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The Effect of Group Role Sharing in Collaborative Problem Solving (CPS) Learning on Cognitive Ability

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Abstract: This study aims to analyze the effectiveness of the Collaborative Problem Solving (CPS) model with group role division in improving students' conceptual understanding. The research problem focuses on CPS learning that previously did not apply role division, resulting in uneven group activities. This study uses a mixed method with an embedded experimental design, where quantitative data is the main focus through concept comprehension tests, while qualitative data in the form of observations of student activities is used to reinforce the analysis results. Quantitative data analysis was performed using statistical techniques, both descriptive and inferential, to see trends, differences, or relationships between variables, while qualitative data was analyzed through reduction, categorization, and interpretation processes. The results showed that the experimental group experienced a higher increase in cognitive ability compared to the control group. The effect size value of 0.7 indicates that the effect of CPS based on group role division is moderate. Furthermore, observations show that the group roles in the experimental class were more active and responsible than those in the control group. These findings confirm that integrating CPS with effective group role sharing improves student learning outcomes and cognitive abilities, particularly in understanding complex physics topics.

Keywords: Cognitive ability; Collaborative problem solving; Group role

Introduction

The development of the 21st century is marked by the rapid advancement of science and technology that has shifted the pattern of society's life, from an agrarian society to an industrial society and finally to a knowledge society (Junanto & Afriani, 2016). These changes have resulted in increasing demands for mastery of 21st-century skills, both in education and the world of work. Ananiadou et al. (2009) emphasized that 21st-century skills must be the main focus of education because modern society requires individuals who are adaptive, innovative, and able to collaborate in facing complex problems. In line with this, Trilling et al. (2009) added that 21st-century education requires students to have high-level thinking skills that not only encompass individual cognitive abilities but also involve collaborative abilities in solving problems. Collaboration, communication, and problem-solving skills have even been recognized as global competencies that every individual must have to be able to adapt to social dynamics and technological developments (Care et al., 2012; Voogt & Roblin, 2012). Therefore, learning must be directed at developing competencies that emphasize not only mastery of knowledge, but also skills that support students' readiness to face global challenges (Saavedra & Opfer, 2012). One approach relevant to these demands is Collaborative Problem Solving (CPS), which has been proven effective in encouraging students to work together to find solutions through discussion, critical thinking, and collective information processing (Care et al., 2016).

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Collaborative Problem Solving (CPS) is a learning model rooted in the constructivist approach, in which students are invited to engage in problem solving together by promoting discussion, argumentation, and reflection. According to Nelson (2013), Collaborative Problem Solving is a combination of two learning approaches: cooperative learning and problem-based learning (Stephen et al., 2017). Collaborative Problem Solving is a form of collaboration between two or more people who have a common goal, namely to solve a specific problem (Dillenbourg, 1999). This model not only trains cognitive aspects but also social skills, such as communication, collaboration, and decision making. Collaborative Problem Solving (CPS) is a learning model that not only emphasizes collaborative problem solving but also develops students' social and cognitive skills (Andrews-Todd & Forsyth, 2020; Fitriyani et al., 2025). Through this model, students are encouraged to discuss, exchange ideas, and find solutions together in groups, enabling them to gain a deeper understanding of concepts (Care et al., 2014).

A problem that arises in implementing Collaborative Problem Solving (CPS) in the classroom is that its implementation is generally not accompanied by a clear division of group roles. In practice, teachers often simply form groups without defining role structures, such as discussion leaders, recorders, timers, or presenters. A research report by Safitri et al. (2024) found that the division of tasks within groups was uneven, with some students being dominant while others were less active. This reduced the contribution of ideas and the effectiveness of discussions for some members. Research by Chang et al. (2018) showed that unclear roles in group work led to some students relying on friends, uneven participation, and poor learning experiences; these factors contributed to lower learning outcomes. Similar findings were also reported by Johnson et al. (2014) who found that positive interdependence only forms when each member has a clear, complementary role. This confirms that unclear role assignments can hinder students' conceptual understanding (Holper et al., 2013; Slavin, 2015). Furthermore, role assignments allow teachers to fairly evaluate each individual's contribution and encourage more objective peer assessment (Davidson et al., 2014).

The concept of physics, especially in mechanical wave material, is becoming increasingly apparent. Understanding wave concepts, such as frequency, period, propagation speed, and identification of compression and tension in longitudinal waves, requires active group work through experimental activities. As a result, the learning experience is uneven and the understanding of physics concepts becomes less profound. Hake (1998) research shows that experiment-based learning has a significant impact on improving conceptual understanding if all group members are actively involved. Similarly, Freeman et al (2014) in their meta-analysis stated that active learning, including collaborative experiments, can significantly improve science learning outcomes compared to traditional lecture methods. Therefore, the use of the CPS model without a clear division of roles within the group can reduce the effectiveness of collaboration, lower the quality of student engagement, and ultimately result in a low level of understanding of mechanical wave concepts that should be achievable through structured cooperative learning.

The CPS model, with its role-sharing within groups, is an important solution for optimizing the resolution of problems encountered in the field. The CPS learning steps in this study utilize the learning steps outlined by the CALMI (Edition, n.d.) These steps have distinct characteristics compared to other steps. However, they are designed to be aligned and consistent, and to encourage continuous quality improvement. These steps consist of four stages of collaborative problem-solving, with two essential interrelated elements: communication and sustainability. The steps of Collaborative Problem-Solving according to the CALMI are: 1) Stage 1: Identify the Problem, 2) Stage 2: Define Our Authority and Agency, 3) Stage 3: Launch Ideas and Test Assumptions, 4) Stage 4: Focus and Reflect on Effectiveness, and 5) Demonstrate Accountability and Transparency Through Communication.

Table 1. CPS Stages in Learning

Stage	Activity Student
Stage 1: Identify the Issue	Students identify and focus on several problems in the LKPD.
Stage 2: Define Our Authority and Agency	Students divide the tasks with their respective groups to solve the problems.
Stage 3: Launch Ideas and Test Assumption	Students solve the problems that have been given
Stage 4: Focus and Reflect on Effectiveness	Reflecting on the cooperation that has been carried out
Stage 5: Demonstrate Accountability and Transparency Through Communication	Each group presents the results of their respective group discussions.

The steps proposed have several weaknesses that require attention, particularly in Stage 2: Define Our Authority and Agency, which does not detail how authority or tasks are allocated to each group member.

This ambiguity can hinder the effectiveness of collaboration because unstructured role allocation can potentially lead to unequal contributions among members. In this study, to address the weaknesses in Stage 2, the researchers implemented a role-sharing strategy within the group, as implemented in the Process Oriented Guided Inquiry Learning (POGIL) model. In POGIL, each group member is assigned a clear and specific role, ensuring active involvement and individual responsibility.

The POGIL group structure serves as a medium that encourages students to exchange ideas, think critically, and collaborate to solve complex problems (Moog & Spencer, 2008; Moog et al., 2006; Simonson, 2023). According to Hanson (2013), group role allocation in POGIL consists of four tasks: (1) Manager: responsible for keeping the team focused on its task, distributing work fairly, assigning responsibilities, resolving any disputes that may arise, and ensuring that all members are actively involved and understand their respective roles. (2) Spokesperson: also actively participates and represents the views and conclusions of the majority of the team. They deliver oral reports and participate in class discussions. (3) Note-taker: responsible for recording instructions and the progress of the team's work, and, together with other members, prepares the final written report and necessary documentation. (4) Reflector: responsible for recording the strategies and problem-solving methods used by the team, assessing what went well and what needs improvement, and documenting insights gained regarding the subject matter and team and individual performance.

Based on these considerations, this study aims to: 1) Determine the increase in students' conceptual understanding using the CPS learning model in the experimental and control classes, 2) Determine the effectiveness of the CPS learning model in improving students' conceptual understanding in the control and experimental classes, 3) Determine the effect of role distribution on the effectiveness of group work in collaborative problem solving (CPS) learning.

Method

This study is classified as quasi-experimental research because it involves two groups that are not randomly selected but are still given different treatments. The research method used is mixed methods with an Embedded Experimental Design model, where the main focus is on quantitative data collection, while qualitative data serves as a complement to enrich the quantitative data analysis. In this study, there are experimental and control classes. The experimental class uses CPS learning with group task division, while the control class uses CPS learning without group role division. The research design applied is a Non-Equivalent Control Group Design, in which both the control and experimental groups are given pre-tests and post-tests. This design allows researchers to observe the effect of treatment on the variables studied while still considering the initial differences between groups.

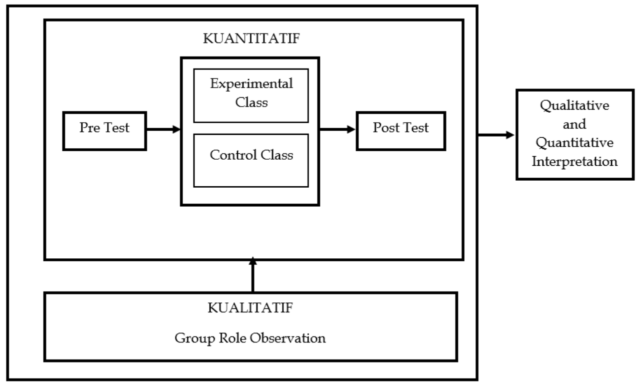

Figure 1. Mix method

The research stages were carried out systematically, starting with a literature study and problem formulation, followed by instrument development and validation, testing, revision, and implementation in the control and experimental classes through pre-tests, post-tests, and observation of learning activities. The data obtained was then processed and analyzed to produce research findings that are expected to contribute to the development of learning models. The research stages are presented in Figure 2.

This research was conducted in June 2025 at an integrated high school in Tasikmalaya. The subjects in this study were class XI students in one of the high schools who had not yet received learning about the material characteristics of mechanical waves. Sampling was carried out using purposive sampling technique, which is a sample selection technique based on certain considerations in accordance with the research objectives (Creswell & Plano Clark, 2006; Creswell & Hirose, 2019). The sample consists of two classes, namely one class as an experimental group and one class as a control group.

The instruments used in this study were 18 multiple choice tests, which were designed to measure students' cognitive increases on mechanical wave characteristics material. This research instrument has gone through a process of validation of contents by three experts and tested to 41 students who have studied related material, to ensure their validity and reliability. Based on the results of validity analysis using Aiken's V of the three validators, all 20 items are declared valid. However, based on data processing using Rasch Models through MNSQ, ZSTD, and PT Measure Corr analysis, only 18 of

20 items meets the eligibility and can be used in research, while other 2 items are declared inappropriate and must be eliminated. The results of the reliability test with the Rasch Model approach showed that the personal value of reliability was 0.66 was included in the low category, while the reliability item reached 0.90 which was classified as very high. In addition, the Cronbach's Alpha value of 0.71 shows that this instrument has a good internal consistency and is suitable for use for research purposes.

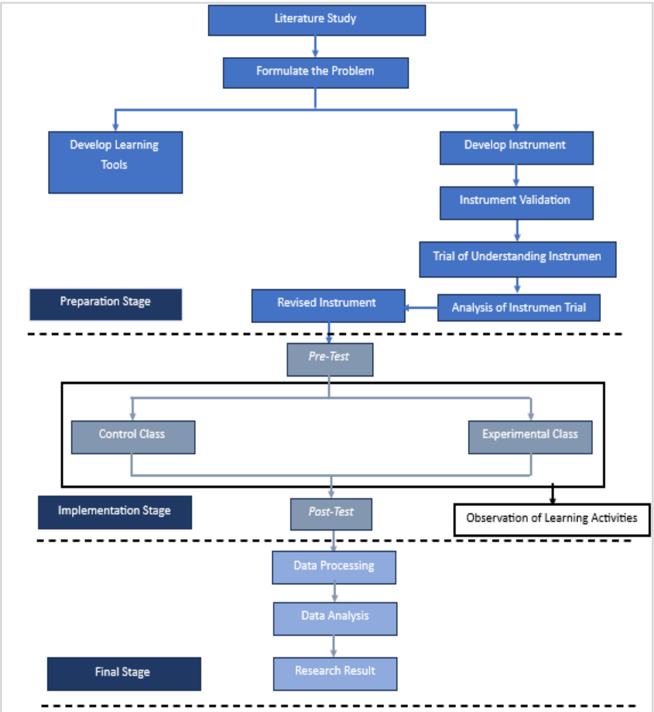

Figure 2. Research stages

Data analysis in this study involved quantitative data analyzed using statistical techniques, both descriptive and inferential, to identify trends, differences, or relationships between variables. Meanwhile, qualitative data was analyzed through a process of reduction, categorization, and interpretation.

The multiple choice test used in this study is to measure cognitive abilities. The cognitive abilities observed consisted of Undesrtand (C2), Apply (C3), Analyze (C4), and Evaluate (C5). Cognitive ability to understand (C2) is in the question number 1,2,3,4,5,15, and 16. Cognitive ability to apply (C3) is in the number 6,7,8, and 18.

In addition, to measure an increase in student learning outcomes, normalized gain analysis (N-Gain) is used with a formula developed by Hake (1998) as follows:

$$< g >= \frac{(<Pos\ test>-<Pre\ test>)}{(<SMID>-<Pre\ test>)} \tag{1}$$

Information:
$< pos\ test >$ = Score post-test
$< Pre\ test >$ = Score pre-test
$< SMID >$= Ideal maximum score – pretest

Table 2. Interpretation of Normalized Gain Score

N-Gain Value	Interprets
$N_{gain} \geq 0.7$	High
$0.7 > N_{gain} \geq 0.3$	Medium
$0.3 < N_{gain}$	Low

To find out whether there is a statistically significant difference between student learning outcomes in the experimental group and the control group, the Mann-Whitney U test is used with the help of SPSS version 27 software. Before using the Mann-Whitney U test, the data is first in the normality and homogeneity test with SPSS software version 27.

To measure how much influence an independent variable on the dependent variable, can be done by calculating the effect size by using the following formula (Maher et al., 2013):

$$d = \frac{\overline{x_t}-\overline{x_c}}{s_{pooled}} \tag{2}$$

Information:
d= Cohen's effect size
$\overline{x}_t$= The average value of the experimental class n-gain
$\overline{x}_c$= The average value of the control class n-gain
S_{pooled} = Pooled standard deviation

The pooled standard deviation if the sample size is the same is calculated using the following formula (Maher et al., 2013):

$$S_{pooled} = \sqrt{\frac{s_t{}^2+s_c^2}{2}} \tag{3}$$

The pooled standard deviation (S_pooled) if the sample sizes are different is calculated using the following formula (Maher et al., 2013):

$$S_{pooled} = \sqrt{\frac{(n_t-1)s_t{}^2+(n_c-1)s_c^2}{n_t+n_c-2}} \tag{4}$$

Information:
n_t=Number of experimental class students
n_c= Number of control class students
s_t= Standard deviation of N-gain of experimental class
s_c=Standard deviation of N-gain of control class

The following table presents the category of interpretation of the Cohen's d value (Cohen, 2013):

Table 3. Effect Size Interpretation

Effect Size	Interpretation
$d < 0.2$	Very Small
$0.2 \leq d < 0.5$	Small
$0.5 \leq d < 0.8$	Medium
$0.8 \leq d < 1.0$	Big
$d \geq 1.0$	Very Big

Result and Discussion

Improvement of Conceptual Understanding

The results of the analysis of the increase in students' conceptual understanding in the control class and the experimental class can be seen in Table 4. This table presents a comparison of the average pretest and posttest scores, as well as the N-gain calculations for both classes. These data are used to determine the extent of improvement in the learning model applied in the experimental class compared to the control class.

Table 4. N-gain of Control and Experimental Class

	Control Class	Experimental Class
N-gain	0.36	0.46
Pretest average	59.6	60.6
Postest average	75	80.2

Based on the results of the average and N-gain calculations, it can be seen that both the control and experimental classes experienced an increase in learning outcomes after the learning took place. The average pretest score in the control class was 59.6, while the experimental class was 60.6, which showed that the initial ability of students from both groups was relatively equal. After the treatment was given, the average posttest score of the experimental class increased to 80.2, while the control class to 75. This increase was also reflected in the N-gain value, where the experimental class obtained a score of 0.46 and the control class of 0.36. According to Hake's classification (1998), both values are included in the medium improvement category, but the experimental class showed a higher improvement. Thus, it can be concluded that the learning model applied to the experimental class is more effective in improving student learning outcomes compared to the learning model in the control class.

An analysis of the improvement in student learning outcomes based on cognitive levels is presented in Table 5. This table shows a comparison of N-gain values, effect sizes, and Mann-Whitney test results at each cognitive level (C2–C5) between the control class and the experimental class. These data provide an overview of the effectiveness of the learning methods applied, particularly in improving student abilities in each cognitive aspect measured.

Table 5. shows the results of comparison of the increase in learning outcomes (N-Gain) between the control class and the experimental class at each C2 to C5 cognitive level, along with the Mann-Whitney statistical test results and the size effect. In general, it appears that the experimental class has a higher N-Gain at all cognitive levels than the control class. At level C2, the experimental class obtained an N-Gain of 0.48, while the control class was only 0.29. This increase also appears at the level of C3, C4, and C5. Although at the level C4 and C5 the difference is not large, the size of the size still shows a stronger effect on the experimental class.

Table 5. Analysis of Improvement in Learning Outcomes for Each Cognitive Level

Statistical Test	Control Class				Experimental Class			
	C2	C3	C4	C5	C2	C3	C4	C5
N-Gain	.29	.10	.34	.38	.48	.41	0.34	.39
Effect Size	.31	.32	.48	.50	.87	.34	.50	.79
Mann-Whitney test	.115	.189	<,001	.002	0.04	<.001	.002	<.001

The Mann-Whitney test results strengthen these findings, where the significance value (Ashmp. SIG.) <0.05 at almost all levels, except C2 and C3 in the control class which shows the value of P> 0.05 (p = 0.115 and 0.189). This shows that N-Gain differences at these cognitive levels are significantly statistically for most categories, especially at the C4 and C5 levels that show a very significant difference both in the control class and experimental (p <0.001 and p = 0.002).

Thus, it can be concluded that the learning model applied to the experimental class has a stronger and significant impact in improving student learning outcomes at various cognitive levels, especially at middle to high levels (C2 and C5). This reflects the advantage of intervention in forming the ability to think conceptual, analytical, and evaluative students more optimally than the control class.

Effectiveness of Learning Models

A normality test was conducted to determine whether the learning outcome data in the control class and experimental class were normally distributed or not. The results of the normality test are presented in Table 6, which shows the significance (Sig.) values of the pretest and posttest for both classes along with their interpretations. This data became the basis for determining the appropriate type of statistical test for further analysis.

Table 6. Normality Test of Control and Experimental Classes

Learning Outcomes	Class	Sig.	Description
Pretest	Control	.058	Normal
Posttest	Control	.572	Normal
Pretest	Experimental	.022	Not Normal
Posttest	Experimental	.010	Not Normal

The normality test results presented in Table 6, it is known that the learning outcome data in the control class, both pretest and posttest, are normally distributed with significance values of 0.058 and 0.572, respectively, which are greater than the significance level of 0.05. Conversely, in the experimental class, the pretest and posttest data showed significance values of 0.022 and 0.010, respectively, which are smaller than 0.05, so it can be concluded that the data are not normally distributed. These results indicate that further data analysis needs to consider the use of non-parametric statistical tests because the data do not meet the assumption of normality, especially in the experimental class.

A homogeneity test was conducted to determine the similarity of variance between the control class and the experimental class. The homogeneity test results shown in Table 6 indicate the significance value (Sig.) for the pretest and posttest data along with their descriptions. This data was used a basis for determining the feasibility of applying parametric and non-parametric statistical tests in the next stage of analysis.

Table 7. Recapitulation of Homogeneity Test Results

Value	Sig.	Description
Pretest	.017	Not Homogeny
Posttest	.382	Homogeny

Based on the results of the homogeneity test presented in Table 6, it was found that the pretest data had a significance value of 0.017, which was smaller than 0.05, so it could be concluded that the data was not homogeneous. This indicated that at the initial stage, there was a difference in the variance of student abilities between the control class and the experimental class. Meanwhile, the posttest data obtained a significance value of 0.382, which is greater than 0.05, so it can be concluded that the data is homogeneously distributed. Thus, after the treatment was given, the learning outcomes of students in both classes had uniform variance, so that comparisons between the control and experimental classes could be made more objectively.

Tables 6 and 7, it shows that the data meets the assumptions to be tested with Mann-Whitney. The Mann-Whitney test was used to determine the significant difference between student learning outcomes in the experimental and control groups after treatment. The Mann-Whitney results are presented in Table 8.

Table 8. Mann-Whitney Test Results

Test Statistics	Value
Mann - Whitney U	165.500
Z	-2.236
.Sig	0.025

Table 8. it can be seen that the sig value. (2-tailed) of 0.001 <0.05, which indicates a significant difference between the experimental and control groups. This means that the Collaborative Problem Solving learning model with group role sharing significantly affects the increase in students' concept knowledge.

Effect size tests were conducted to determine the extent to which the treatment in the experimental class influenced students' cognitive abilities compared to the control class. The effect size calculation results are shown in Table 9, which includes the mean (M), standard deviation (SD), pooled standard deviation (SDpooled), and Cohen's d value and its category. This data provides an overview of the strength of the influence of the learning model applied.

Table 9. Effect Size Test Results of Cognitive Ability Data

Class	M	SD	SDpooled	D	Category
Experiment	80.2	8.8	7.22	0.7	Medium
Control	75	5.2			

Table 9 is shown that the effect value between the control group and the experimental group is 0.7 which is included in the medium category. Effect size values that are classified as showing that the intervention or treatment given in the learning process has a significant influence on student learning outcomes. In the context of this study, the Effect Size is reflecting that the learning model applied has succeeded in having a practical significant impact, although it has not yet reached a very strong level of influence. This moderate influence indicates that most students who participate in CPS learning with the division of groups have increased learning outcomes better compared to students who receive learning with CPS learning with the issuance of the division of group roles.

The Effect of Role Distribution on Group Work Effectiveness

Observations during the learning process, it appears that the division of roles in the group has a positive impact on the dynamics of student cooperation. When roles such as group leaders, recorders, spokespersons, and observers are clearly divided from the beginning, each student shows a more active and responsible involvement in their respective tasks. The teacher notes that students who act as group leaders are more alert in managing the course of discussions and maintaining the focus of group members to remain on learning objectives. Meanwhile, the recorder tends to be more thorough in recording ideas that arise, and a spokesman is able to convey the results of group discussions with confidence. This division of roles also minimizes the dominance of certain students and encourages student participation that is usually passive. In addition, interactions between members become more directed and constructive, because every student feels that he has an important contribution. From this observation, the teacher concludes that the planned role structure can create a more collaborative learning atmosphere, improve communication between students, and support the development of social skills and individual responsibilities in group learning.

Learning based on Collaborative Problem Solving (CPS), the division of group roles played an important role in increasing the effectiveness of students' cooperation and cognitive achievements. A clear division of roles in groups can improve coordination, strengthen individual responsibilities, as well as clarify the contribution of each member to the problem solving encountered. Thedivision of roles such as facilitators, recordings, spokespersons, and critics allows the occurrence of more structured and productive social interaction. Studies by Rummel et al. (2005) show that explicit role structures in collaborative groups can direct students to focus more on learning objectives, increase active involvement, and reduce unproductive conflicts in discussions. Furthermore, Hmelo-Silver et al. (2008) that when each group member has a complementary role, the process of negotiating meaning and exchange of ideas becomes more intensive and meaningful. This is in line with the findings of PISA (OECD, 2017), which states that the competency of collaborative problem solving develops better in an environment that supports the distribution of responsibilities fairly. Without a systematic division of roles, collaboration tends to be unbalanced, where some members become dominant while others are passive (Barron, 2003). This participation inequality can hamper the development of social and cognitive skills which are the main objectives in CPS learning. Thus, the integration of the division of roles in CPS learning design not only increases the effectiveness of group work, but also supports the development of critical thinking skills, communication, and social responsibility of students. The division of roles into a structural element that guarantees meaningful interaction in groups, as well as a foundation to build a reflective collaborative culture and is oriented towards solving problems collectively

Conclusion

This study concludes that the application of the Collaborative Problem Solving (CPS) model with group role division is effective in improving students' conceptual understanding and cognitive abilities. This is demonstrated by the higher N-gain of the experimental class compared to the control class, as well as the effect size which shows a moderate effect. In addition, students in the experimental class were more active, responsible, and demonstrated more effective group cooperation than the control class. Through structured role division, physics learning can be more effective because each group member has specific, complementary focuses and responsibilities. For further research, more detailed observation and analysis of interactions within groups is needed to identify the most effective communication and coordination strategies for improving cooperation and solution quality.

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Conceptualization, Firda Fikri Andini, Winny Liliawati, Mimin Iryanti; Data curation, Firda Fikri Andini; Formal analysis, Firda Fikri Andini; Investigation, Firda Fikri Andini; Writing-original draft, Firda Fikri Andini; Writing-review & editing, Firda Fikri Andini, Winny Liliawati, Mimin Iryanti.

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The authors declare no conflict of interest in this research.

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