



The Effect of Flipped Classroom Combination of Cooperative Methods and Group Investigation Type (MKGI) on Mathematical Communication Skills

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Penelitian ini bertujuan menganalisis pengaruh model Flipped Classroom kombinasi metode kooperatif tipe Group Investigation terhadap kemampuan komunikasi matematis siswa sekolah dasar ditinjau dari kemandirian belajar. Penelitian menggunakan pendekatan kuantitatif dengan desain eksperimen semu faktorial 2×2 . Sampel penelitian terdiri atas 32 siswa kelas V yang dibagi ke dalam kelas eksperimen dan kelas kontrol. Instrumen penelitian meliputi tes kemampuan komunikasi matematis dan angket kemandirian belajar. Data dianalisis menggunakan uji two-way ANOVA. Hasil penelitian menunjukkan bahwa siswa yang belajar dengan model Flipped Classroom kombinasi Group Investigation memiliki kemampuan komunikasi matematis yang lebih tinggi dibandingkan pembelajaran ekspositori. Kemandirian belajar juga berpengaruh signifikan, serta terdapat interaksi antara model pembelajaran dan kemandirian belajar. Temuan ini menunjukkan bahwa integrasi pembelajaran berbasis teknologi dan kooperatif efektif dalam meningkatkan kemampuan komunikasi matematis siswa sekolah dasar.

Abstract

This study aims to analyze the effect of the Flipped Classroom model combined with the Group Investigation cooperative method on the mathematical communication skills of elementary school students in terms of learning independence. The study used a quantitative approach with a 2×2 factorial quasi-experimental design. The study sample consisted of 32 fifth-grade students divided into an experimental class and a control class. The research instruments included a mathematical communication ability test and a learning independence questionnaire. Data were analyzed using a two-way ANOVA test. The results showed that students who learned with the Flipped Classroom model combined with Group Investigation had higher mathematical communication skills than those who learned with expository learning. Learning independence also had a significant effect, and there was an interaction between the learning model and learning independence. These findings indicate that the integration of technology-based and cooperative learning is effective in improving elementary school students' mathematical communication skills.



INTRODUCTION

Mathematics is one of the essential subjects taught continuously at every level of education due to its strategic role in developing students' logical, systematic, and critical thinking skills. In addition to functioning as a problem-solving tool, mathematics also serves as a means of communication that enables individuals to express ideas, concepts, and mathematical relationships clearly and in a structured manner (Safari & Nurhida, 2024). Therefore, mathematics learning should not only be oriented toward mastering concepts and procedures but also toward developing process competencies that support deep and meaningful understanding.

The National Council of Teachers of Mathematics (NCTM) emphasizes that there are five main process standards in mathematics learning: problem solving, reasoning and proof, communication, connections, and representation (Hafriani, 2021). Among these five standards, mathematical communication occupies a particularly important position, as it serves as a bridge for students to construct, clarify, and strengthen their understanding of mathematical concepts. Through mathematical communication, students are able to convey ideas both orally and in writing, represent concepts in the form of symbols, images, tables, or diagrams, and interpret and evaluate mathematical ideas expressed by others (Yurniwati, 2019).

Mathematical communication is understood as an individual's ability to express and interpret mathematical ideas through various forms of representation—verbal, written, and visual—and to use them appropriately in problem-solving contexts (Solihah & Suparman, 2020; Lubis & Rahayu, 2023). Baroody, Greenes, and Schulman emphasize that mathematical communication is a fundamental means for conducting exploration, investigation, and social mathematical activities involving discussion, argumentation, and justification of ideas (Hendriana, Rohaeti, & Sumarmo, 2017). Therefore, mathematical communication skills constitute essential mathematical soft skills that should be developed from the elementary education level.

However, various research findings indicate that students' mathematical communication skills, particularly at the elementary school level, remain relatively low (Chasanah & Usodo, 2020). Students often experience difficulties in understanding word problems, translating problems into mathematical models, and communicating solutions in a coherent and accurate manner (Mabruroh et al., 2020). In addition, students face obstacles in presenting mathematical ideas using symbols, images, or other forms of representation, especially in contextual problems (Indriani & Pasaribu, 2022; Fauziyah & Jupri, 2020). This condition indicates that current mathematics instruction has not yet fully provided opportunities for students to optimally develop their mathematical communication skills.

The low level of students' mathematical communication skills cannot be separated from instructional practices that are still predominantly dominated by expository approaches, in which the teacher serves as the primary source of information and students tend to passively receive knowledge. Such instructional practices provide limited opportunities for students to actively engage in discussions, express their ideas, or

construct understanding through social interaction. In fact, the development of mathematical communication skills requires an active, collaborative learning environment that offers ample opportunities for students to express their mathematical ideas (Putri & Nuvitalia, 2024).

Along with advances in educational technology, the flipped classroom model has emerged as an innovative instructional alternative with the potential to address these challenges. The flipped classroom is a learning approach that reverses the traditional instructional pattern, in which content delivery occurs prior to face-to-face instruction through media such as videos or digital modules, while class time is devoted to meaningful activities such as discussion, problem solving, and reflection (Nurhadiat & Syakdiyah, 2019; Wasriep & Lajium, 2019). This model is student-centered and provides learners with flexibility to study according to their individual learning pace and styles (Purwanti & Suryawati, 2022).

Along with advances in educational technology, the flipped classroom model has emerged as an instructional alternative that reorganizes learning time by shifting initial content exposure to the pre-class phase, while reserving classroom sessions for discussion, problem solving, and reflection (Nurhadiat & Syakdiyah, 2019; Wasriep & Lajium, 2019). In mathematics education, this model is often associated with increased student participation and more interactive classroom dynamics (Huynh & Nguyen, 2019). Theoretically, the flipped format offers opportunities for deeper engagement because class time can be dedicated to higher-order cognitive activities rather than direct explanation.

However, the effectiveness of flipped learning is not universally established, particularly at the elementary level. Meta-analytic evidence suggests that learning gains associated with flipped classrooms are often moderate and highly dependent on design features such as the inclusion of structured formative assessment and the preservation of meaningful in-class interaction (van Alten et al., 2019; Strelan et al., 2020). Moreover, studies conducted in K–12 settings report practical and developmental challenges, including unequal access to technology, varying levels of parental support, and students' limited readiness for independent learning (Lo & Hew, 2017; Hew et al., 2021).

These challenges are especially relevant in elementary contexts, where learners are still developing self-regulation and metacognitive skills. The expectation that students independently study instructional materials before class may place additional cognitive and motivational demands on those who are not yet accustomed to autonomous learning. Without careful scaffolding, flipped instruction may risk transferring instructional responsibility prematurely to students who require structured guidance. Therefore, the pedagogical value of flipped classroom in primary mathematics should be examined within a framework that considers both instructional design and learner characteristics.

Several studies have shown that the flipped classroom can enhance students' active participation, improve the quality of classroom interactions, and increase cognitive engagement in mathematics learning (Huynh & Nguyen, 2019). In addition, the flipped classroom contributes positively to the development of learner autonomy, as students are required to manage their own learning processes prior to in-class

instruction (Ishartono et al., 2022; Suryawan et al., 2021). Nevertheless, the effectiveness of the flipped classroom largely depends on how in-class learning activities are designed and facilitated.

To optimize the implementation of the flipped classroom, it is necessary to integrate it with cooperative learning methods that can systematically guide student activities. One relevant method is Group Investigation (GI), a cooperative learning approach that emphasizes students' active involvement in inquiry processes, group discussions, and the presentation of results (Elfada & Prasetyo, 2020). GI encourages students to exchange ideas, engage in argumentation, and construct shared understanding through social interaction (Rosiani & Taufiq, 2020). Through GI, students not only learn to understand mathematical concepts but also develop the ability to communicate mathematical ideas both orally and in writing.

Previous studies indicate that the implementation of Group Investigation has a positive impact on students' mathematical communication skills, collaboration, and thinking skills (Ardiana, 2018; Susanti, 2020). Furthermore, the combination of the flipped classroom with collaborative approaches has been shown to enhance cognitive engagement and improve the quality of mathematics instruction (Amir et al., 2020; Tegeh et al., 2022). However, most existing studies have focused on secondary education levels or have been conducted in online learning contexts, and have not specifically examined the mathematical communication skills of elementary school students.

In addition to external factors such as instructional models, students' mathematical communication skills are also influenced by internal factors, one of which is learning independence. Learning independence, or self-regulated learning, refers to students' ability to consciously and responsibly regulate, monitor, and evaluate their own learning processes (Zimmerman, 1989; Hendriana, Rohaeti, & Sumarmo, 2017). Students with high levels of learning independence tend to demonstrate stronger intrinsic motivation, greater learning initiative, and more effective management of learning strategies, all of which positively influence mathematics learning outcomes (Sutrisno & Yusri, 2021; Ego, 2016).

Research has shown that students with high learning independence exhibit better mathematical communication skills than those with low levels of learning independence (Dalimunthe et al., 2023). This finding indicates that learning independence functions as an important moderating variable in instructional effectiveness, particularly in learning models that require active engagement and autonomous learning, such as the flipped classroom.

Although numerous studies have separately examined flipped classrooms, group investigation, mathematical communication skills, and learning independence, research that integrates these four aspects within the context of elementary school mathematics instruction remains limited. Therefore, this study aims to analyze the effect of implementing a flipped classroom combined with the cooperative learning method of the Group Investigation type on elementary school students' mathematical communication skills, viewed in terms of their learning independence. This study is expected to contribute theoretically to the development of mathematics instructional models and practically to assist elementary school teachers in designing innovative, student-centered learning experiences.

METHOD

This study employed a quantitative approach using an experimental method, as it aimed to systematically and controllably examine the effect of a specific treatment on the dependent variable. The research design used was a quasi-experimental design with a 2×2 factorial arrangement. This design enabled the researchers to analyze the main effects of the instructional model and learning independence, as well as to examine the interaction between these two variables on elementary school students' mathematical communication skills. For clarity, the research design is illustrated in the following figure:

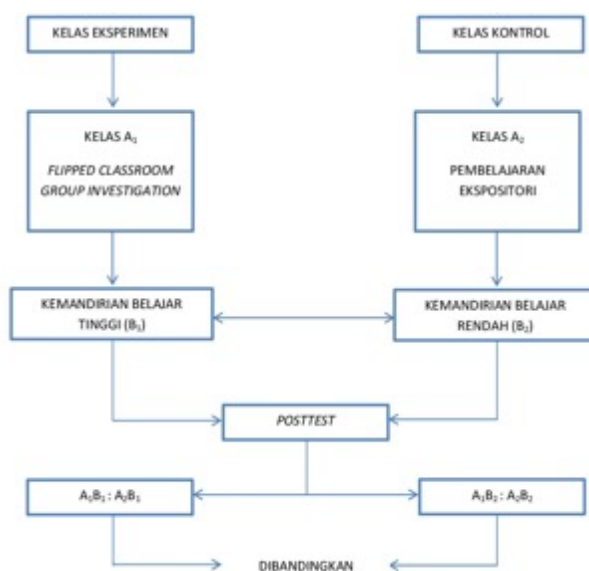


Figure 1. Research Design

This research design compared two groups: an experimental class that implemented the flipped classroom model combined with the Group Investigation method (A_1) and a control class that employed expository instruction (A_2), while considering students' levels of learning independence classified as high (B_1) and low (B_2). After the treatment was administered, all groups were given a posttest to measure mathematical communication skills. The results of the A_1B_1 , A_1B_2 , A_2B_1 , and A_2B_2 group combinations were then compared to determine the main effects and interaction effects of the research variables.

The sample in this study consisted of fifth-grade students from SDN 2 Citundun as the experimental class and SDN Citikur as the control class. After the samples (experimental and control groups) were determined, students in both classes were administered a learning independence questionnaire. Based on the questionnaire results, students were divided into two groups: those with high learning independence and those with low learning independence. The scores obtained from the questionnaire were ranked from the highest to the lowest (Surapranata, 2019). Based on this ranking, the top 27% of scores were classified as the upper group and the bottom 27% as the lower group. The upper 27% were designated as students with high learning independence, while the lower 27% were designated as students with low learning independence. The use of the upper and lower 27% categorization follows conventional procedures in educational research to maximize contrast between high and low groups.

However, this approach necessarily reduces the effective sample size within each cell ($n = 8$), which may limit statistical power and increase the sensitivity of interaction estimates. While this strategy strengthens group differentiation, the findings particularly the interaction effect should therefore be interpreted with caution. Consequently, the sample groups were formed as follows:

Table 1. Number of Research Samples in Each Treatment Group

Learning Independence (B)	Instructional Model (A)		Total
	Flipped Classroom Combined with Cooperative Learning Method (Group Investigation) (A ₁)	Expository Instruction (A ₂)	
High (B ₁)	8 students	8 students	16 students
Low (B ₂)	8 students	8 students	16 students
Total	16 students	16 students	32 students

The instructional implementation in the experimental class was conducted through three main stages of the flipped classroom model: before class, during class, and after class. In the before class stage, students independently studied the topics of perimeter and area of plane figures (squares, rectangles, and triangles) through instructional videos and practice exercises provided via a web-based application. During the during class stage, face-to-face learning activities were carried out using the cooperative learning method of the Group Investigation type, which involved forming heterogeneous groups, identifying problems, planning investigations, conducting investigations, preparing reports, presenting findings, and evaluation. Subsequently, in the after class stage, students completed follow-up exercises and individual tests to reinforce conceptual understanding.

Meanwhile, the control class implemented expository instruction dominated by teacher explanations, worked examples, and individual practice, following the stages of preparation, linkage, presentation, and evaluation. The research instruments consisted of a mathematical communication skills test, a learning independence questionnaire, and a basic mathematics ability test. The mathematical communication skills test was developed based on indicators of mathematical communication, including the ability to express problems in mathematical language, connect visual representations with mathematical ideas, and explain solutions in written form. The learning independence questionnaire was used to classify students into high and low learning independence categories. Prior to implementation, all instruments were tested for validity and reliability to ensure their suitability as research measurement tools.

The research data were analyzed using inferential statistics. Before hypothesis testing, prerequisite analyses were conducted, including tests of normality and homogeneity of variance. Hypothesis testing was performed using a two-way analysis of variance (two-way ANOVA) to examine the effects of the instructional model, learning independence, and their interaction on students' mathematical communication skills. All data analyses were conducted at a significance level of 0.05.

RESULT AND DISCUSSION

This section presents the research findings, which include: (a) descriptive statistics for each research group, consisting of the mean, median, minimum score, maximum score, standard deviation, and N-Gain score analysis to describe changes in students' achievement before and after the treatment; (b) hypothesis testing using a two-way ANOVA; and (c) discussion of the research findings.

The data collected in this study consist of students' scores on the mathematical communication skills test and scores from the learning independence questionnaire. The research data were obtained from groups of students who received instruction using the flipped classroom model combined with the cooperative learning method of the Group Investigation type and those who received expository instruction. A summary of the descriptive statistics for each group is presented in the following table:

Table 2. Summary of Research Findings

Learning Independence (B)		Experimen Class	Control Class
		<i>Flipped Classroom Combined with Cooperative Learning Method (Group Investigation) (A₁)</i>	<i>Expository Instruction (A₂)</i>
High	N	8	8
	Average	92,25	71,63
	Min	81	67
	Max	98	77
	Stdev	6,38	3,37
Low	N	8	8
	Average	75,00	78,13
	Min	69	74
	Max	80	82
	Stdev	4,00	3,18
Total	N	16	16
	Average	83,63	75,00
	Min	69	67
	Max	98	82
	Stdev	10,28	4,61

The table shows that among students with high learning independence, the mean mathematical communication score of the experimental class ($M = 92.25$) was higher than that of the control class ($M = 71.63$), with a relatively wider score range and larger standard deviation observed in the experimental class. In contrast, among students with low learning independence, the mean score of the control class ($M = 78.13$) was slightly higher than that of the experimental class ($M = 75.00$).

Overall, the mean score of the experimental class ($M = 83.63$) exceeded that of the control class ($M = 75.00$), indicating a tendency toward a positive effect of implementing the flipped classroom combined with the Group Investigation method on students' mathematical communication skills.

Based on the descriptive data summarized above, hypothesis testing was subsequently conducted using a two-way analysis of variance (two-way ANOVA). The results are presented as follows:

Table 3. Summary of Research Findings

Tests of Between-Subjects Effects

Dependent Variable: Hasil Belajar Kognitif

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1971.750 ^a	3	657.250	33.567	<,001
Intercept	200978.000	1	200978.000	10264.266	<,001
Instructional Model	612.500	1	612.500	31.281	<,001
Learning Independence	231.125	1	231.125	11.804	.002
Instructional Model * Learning Independence	1128.125	1	1128.125	57.615	<,001
Error	548.250	28	19.580		
Total	203498.000	32			
Corrected Total	2520.000	31			

a. R Squared = .782 (Adjusted R Squared = .759)

Based on the results presented in the table above, the two-way ANOVA revealed a significant difference in mathematical communication skills between students who were taught using the Flipped Classroom model combined with the Cooperative Learning method of the Group Investigation type (A_1) and those who were taught using expository instruction (A_2). The analysis yielded an F value of 31.281 with a significance level of $p < 0.001$; therefore, H_0 was rejected and H_1 was accepted. This finding indicates that students who received instruction through the Flipped Classroom combined with the Group Investigation method demonstrated significantly higher mathematical communication skills than those who received expository instruction.

The results of this study indicate that the implementation of the Flipped Classroom combined with the Cooperative Learning method of the Group Investigation type (FC–MKGI) significantly enhances students' mathematical communication skills compared to expository learning. This conclusion is supported by the two-way ANOVA results, which revealed a significant main effect of the instructional model, a significant effect of learning independence, and a significant interaction between the two variables. Empirically, students with high learning independence who learned through the FC–MKGI model achieved the highest mathematical communication scores among all groups.

These findings are consistent with previous studies reporting that the flipped classroom approach increases students' active engagement, improves the quality of instructional interactions, and enhances mathematical communication and representation skills (Huynh & Nguyen, 2019; Ardila et al., 2021). Furthermore, the integration of the flipped classroom with cooperative learning has been shown to strengthen knowledge construction processes through discussion and collaboration (Amir et al., 2020). Nevertheless, much of the prior literature reports aggregated positive outcomes without disaggregating

effects across learner characteristics. The present findings indicate that such aggregation may conceal important subgroup variations.

The ability to express problems in mathematical language improved significantly in the experimental class because students experienced multilayered and meaningful learning processes. During the before class stage, the flipped classroom facilitated students' independent understanding of problems through instructional videos that incorporated contextual explanations, visual illustrations, and worked examples. These activities helped students build prior knowledge and enhance cognitive readiness before face-to-face learning, as emphasized in Ausubel's theory of meaningful learning. A study by Anggo and Samparadja (2022) demonstrated that the flipped classroom provides students with greater preparedness to interpret problems and construct mathematical models, as they have already understood the problem context prior to in-class discussions. Subsequently, during the Group Investigation stage, students actively discussed the problems, identified key information, and formulated the problems into mathematical symbols or expressions. This process aligns with the findings of Hendriana, Rohaeti, and Sumarmo (2017), who reported that mathematical communication develops optimally through investigative activities and social discourse.

In contrast, under expository instruction, students tend to receive the formulation of problems and mathematical models directly from the teacher. As a result, students are less trained to interpret problems independently. This finding is consistent with Sulistiyo (2021), who reported that teacher-centered instruction is less effective in developing students' mathematical communication skills.

The indicator related to the ability to connect visual representations with mathematical ideas developed more effectively in the experimental class because the flipped classroom provides rich and flexible visual media. Instructional videos allow students to repeatedly observe the relationships among images, symbols, and mathematical concepts according to their individual needs. Studies by Yang and Theng (2019) and Widodo et al. (2021) emphasize that video-based media support students' understanding of abstract concepts through concrete visualizations. During the Group Investigation stage, students not only observed visual representations but also produced them through drawings, diagrams, and mathematical models in their group reports. This activity strengthened students' representational and visual interpretation skills, as reported by Ardiana (2018) and Susanti (2020), who found that the Group Investigation method effectively enhances mathematical communication skills, particularly in the aspect of visual representation.

Conversely, in expository instruction, visual representations tend to be used in a limited manner as examples provided by the teacher, without actively involving students in their construction. Consequently, students are less trained to independently connect visual representations with mathematical ideas, as also noted by Nababan et al. (2023).

The ability to explain solutions in written form showed a significant improvement in the experimental class because the FC-MKGI syntax systematically trained students to express mathematical ideas in a coherent and argumentative manner. During the before class stage, students became accustomed to making

notes and summarizing learning materials, which represent an initial form of written communication. Subsequently, during the during class stage, students prepared a final report (final project) that required them to explain solution steps logically and systematically. Studies by Anwar and Musdi (2019) and Putri et al. (2022) demonstrated that the flipped classroom is effective in training students to clearly articulate reasoning, solution procedures, and mathematical conclusions in writing. In addition, discussions within the Group Investigation process allowed students to revise and refine their written explanations based on peer feedback, as emphasized by Vygotsky's social constructivist theory.

In contrast, under expository instruction, students primarily copied solution steps provided by the teacher, resulting in written explanations that tended to be procedural and less argumentative. This finding aligns with Sanjaya (2006) and Supriyadi et al. (2023), who reported that expository instruction provides limited opportunities for students to develop in-depth written communication skills.

The significant interaction between the instructional model and learning independence indicates that the effectiveness of FC–MKGI is strongly influenced by students' internal characteristics. However, a closer examination of subgroup results reveals a counterintuitive pattern. Within the low learning independence group, students in the control class outperformed those in the experimental class. This finding challenges the assumption that flipped–cooperative models are uniformly advantageous and suggests that instructional effectiveness may depend on learner readiness. Students with high learning independence were better able to optimally utilize the before class stage, manage their learning time, and prepare themselves for classroom discussions and investigations. This finding is consistent with Dalimunthe et al. (2023), who reported that students with high learning independence demonstrate stronger mathematical communication skills.

Furthermore, studies by Ishartono et al. (2022) and Suryawan et al. (2021) showed that the flipped classroom significantly enhances students' learning independence, which in turn positively affects mathematics learning outcomes. Conversely, students with low learning independence tend to rely more heavily on teacher explanations; therefore, expository instruction may be relatively more suitable for them, although their overall mathematical communication performance remains lower.

The improvement in mathematical communication skills observed in the experimental class can be attributed to the strong alignment between the FC–MKGI instructional syntax and the core indicators of mathematical communication, namely independent problem comprehension, construction of visual representations, and the written and oral presentation of solutions. In contrast, teacher-centered expository instruction is less capable of comprehensively facilitating these three indicators, resulting in relatively lower levels of mathematical communication skills.

The results of this study demonstrate that the implementation of the Flipped Classroom combined with the Cooperative Learning model of the Group Investigation type (FC–MKGI) has a significant effect on elementary school students' mathematical communication skills. This conclusion is supported by the two-way ANOVA results, which revealed a significant main effect of the instructional model, a significant

effect of learning independence, and a significant interaction between the two variables. Descriptively, students with high learning independence who learned through the FC–MKGI model achieved the highest mathematical communication scores among all groups, whereas among students with low learning independence, the advantages of FC–MKGI did not emerge optimally.

From a pedagogical perspective, these findings indicate that FC–MKGI influences learning outcomes not only directly but also through changes in the structure and quality of students' learning activities. In the flipped classroom model, fundamental concept acquisition is shifted to the pre-learning phase (before class), allowing face-to-face classroom time to be devoted to higher-order cognitive activities such as discussion, investigation, representation construction, and presentation of findings. International meta-analyses have consistently shown that flipped learning has a positive impact on academic achievement and student engagement, particularly when in-class time is used for active learning (Strelnan et al., 2020; Ma et al., 2025).

Within the context of elementary mathematics education, this approach is particularly relevant because students are transitioning from the concrete operational stage to the early formal operational stage of cognitive development. At this stage, learners require instructional experiences that enable them to connect mathematical concepts with visual representations, language, and social interaction. International studies at the elementary level indicate that learning environments emphasizing structured discussion and collaborative group work contribute significantly to the development of mathematical communication and conceptual understanding (Veldman et al., 2020; Legesse et al., 2020).

The integration of the flipped classroom with the Group Investigation model further strengthens this process. Group Investigation requires students to identify problems, collect and process information, and present investigation results both orally and in writing. These investigative activities directly align with key indicators of mathematical communication, including the ability to explain ideas, use symbols and visual representations, and construct coherent mathematical arguments. Research in elementary education has shown that investigation-based cooperative learning models are effective in improving the quality of mathematical discourse and increasing students' confidence in communicating ideas (Sholihah et al., 2021; Talkhan et al., 2025).

The findings also confirm that learning independence serves as a critical determinant of the effectiveness of FC–MKGI among elementary school students. Learners with high learning independence are better able to utilize the before class phase to build prior understanding, manage their learning time, and prepare for classroom discussions. This readiness enables them to participate more actively in group investigations and to produce deeper and more meaningful mathematical communication. These results are consistent with international studies indicating that the success of flipped classrooms is strongly influenced by students' self-regulation abilities, particularly at the elementary level where self-regulation is still developing (Liu et al., 2024; Rincón et al., 2025).

Conversely, for students with low learning independence, the effectiveness of FC–MKGI has not yet been fully optimized. Insufficient preparation during the pre-learning phase results in limited conceptual readiness, which constrains participation in discussions and group investigations. This condition helps explain why, among students with low learning independence, the control group receiving expository instruction exhibited relatively higher mean mathematical communication scores. International research suggests that elementary students with underdeveloped self-regulation still require structured guidance and direct teacher support to understand fundamental concepts (Algarni & Lortie-Forgues, 2023).

Nevertheless, these findings do not diminish the advantages of FC–MKGI; rather, they highlight the need for scaffolding learning independence when implementing flipped classrooms at the elementary level. International studies recommend the use of structured learning guides, developmentally appropriate short videos, pre-class quizzes, and timely feedback to support elementary students in adapting to the demands of self-directed learning (Wei et al., 2020; Egara et al., 2024). With such support, the flipped classroom not only enhances learning outcomes but also gradually fosters students' learning independence.

From the perspective of mathematical communication, the findings align with evidence that communication skills develop most effectively when students are given opportunities to explain, revise, and defend mathematical ideas within social contexts. International research emphasizes that mathematical discourse in collaborative group settings enhances students' ability to use mathematical language, connect multiple representations, and demonstrate deeper conceptual understanding (Tong et al., 2021; Suh & Seshaiyer, 2022). In FC–MKGI, the requirement to communicate investigation results positions mathematical communication as an integral component of the learning process rather than merely an end product.

Overall, this study strengthens empirical evidence that the Flipped Classroom combined with the Group Investigation model represents an effective and contextually appropriate approach for improving elementary school students' mathematical communication skills, particularly when supported by adequate levels of learning independence. The findings suggest that learning independence functions as a boundary condition for flipped–cooperative effectiveness. Rather than positioning FC–MKGI as universally superior, this study demonstrates that its impact depends on alignment between instructional demands and students' regulatory capacity.

These findings underscore that the development of mathematical communication in elementary education requires not only the selection of appropriate instructional models but also deliberate strategies to strengthen students' learning independence as a foundational competence for 21st-century mathematics learning.

CONCLUSION

This study affirms that the integration of the Flipped Classroom with the Group Investigation model holds substantial potential for strengthening elementary students' mathematical communication. However, its effectiveness is not merely a function of instructional format, but of alignment between pedagogical demands and learner readiness. The model supports the development of mathematical expression, representational connection, and structured explanation by positioning communication as an integral component of the learning process rather than as a final outcome.

Importantly, the findings highlight learning independence as a determining condition of instructional impact. The advantages of flipped-cooperative integration become most visible when students possess sufficient capacity for self-directed engagement. In this sense, the study moves beyond a simple comparison between innovative and traditional approaches, instead demonstrating that instructional effectiveness is shaped by the interaction between design structure and learner characteristics.

These results suggest that technology-supported, student-centered learning environments can enhance mathematical communication when accompanied by adequate regulatory support. For elementary mathematics education, this implies that pedagogical innovation should be implemented alongside deliberate efforts to cultivate students' learning independence. Aligning instructional design with developmental readiness offers a more sustainable pathway for improving communicative competence in mathematics classrooms.

REFERENCES

- Amir, D., Johar, R., & Mailizar, M. (2020). Mathematical communication skills and students' self-regulated learning through flipped classroom-collaborative learning. *Jurnal Peluang*, 8(1), 11–23. <https://doi.org/10.24815/jp.v8i1.20557>.
- Albalawi, A. S. (2021). Effectiveness of the flipped classroom in elementary mathematics. *Education and Information Technologies*.
- Algarni, B., & Lortie-Forgues, H. (2023). An evaluation of the impact of flipped-classroom teaching on mathematics proficiency and self-efficacy. *British Journal of Educational Technology*, 54(1), 414–435.
- Anggo, M., & Samparadja, H. (2022). Profile of students' mathematical communication skills in flipped classroom-based blended learning. *Jurnal Pendidikan Matematika*, 13(2), 228–241. <https://doi.org/10.36709/jpm.v13i2.7>.
- Anwar, F., & Musdi, E. (2019). The effect of flipped classroom implementation on students' mathematical communication skills. *Journal of RESIDU*, 3(14), 27–35.
- Ardiana, N. (2018). The effect of the Group Investigation learning model on students' mathematical communication skills. *Journal of Education and Development*, 5(2), 33–37. <https://journal.ipts.ac.id/index.php/ED/article/view/397>.
- Ardila, A., Marzal, J., & Siburian, J. (2021). Development of trigonometry learning tools using the flipped classroom model to improve students' mathematical communication skills. *Edumatica: Jurnal Pendidikan Matematika*, 11(3), 65–77.

- Chasanah, C., & Usodo, B. (2020). Analysis of written mathematical communication skills of elementary school students. In Proceedings of the 3rd International Conference on Learning Innovation and Quality Education (ICLIQE 2019) (pp. 648–656). Atlantis Press. <https://download.atlantispress.com/article/125933514.pdf>
- Dalimunthe, Y., Dalimunthe, S. Z., & Hasibuan, I. S. (2023). Analysis of students' mathematical communication ability based on self-regulated learning. *Journal of Medives: Journal of Mathematics Education IKIP Veteran Semarang*, 7(1), 86–92.
- Drijvers, P., et al. (2023). Mathematical communication in collaborative learning environments. *ZDM—Mathematics Education*.
- Egara, F. O., et al. (2024). Effect of the flipped classroom learning approach on mathematics achievement and interest. *Education and Information Technologies*.
- Egok, A. S. (2016). Critical thinking skills, self-regulated learning, and mathematics learning outcomes. *Jurnal Pendidikan Dasar UNJ*, 7(2), 186–199.
- Elfada, F., & Prasetyo, A. (2020). Improving students' learning outcomes through the Group Investigation cooperative learning model. *Sumatra Journal of Disaster, Geography and Geography Education*, 4(1), 72–76.
- Fauziah, R. R., & Jupri, A. (2020). Analysis of elementary school students' mathematical communication and representation skills. *Journal of Physics: Conference Series*, 1521, 032080. <https://iopscience.iop.org/article/10.1088/1742-6596/1521/3/032080>.
- Hafriani, H. (2021). Developing students' basic mathematical abilities based on NCTM through structured ICT-based tasks. *Jurnal Ilmiah Didaktika*, 22(1), 63–80.
- Hendriana, H., Rohaeti, E. E., & Sumarmo, U. (2018). Students' mathematical hard skills and soft skills. Refika Aditama.
- Huynh, T. L., & Nguyen, U. N. T. (2019). Students' perceptions and design considerations of flipped interpreting classrooms. *Theory and Practice in Language Studies*, 9(9), 1100–1110. <https://doi.org/10.17507/tpls.0909.05>.
- Indriani, W. D., & Pasaribu, L. H. (2022). Improving students' mathematical communication skills through hybrid learning. *Jurnal Cendekia*, 6(1), 291–299. <https://doi.org/10.31004/cendekia.v6i1.1196>.
- Ishartono, N., et al. (2022). Integrating GeoGebra into flipped learning to improve students' self-regulated learning. *Journal on Mathematics Education*, 13(1), 69–86. <https://doi.org/10.22342/jme.v13i1.pp69-86>.
- Legesse, M., Luneta, K., & Ejigu, T. (2020). Effects of mathematical discourse-based instruction on students' learning outcomes. *Studies in Educational Evaluation*, 67, 100918.
- Liu, L., et al. (2024). Supporting self-regulated learning in flipped classrooms: A systematic review. *Computers & Education*.
- Ma, Y., et al. (2025). The effectiveness of the flipped classroom: A second-order meta-analysis. *Computers & Education*.
- Nababan, D., et al. (2023). Analysis of expository and contextual learning strategies. *Jurnal Pendidikan Sosial dan Humaniora*, 2(2), 585–590.
- Strelan, P., Osborn, A., & Palmer, E. (2020). The flipped classroom: A meta-analysis. *Educational Research Review*, 30, 100314.

Tong, D. H., et al. (2021). Mathematical communication skills in school students. *Heliyon*, 7(11), e08282.

Zimmerman, B. J. (1989). A social cognitive view of self-regulated academic learning. *Journal of Educational Psychology*, 81(3), 329–339.