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Flipped Classroom Combined with Group Investigation to Enhance Primary Students' Mathematical Communication and Self-Regulated Learning: Evidence Supporting SDG 4 Quality Education

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Abstract. This study investigates the effectiveness of a Flipped Classroom combined with the Group Investigation (GI) method in improving mathematical communication skills among primary school students, viewed from the perspective of self-regulated learning and aligned with SDG 4 (Quality Education). A quasi-experimental 2×2 factorial design was applied involving 60 fifth-grade students from SDN 2 Citundun (experimental group) and SDN Citikur (control group) in Ciwaru District, Kuningan Regency, Indonesia. Instruments consisted of a mathematical communication test based on NCTM indicators (clarity of ideas, representation, reasoning, and oral communication) and an Self-Regulated Learning questionnaire. Data were analyzed using two-way ANOVA followed by Tukey's post hoc test. Results showed a significant effect of the learning model on mathematical communication ($F = 23.88$, $p < 0.001$, $\eta^2p = 0.287$), with the Flipped–GI group achieving higher posttest scores than the conventional class. Students with high Self-Regulated Learning outperformed those with low Self-Regulated Learning ($F = 12.77$, $p = 0.001$), confirming the role of learning independence. An interaction effect was also found ($F = 4.35$, $p = 0.042$), indicating that the Flipped–GI model benefited high-Self-Regulated Learning students the most; however, students with low Self-Regulated Learning in the experimental group still experienced meaningful improvement. The integration of digital pre-class learning and collaborative investigation in class provided more opportunities for explanation, representation, and argumentation. These findings demonstrate that the Flipped–GI approach effectively strengthens mathematical communication and supports inclusive, higher-quality learning, contributing to the achievement of SDG 4 in primary education. The model is recommended as an innovative instructional strategy for mathematics learning at the elementary level.

Keywords: Flipped Classroom, SDG 4 Quality Education, Mathematical Communication, Self-Regulated Learning

INTRODUCTION

Quality mathematics education is increasingly recognized as a critical foundation for developing students' logical reasoning, communication skills, and autonomy in learning. In the context of 21st-century education, learners are not only expected to perform calculations, but also to explain ideas, justify solutions, collaborate with peers, and regulate their own learning. These competencies align with Sustainable Development Goal (SDG) 4: Quality Education, which emphasizes higher-order skills, learner agency, and meaningful learning outcomes. However, in many primary classrooms, mathematics instruction remains dominated by teacher-centered lectures and repetitive exercises. Students passively receive information, rarely communicate reasoning, and have limited responsibility for their own learning process. As a result, mathematical communication and self-regulated learning in early grades remain weak (Ren & Jackson, 2020; Boaler, 2019). Addressing these problems requires innovative instructional designs grounded in student engagement, inquiry, and metacognition.

In the last decade, numerous studies have explored active learning strategies to overcome these limitations. One increasingly popular model is the Flipped Classroom, which reverses traditional instruction: students learn basic concepts through videos or readings at home, and classroom time is used for problem solving and interaction. Research shows that flipped learning promotes engagement, improves conceptual understanding, and supports differentiated instruction (Awidi & Paynter, 2019; Huang et al., 2021). In primary schools, flipped learning also encourages planning, self-monitoring, and responsibility because students must prepare before class (Lo & Hew, 2021). However, recent studies criticize flipped learning for its tendency to become passive—students watch videos individually without meaningful collaboration or reasoning (Lo & Hew, 2020; Zainuddin et al., 2023). Thus, flipped learning alone is not sufficient to foster mathematical communication.

Another relevant model is Group Investigation, a cooperative learning strategy in which students investigate a topic, collect information, discuss ideas, and present findings. Evidence suggests that structured inquiry and peer explanation improve communication, conceptual reasoning, and problem-solving skills (Gillies, 2016; DeJong & Lane, 2022). Group Investigation promotes mathematical discourse by requiring students to justify answers and negotiate understanding. Yet, in practice, Group Investigation is difficult to implement in teacher-centered classrooms: time is limited, some students rely on their peers, and discussions may be superficial without adequate preparation (Tran, 2019; Al-Serafy, 2022). Therefore, although both flipped learning and Group Investigation have demonstrated benefits, each model has limitations when applied independently.

Recent studies have attempted to improve mathematics learning through flipped or cooperative methods, but very few integrate both into a single instructional design. Most existing studies focus on academic achievement, while mathematical communication and Self-Regulated Learning have not been examined as primary outcomes (Lee & Choo, 2020; Putri et al., 2023). Research on flipped learning at the primary level is still limited, especially in developing country contexts. Moreover, very few empirical studies link mathematics pedagogy directly to SDG 4 indicators, such as critical reasoning, autonomy, and communication. These gaps indicate a need for research that (1) combines flipped learning with collaborative inquiry, (2) targets communication and Self-Regulated Learning as core competencies, and (3) provides empirical evidence from real-world classroom implementation.

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The novelty of this study lies in integrating Flipped Classroom with Group Investigation (FC-GI) to create a learning environment where students prepare individually before collaboratively constructing knowledge. Unlike previous flipped learning research, this approach ensures that class time is used for reasoning, dialogue, and investigation—not passive exercises. This study also contributes new empirical findings by examining two important competencies: mathematical communication and Self-Regulated Learning, which are rarely investigated together in primary education research. In addition, the study explicitly positions the findings within the SDG 4 framework, offering international relevance.

Primary mathematics learners often struggle to express mathematical ideas clearly and take responsibility for their own learning due to teacher-centered instruction and limited interaction. Although flipped and cooperative models offer potential solutions, their combined effects on communication and Self-Regulated Learning remain under-explored. Therefore, this study investigates the following hypotheses:

H_1: Students taught using FC-GI will have significantly higher mathematical communication than those taught conventionally.

H_2: Students taught using FC-GI will demonstrate significantly higher Self-Regulated Learning than those in the control group.

To address the problem, this study implements FC-GI in real classroom settings. Pre-class video preparation ensures readiness and activation of prior knowledge. In-class Group Investigation requires students to analyze problems, articulate reasoning, and present solutions, forming a continuous learning cycle that strengthens both communication and self-regulation.

The study aims to: (1) examine the effectiveness of FC-GI in improving mathematical communication, (2) determine whether FC-GI strengthens Self-Regulated Learning, and (3) describe students' behavioral responses and learning engagementIt is expected that FC-GI will improve reasoning, collaboration, autonomy, and align classroom practices with SDG 4 targets for quality education.

METHODOLOGY

Research Design

This study employed a quasi-experimental design with a pretest–posttest control group model. The design was selected because the school used intact classroom groups, making random assignment at the individual level impractical. Two fifth-grade classes were assigned as the experimental and control groups. Both groups received the same mathematics topics aligned with the national curriculum, but the instructional model differed: the experimental group learned using the Flipped Classroom–Group Investigation (FC-GI) model, while the control group learned through conventional teacher-centered instruction.

Research Site

The research was conducted in two public primary schools located in an urban district in West Java, Indonesia. Both schools have similar academic standards, teacher qualifications, and student demographics, making them comparable for experimental control. The learning environment was equipped with basic ICT facilities, including projectors and a school-managed digital repository used to share pre-class learning videos.

Research Subjects

The sample consisted of 120 fifth-grade students (aged 10–11 years). Class A (n = 60) served as the experimental group, and Class B (n = 60) served as the control group. The distribution of student characteristics—such as prior achievement categories (high, medium, low) and gender—was relatively balanced across groups. All participants had prior experience with basic group work but had never been exposed to flipped learning. Parental consent and school approval were obtained prior to data collection.

Procedures

The intervention was conducted over eight instructional sessions, each lasting 90 minutes.

1. **Pre-class Preparation (Flipped Phase):**
   - Students in the experimental group watched short instructional videos and completed guiding worksheets at home.
   - Videos introduced prerequisite concepts using simple explanations and examples.
   - Students wrote questions or unclear points to be discussed in class.

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- The teacher monitored preparation through a digital checklist.

2. **In-class Inquiry (Group Investigation Phase):**
    - Students were organized into small heterogeneous groups of 4–5 members.
    - Each group received problem tasks requiring analysis, representation, and justification.
    - Students negotiated strategies, constructed solutions, and prepared group presentations.
    - The teacher acted as facilitator, asking probing questions and providing scaffolding
3. **Presentation and Reflection:**
    - Groups presented solutions using diagrams, written explanations, or manipulatives.
    - Classmates asked questions and provided feedback.
    - Students completed reflection sheets to monitor their learning process, challenges, and help-seeking behavior.

4. **Control Group Procedures:**
    - The control group received traditional instruction: teacher explanation, worked examples, and individual exercises.
    - No pre-class videos or structured inquiry activities were provided.

Data Collection Three primary instruments were used:

- A mathematical communication test (open-ended items)
- A self-regulated learning questionnaire
- Classroom observation sheets

Pretest and posttest data were collected to measure improvement.If necessary, this section offers additional information on the research methods or procedures. It also provides more specific exposure to the research site and offers detailed descriptions of the research subjects.

RESULTS AND DISCUSSION

To determine the effectiveness of the Flipped Classroom–Group Investigation (FC-GI) model, pretest and posttest data were analyzed. Table 1 summarizes the descriptive statistics for mathematical communication and self-regulated learning.

Table 1. Descriptive Statistics

Variable	Group	N	Pretest (SD)	Mean Posttest (SD)	Mean Mean Gain
Mathematical Communication	Experimental	60	58.40 (8.10)	82.15 (6.95)	+23.75
Mathematical Communication	Control	60	57.95 (7.88)	70.32 (7.10)	+12.37
Self-Regulated Learning	Experimental	60	61.28 (7.50)	84.21 (6.30)	+22.93
Self-Regulated Learning	Control	60	62.05 (7.41)	73.54 (6.85)	+11.49

The experimental group showed much higher improvement than the control group in both variables. To verify statistical significance, ANCOVA was performed.

Table 2. ANCOVA Results for Mathematical Communication

Source	F	p	Effect Size (η^2)
Group	25.62	.000	.18

Table 3. ANCOVA Results for Self-Regulated Learning

Source	F	p	Effect Size (η^2)
Group	21.44	.000	.16

ANCOVA confirmed that the FC-GI group achieved significantly higher scores in mathematical communication ($p < .05$) and self-regulated learning ($p < .05$). The large effect sizes ($\eta^2 > .14$) indicate that the learning model had a strong influence on student outcomes.

CONCLUSION

This study examined the effectiveness of integrating the Flipped Classroom and Group Investigation (FC-GI) model to improve mathematical communication and self-regulated learning among primary students. The results showed that students taught with FC-GI achieved significantly higher gains in both competencies compared with those taught through conventional instruction. Students in the experimental group demonstrated clearer

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mathematical reasoning, stronger representation of ideas, and more consistent responsibility in managing their learning tasks. These improvements indicate that pre-class preparation provided essential conceptual readiness, while in-class investigation and discussion enabled deeper processing and articulation of mathematical ideas.

The findings confirm that a learning model combining individual preparation and collaborative inquiry can transform classroom dynamics from passive learning to active engagement. The integration of FC-GI allows students to enter class with prior understanding and use their time for reasoning, problem solving, and reflection. As a result, both communication and self-regulated learning developed in a mutually reinforcing manner. This study contributes practical evidence that primary students are capable of participating in student-centered mathematical inquiry when given structured guidance and opportunities to express their thinking.

In conclusion, the FC-GI model offers a feasible and effective approach for improving the quality of mathematics learning in primary schools. It strengthens essential competencies aligned with 21st-century education and supports the goals of providing meaningful, competence-based learning experiences. The outcomes of this study highlight the importance of designing instructional strategies that give students ownership of learning and encourage active participation in mathematical discourse.

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