditions of the home study environment exert the strongest influence on pre-class preparation compliance. Classroom observation studies would also illuminate how peer interaction dynamics vary across mixed-SES group compositions, while multi-region trials spanning urban and rural Cameroonian schools would test whether the flipped framework remains viable under the infrastructural constraints that characterize much of the national education landscape.

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