

Mathematical Thinking and Self-Concepts of Elementary School Students in Geometry Through 4C-Based Problem-Based Learning

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ABSTRACT:

. This study aims to analyze the effectiveness of 21st-century skills-based Problem-Based Learning (4C: critical thinking, creativity, collaboration, and communication) in developing mathematical thinking and mathematics self-concept in elementary school students on flat shape material. The method used is research design which includes three stages: preparing for the experiment, designing the experiment (pilot and teaching experiment), and retrospective analysis. The research was conducted in three different school contexts, namely MIN 1 Bireuen, SDN 3, and SDIT Peusangan, involving an experimental class that received 4C-based PBL and a control class that received PBL learning without 4C. Data were collected through observation, interviews, video recordings, mathematical thinking tests, and self-concept questionnaires, then analyzed qualitatively and descriptively quantitatively. The results showed that 4C-based PBL had a consistent positive impact on both variables. The most significant improvement occurred in representation, pattern identification, generalization, and mathematical argumentation skills, especially in schools with strong classroom management and a culture of discussion (SDIT Peusangan). Students' mathematics self-concept also improved through collaborative experiences, role sharing, and class discussions that enabled students to gain mastery experiences. A comparison between Prototype 1 and Prototype 2 shows that the use of concrete media and more structured scaffolding significantly improves the effectiveness of the learning pathway. Cross-school synthesis confirms that the success of 4C-based PBL is influenced by student readiness, the quality of teacher scaffolding, and a collaborative classroom culture. These findings reinforce the position of 4C-based PBL as a holistic and relevant approach in developing the mathematical and affective competencies of elementary school students.

Keywords: Problem-Based Learning, 4C, mathematical thinking, mathematics self-concept, design research.

1. Introduction

Indonesia was the country that located in the Southeast Asia with the fourth largest population in the world. The low level of mathematical thinking among elementary school students has not been fully addressed in elementary school mathematics teaching. Various studies show that students often experience difficulties in developing higher order thinking skills such as logical reasoning, problem solving, mathematical representation, and generalization, especially in geometry (Alim, Sutarto, & Cahyadi, 2024). This limitation is exacerbated by a learning approach that is not challenging and minimizes student involvement.

Learning cannot guide students to be creative and only relies on procedural exercises without providing space for concept exploration or in-depth mathematical dialogue (Widiastuti, Budayasa, & Lukito, 2021). As a result, students memorize formulas rather than understand concepts and have difficulty relating mathematical knowledge to real-life contexts. This low level of mathematical thinking not only hinders cognitive achievement but also affects students' affective aspects, such as motivation and confidence in learning mathematics. This condition emphasizes the urgency of implementing innovative learning models that can stimulate higher order thinking skills from an early age, using approaches that are in line with the developments of the 21st century.

Mathematical thinking ability is thought to affect the mathematical self-concept of fourth-grade elementary school students, which is how students view their abilities in mathematics. According to Marsh (2020), academic self-concept, including in mathematics, has a strong positive correlation with learning achievement. As shown by the results of Sujadi's (2021) research, most elementary school students have a low self-concept in mathematics, resulting in a lack of motivation, confidence, and resilience in facing challenges when solving mathematical

problems. This is a major obstacle in the development of higher mathematical thinking skills.

Mathematics learning in Indonesia has not been optimal even though it uses methods/models and student learning oriented towards procedural memorization, so it has not been able to optimally foster students' mathematical thinking skills. This is due to a lack of innovation by teachers in designing contextual and meaningful learning (Fitriani, 2021; Mardiyana & Mulyana, 2022). In fact, mathematics learning designed with an approach that encourages 4C skills has been proven to improve students' mathematical thinking in understanding concepts and solving problems logically (Nuraini & Jailani, 2020).

Therefore, a paradigm shift in learning from teacher-centered to student-centered through innovative 4C-based learning models is essential to address the challenges of mathematics education in the era of the 4.0 industrial revolution (Suryanto et al., 2023). The development of 21st-century skills known as 4C—Critical Thinking, Communication, Collaboration, and Creativity—is an essential requirement in basic education, especially in mathematics learning. These skills encourage students to think critically, creatively, and collaboratively in solving problems and to be able to communicate their mathematical ideas clearly.

2. Materials and methods

The type of research used was design research, which aimed to develop local instruction theory through collaboration between researchers and teachers in improving the quality of mathematics learning. This method was chosen to analyse the characteristics of students' mathematics thinking and mathematical self-concept through 4C-based PBL learning, as well as to determine the effectiveness of the designed learning pathway. Design research consisted of three main stages, namely preparing for the experiment, designing the experiment, and retrospective analysis. Data

collection was carried out through documentation, interviews, observation, mathematics thinking tests, and mathematical self-concept questionnaires. Qualitative data were analysed descriptively, while quantitative data were analyzed using simple statistical techniques.

2.1. Research Variable

This study uses two main types of variables. The independent variable is the 4C-based Problem Based Learning (PBL) model, which emphasizes problem solving through critical thinking, creativity, communication, and collaboration skills. The dependent variables in this study include students' mathematics thinking skills and mathematical self-concept after receiving treatment. Mathematical thinking ability was measured using tests on geometry material, while mathematical self-concept was measured using a questionnaire that described students' perceptions of their mathematical competence.

The research design used an experimental design with a nonequivalent pretest–posttest control group design. Two groups of students were involved, namely the experimental group that received 4C-based PBL learning and the control group that received PBL learning without 4C. Both groups were given a pretest to measure their initial mathematics thinking ability and mathematical self-concept, then given different treatments, and finally given a posttest to see the changes and characteristics of student learning.

This design was used to compare the effectiveness of the 4C-based PBL model in improving mathematical abilities compared to PBL learning without 4C. This study was conducted in the even semester of the 2023/2024 academic year in several public elementary schools, private elementary schools, and Islamic elementary schools that had parallel classes in Bireuen Regency, Aceh.

2.2. Research Procedure

Preparing for the Experiment, this stage begins with the development of a Hypothetical Learning Trajectory (HLT) that contains predictions of students' thinking development during the

learning process. Researchers conducted a literature review on geometry material, learning outcomes, and school curriculum. In addition, researchers discussed with teachers about student conditions, reviewed teaching materials, and developed an HLT prototype.

The prototype is then revised based on teacher input and tested on a small group to obtain information about its feasibility before being used on a large group. At this stage, observations of the students' initial conditions and classroom culture are also carried out to ensure readiness for learning. Design Experiment, this stage includes two forms of testing, namely a pilot experiment and a teaching experiment.

The pilot experiment was conducted to obtain an initial picture of students' responses to the learning design, so that researchers could improve the HLT before applying it in the teaching experiment. The teaching experiment involved testing small and large groups to collect data on students' learning trajectories in depth. The entire learning process was recorded on video, and several students were interviewed to confirm the data so that it could support the development of Local Instructional Theory.

Retrospective analysis research procedure. This stage involves a comprehensive analysis of all data obtained during the design experiment. The researcher compares classroom learning implementation with the HLT that has been developed to evaluate the effectiveness of the design. The analysis is conducted through observation of video recordings, student work, field notes, and interviews. The main objectives are to assess the success of the learning process, identify the development of students' mathematical abilities, and formulate recommendations for further research.

2.3. Analysis Methods

There are two methods of qualitative data analysis. Data analysis is carried out by following the steps outlined by Miles and Huberman, namely data reduction, data presentation, and drawing conclusions. In the reduction stage, researchers filter important data from observations, interviews, video recordings, and

test results. Next, the reduced data is presented in narrative form to facilitate the identification of patterns and relationships between findings. The final stage is drawing conclusions, which is a synthesis of all the data that has been analyzed to answer the research questions and describe the implementation of the 4C-based PBL model in geometry learning. This was done during the testing of the Hypothetical Learning Trajectory Prototype 1 and Prototype 2 teaching materials in the fourth-grade class at MIN 1 Bireuen. Meanwhile, for the data on the results of the treatment of the two other schools, namely SDN 3 and SDIT Peusanagan, descriptive statistical analysis was carried out for both Mathematical Thinking and self-concept to compare the experimental class with the control class in each school.

3. Result

The results presented in this section are derived from the implementation and evaluation of the Hypothetical Learning Trajectory (HLT) Prototype 1 and Prototype 2 teaching materials in the fourth-grade class at MIN 1 Bireuen. The analysis also incorporates data obtained from the implementation of the intervention in two additional schools, SDN 3 and SDIT Peusanagan. In these schools, descriptive statistical analyses were conducted on students' mathematical thinking skills and mathematics self-concept to compare the performance of the experimental and control classes within each institution. Collectively, these analyses provide an empirical basis for examining the effectiveness of the revised 4C-based PBL model across different school contexts.

3.1. Hypothetical Learning Trajectory in MIN 1 Bireuen

The implementation of the Hypothetical Learning Trajectory (HLT) in MIN 1 Bireuen was

conducted in the fourth-grade class through two stages of teaching material trials, namely Prototype 1 and Prototype 2. This implementation aimed to examine the alignment between the designed learning trajectory and students' actual learning processes in geometry. During the trials, students engaged in a sequence of 4C-based Problem-Based Learning activities that had been systematically structured to support the development of mathematical thinking and self-concept. The findings from these trials provided empirical evidence for refining the learning design and evaluating the practicality and effectiveness of the proposed instructional trajectory.

3.1.1. Objective Result of Prototype 1

Observations of the implementation of Prototype 1 revealed three important findings. First, learning media in the form of objects from the school environment had contextual value but did not fully support classroom order. Students' activities of searching for geometric objects caused intense movement and disrupted their focus on learning. Second, some students still had misconceptions, particularly in distinguishing between squares and rectangles and in determining area and perimeter. Students often measured sides without understanding the relationship between side lengths or the rules for using formulas. Third, the 4C aspects were not optimally developed; critical thinking emerged when students compared shapes, but creativity, collaboration, and communication were not evenly distributed. Class discussions are dominated by certain students, indicating that a culture of discussion has not yet been strongly established. These findings indicate the need for design improvements to make learning more organized, interactive, and supportive of equitable mathematical thinking experiences.

Table 1. Descriptive Statistics for Mathematical Thinking at MIN 1 Bireuen

DESCRIPTION	EXPERIMENT	
	<i>PRE-TEST</i>	<i>POST-TEST</i>
Mean	40,571	45,71
Standard Deviation	19,361	23,64
Minimum	5	0
Maximum	85	75
N	21	

The average score of students is in the moderate category, but the large spread of scores, as indicated by the high standard deviation, illustrates the disparity in abilities among students in the class. The wide range of scores, from 0 to 75, shows that some students have not yet mastered basic mathematical thinking skills, while others have achieved relatively high scores. This wide variation is important to note because it indicates the need for more adaptive and differentiated learning strategies in order to meet the learning needs of students with heterogeneous abilities.

Development of Self-Concept. The aspect of self-concept was also an important focus in this pilot experiment. Findings in the field showed a striking difference between high-ability and low-ability students. Students with a strong understanding tended to be more confident, active in answering questions, and did not hesitate to express their ideas during discussions. Conversely, students with lower academic

abilities tended to be passive, waiting for instructions, and reluctant to participate actively. However, when teachers provided positive encouragement, appreciation, and emotional support, some students who were initially passive began to show the courage to express their opinions, even if only in the form of simple answers. This shows that a supportive classroom climate plays an important role in building students' confidence, which in turn can increase their active participation in the learning process.

Based on the results of a pilot test conducted on 21 students in class MIN 1 Bireuen, it was found that the students' mathematical self-concept was in the moderate to high category. The overall average score was 51.048 with a standard deviation of 4.353, and a score range of 39 to 56.

Self-concept ability, each self-concept item uses a 1–4 Likert scale, so the average score per indicator can be expressed in the range of 1.00–4.00.

Table 2. Descriptive statistics of the self-concept of fourth-grade students at MIN 1 Bireuen conducted in the first pilot experiment

DESCRIPTION	FIRST CLASS EXPERIMENT
Mean	51,048
Standard Deviation	4,353
Minimum	39
Maximum	56
N	21

Using a 1–4 Likert scale, the average score for each indicator shows a positive trend. The Confidence in Mathematics indicator scored 3.20, which is in the “fair” category, indicating that students have confidence in their mathematical abilities, although some still need reinforcement in problem solving and the courage to perform. The Effort & Perseverance indicator scored 3.35 (category “high”), indicating students' persistence and perseverance in understanding mathematical concepts. The Attitude toward Mathematics indicator scored an average of 3.30 (category “high”), reflecting students' positive attitude toward mathematics as

an important and interesting subject. The Independence in Learning indicator scored 3.15 (category “adequate”), indicating that although students have sufficient independence in learning, they still need guidance to optimize their independent learning abilities. Finally, the Social Interaction & Responsibility indicator scored 3.25 (category “high”), describing students' ability to collaborate, interact positively, and demonstrate responsibility during learning. Overall, these findings indicate that students' mathematical self-concept has developed well and can serve as a strong foundation for continuing the experiment to the next stage.

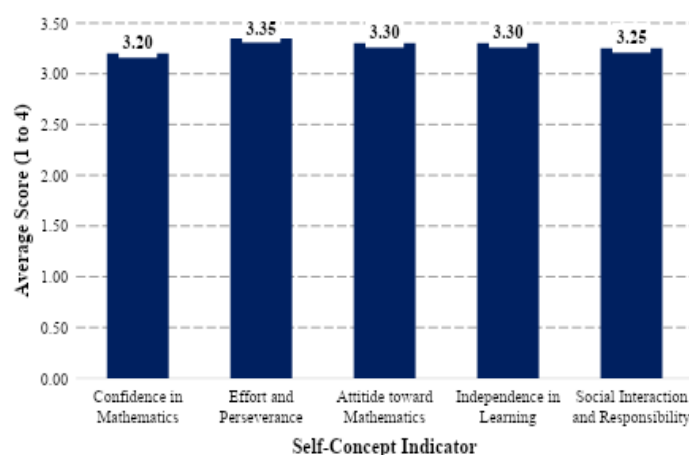


Figure 1. Graph of Self-Concept Indicator Score

Reflection: The results of the pilot experiment on HLT Prototype 1 provide important initial insights into the direction of learning path development. The findings show that the initial design has integrated the potential of 4C Critical Thinking, Creativity, Communication, and Collaboration-based Problem Based Learning (PBL), but its implementation has not been fully effective in developing mathematical thinking or forming positive self-concepts in students. Several obstacles were identified, including the use of learning media that was not focused enough to draw students' attention to flat shape concepts, the presentation of problems that were not challenging enough to encourage high-level mathematical reasoning, and teacher facilitation strategies that still needed strengthening to stimulate discussion and independent collaboration among students. In addition, the level of difficulty of the questions on the post-

test tended to be too high, which was not in line with the learning experience provided. These findings form an important basis for revising the learning pathway design in the next stage of development.

3.1.2. Objective Result of Prototype 2

Based on the evaluation results of Prototype 1, a comprehensive revision was carried out, resulting in HLT Prototype 2. The main improvements included the use of concrete media in the form of flat shapes prepared by the teacher, so that exploration was more controlled and focused. The revision also included the addition of scaffolding through demonstrations of the use of measuring tools, examples of side measurements, and sparking questions that encouraged students to think critically when distinguishing the properties of flat shapes. The group work structure was improved with a clear distribution

of roles, so that each member participated actively. In the problem application stage, the teacher added a transition from simple problems to more complex contextual problems, so that the concepts of area and perimeter were understood gradually. These revisions made Prototype 2 more stable in terms of classroom management and richer in terms of mathematical thinking experience.

The implementation of Prototype 2 resulted in significant improvements compared to Prototype 1. The classroom atmosphere became more orderly because students worked with concrete media at their respective desks, so that exploration no longer disrupted the learning process. Students were able to identify shapes, measure sides more accurately with measuring

tools, and communicate measurement results verbally and in writing. During discussions, students appeared more confident in expressing their ideas, and interactions among group members were more balanced. The 4C skills developed noticeably:

- Critical thinking was evident when students compared measurement strategies or distinguished between area and perimeter.
- Creativity emerged when students attempted to create their own representations of flat shapes to validate their measurement results.
- Collaboration increased through clear division of group tasks.
- Communication was evident in presentations where more students contributed.

Table 3. Descriptive Statistics for Mathematical Thinking at MIN 1 Bireuen

DESCRIPTION	CLASS EXPERIMENT	
	<i>POST-TEST OF THE FIRST EXPERIMENTAL</i>	<i>POST-TEST OF THE SECOND EXPERIMENTAL</i>
Mean	45,71	64,762
Standard Deviation	23,64	30,822
Minimum	0	0
Maximum	75	95
N	21	

In addition, students' self-concept also improved, as shown by their increased courage to ask questions and willingness to express their opinions in discussions.

Based on the pretest and posttest results, there was a significant difference between the results of the first pilot experiment, which used 4C-based Problem Based Learning. In the experimental class, there was an increase in the average score from 45.71 in the first pilot experiment to 64.762 in the second pilot experiment posttest. This difference indicates that the application of 4C-based PBL has a greater impact on the development of students' mathematical thinking.

In addition, the higher standard deviation in the experimental class shows that the diversity of students' abilities is increasingly explored through critical, creative, collaborative, and communicative thinking activities. These findings are reinforced by observations of the learning process, in which students in the experimental class showed development in analytical thinking, creativity in representing flat shapes, more balanced collaboration, and more confident and structured mathematical communication. Thus, the integration of 4C in the PBL model proved to be more effective in improving students' mathematical thinking competencies.

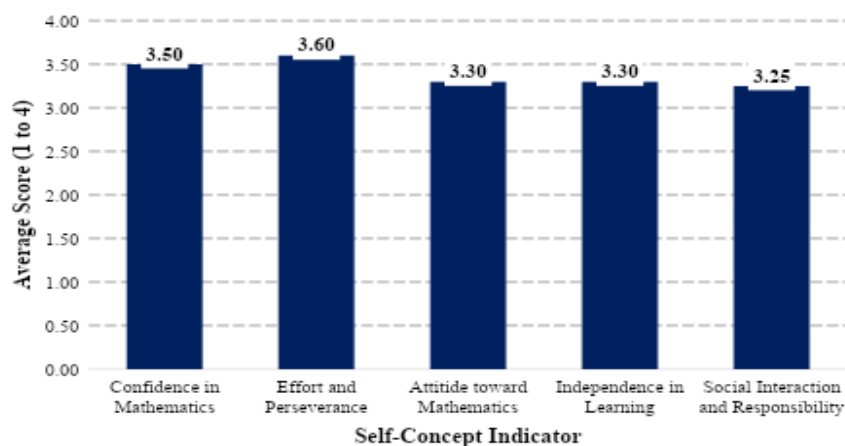
Table 4. Descriptive Statistics for Self-Concept at MIN 1 Bireuen

DESCRIPTION	THE SECOND-CLASS EXPERIMENT
Mean	52,190
Standard Deviation	3,983
Minimum	44
Maximum	59
N	21

The mean self-concept score in the second experimental pilot was 52.190, higher than the self-concept ability of the first experimental pilot, which was 51.048. This indicates that the application of the 4C-based PBL model has a positive contribution to changes in students' self-concept. This difference also shows that students in the experimental pilot class tend to have a more positive self-perception in the geometry learning process on flat shapes. The standard deviation value in the experimental pilot class was 3.983. This means that the distribution of

students' mathematics self-concept scores in both groups was quite homogeneous. In general, the descriptive results show that the use of the 4C-based PBL model provides a higher average mathematics self-concept.

Self-concept ability, mapping of self-concept indicators in accordance with the "Mathematics Self-Concept" questionnaire based on 30 items. This mapping groups the statement items into five main indicators along with their descriptions.

**Figure 2. Graph of Self-Concept Indicator Score for the Second Experiment**

Mapping of mathematics self-concept indicators based on 30 questionnaire items shows a conceptual structure consisting of five main dimensions that reflect students' perceptions of themselves in the context of mathematics learning. The Confidence in Mathematics indicator has an average of 3.50. This describes students' confidence in their ability to understand concepts and appear confident in learning to

solve mathematical problems. Furthermore, the Effort & Perseverance indicator averaged 3.60, reflecting students' diligence, tenacity, and active efforts to continue learning, practicing, and not giving up easily when facing difficulties in mathematics. The Attitude toward Mathematics indicator averaged 3.30, describing students' positive or negative attitudes toward mathematics, including their interest and comfort

level in learning. The Independence in Learning indicator averaged 3.30, showing students' ability to learn independently and take initiative in completing tasks. Finally, the average Social Interaction & Responsibility indicator of 3.25 shows an assessment of students' social interaction, cooperation, and responsibility in mathematics learning activities. Overall, this mapping provides a comprehensive picture of students' mathematical self-concept profiles, which can be used as a basis for further analysis in developing learning strategies.

3.1.3. Comparison of Prototype 1 and Prototype 2

A systematic comparison between the two prototypes shows that design changes have a direct impact on learning quality. In Prototype 1, learning was exploratory but lacked structure, resulting in suboptimal student performance in observation and measurement. In Prototype 2, the use of concrete media and reinforced scaffolding made learning more focused and facilitated gradual concept development. From a 4C perspective, there was a significant improvement, especially in the areas of collaboration and communication. Prototype 1 showed the dominance of active students, while Prototype 2 succeeded in creating a more democratic division of roles. In terms of mathematical thinking, Prototype 2 facilitated a deeper understanding of area and perimeter through tiered examples that minimized misconceptions. Thus, Prototype 2 is not only an administrative revision but also a substantive improvement that significantly increases the effectiveness of the learning path.

3.1.4. Implications of the result

The results of this study provide three important implications for the development of local instructional theory. First, learning success is greatly influenced by the suitability of media and activity structures to the cognitive characteristics of elementary school students. Concrete media proved to be more effective than free exploration

with objects found in the school environment. Second, the integration of 4C-based PBL not only improves cognitive abilities but also strengthens mathematical self-concept through experiences of success and social interaction. Third, mathematics learning designs based on HLT must consider the gradual development of concepts, starting from concrete representations to generalization. With these findings, HLT Prototype 2 can be considered a stronger, more sustainable, and replicable local instructional theory for the context of geometry learning in elementary schools.

3.2. Statistical Analyses in SDN 3 Peusangan

Following the pilot implementation conducted in the fourth-grade class at MIN 1 Bireuen, which indicated improvements in students' mathematical thinking and mathematics self-concept, a teaching experiment was subsequently carried out at SDN 3 Peusangan. This implementation aimed to examine the effectiveness of the revised 4C-based PBL model in a different school context. The study involved both experimental and control classes in order to analyse differences in students' mathematical thinking and self-concept after the intervention.

3.2.1. Result of Mathematical Thinking Concept

The average pretest score in the experimental class was 47.89, which only increased to 49.04 in the post-test. Although there were students who achieved high scores of up to 95, most of the others remained at a low level of ability, as indicated by the minimum score remaining at 0. The standard deviation increased sharply from 27.03 to 40.57, indicating an increase in the disparity in learning outcomes between students. Meanwhile, the control class had an average pretest score of 29.464, which increased to 50.714 on the posttest, with a standard deviation from 18.824 to 24.597. The lowest score was 0, while the highest was 75.

Table 5. Descriptive Statistics for Mathematical Thinking in SD N 3 Peusangan

DESCRIPTION	CLASS EXPERIMENT		CLASS CONTROL	
	<i>PRE-TEST</i>	<i>POST-TEST</i>	<i>PRE-TEST</i>	<i>POST-TEST</i>
Mean	47,885	49,038	29,464	50,714
Standard Deviation	27,025	40,571	18,824	24,597
Minimum	0	0	0	0
Maximum	80	95	80	75
N	26		28	

Observations of the experimental class showed that students often tried to solve problems in creative ways, for example, cutting a square piece of paper into two parts to prove the area equation, but not all students were able to reflect their findings into systematic mathematical arguments. This phenomenon indicates that 4C-based PBL can trigger students' creativity and

investigative activities, but it does not yet fully facilitate the equalisation of analytical abilities.

3.2.2. Result of Mathematical Self Concept

The research instrument, in the form of a mathematics self-concept questionnaire, consisted of 30 statements given to students.

Table 6. Descriptive Statistics for Mathematical Thinking in SD N 3 Peusangan

DESCRIPTION	CLASS EXPERIMENT	CLASS CONTROL
Mean	53,292	48,458
Standard Deviation	3,342	6,331
Minimum	47	33
Maximum	59	60
N	26	28

Based on the results of descriptive data analysis of the self-concept of fourth-grade elementary school students on flat shapes at SD Negeri 3 Peusangan, a clear picture of the differences between the experimental class and the control class was obtained. First, in terms of mean, the self-concept score of students in the experimental class reached 53.292, while in the control class it was only 48.458. This difference shows that the application of 4C-based Problem Based Learning has a positive impact on improving students' self-perception. The higher average score in the experimental class reflects that students feel more confident in the learning

process, especially when faced with contextual mathematical problems. Learning strategies that provide space for critical thinking, open communication, collaboration, and creativity have been proven to create a more meaningful learning atmosphere, thereby helping students develop a stronger self-concept. Second, in terms of data distribution (standard deviation), the experimental class had a standard deviation of 3.342, while the control class had a standard deviation of 6.331.

This indicates that the mathematics self-concept scores in the experimental class were more

homogeneous than those in the control class. This means that the self-perceptions of students in the experimental class were relatively uniform and consistent. Conversely, the greater variation in the control class reflects a wider gap in self-perceptions among students. Third, from the minimum and maximum values, it is known that the minimum self-concept score in the experimental class is 47 and the maximum is 59, while in the control class the minimum value is 33 and the maximum is 60. Although the maximum value in the control class is slightly higher, the wider score range indicates that there are students with very low mathematics self-concept in that class. Conversely, the higher minimum score in the experimental class shows that almost all students are in the upper-middle mathematics self-concept category, so that the distribution of self-perception is more even. This condition reinforces the previous finding that the 4C learning approach supports a more positive distribution of learning experiences and psychological development among students. In general, the results of this descriptive analysis show that the use of the 4C-based PBL model is more effective in improving students' mathematics self-concept than the PBL model without 4C.

3.3. Statistical Analyses in SDIT Peusangan

After the initial pilot findings at MIN 1 Bireuen demonstrated positive development in students' mathematical thinking and mathematics self-concept, further implementation was conducted at SDIT Peusangan. The teaching experiment in

this school sought to assess the consistency of the 4C-based PBL model's effectiveness across diverse educational settings. As in the previous site, comparisons were made between the experimental and control classes to evaluate the impact of the intervention on students' mathematical thinking and self-concept.

3.3.1. Result of Mathematical Thinking Concept

Unlike the previous two schools, students at SDIT Peusangan showed greater readiness in implementing 4C-based learning. Critical thinking was evident when students not only answered questions but also attempted to make generalisations. For example, they concluded that determining the perimeter of a combined flat shape by calculating manually did not require the use of a formula, and that using a formula would be incorrect. This activity demonstrates originality of thought. In terms of collaboration, students are accustomed to sharing roles. Some take notes, some speak, and some calculate the results of adding sides or multiplying numbers needed for learning activities, so that every student feels they are contributing. This pattern of cooperation demonstrates social skills that support academic achievement. Communication is most strongly developed at this school. Students dare to express their opinions even when they differ from their peers, then discuss those differences with logical arguments. These communication skills demonstrate a positive mathematics self-concept, namely confidence and the belief that their opinions are valuable.

Table 7. Descriptive Statistics for Mathematical Thinking in SDIT Peusangan

DESCRIPTION	CLASS EXPERIMENT		CLASS CONTROL	
	<i>PRE-TEST</i>	<i>POST-TEST</i>	<i>PRE-TEST</i>	<i>POST-TEST</i>
Mean	70	85,577	40	30,44
Standard Deviation	10,296	7,393	19,419	23,817
Minimum	45	75	0	0
Maximum	90	100	70	70
N	26		25	

Based on the results of descriptive analysis, the experimental class that applied the 4C-based Problem-Based Learning (PBL) model showed a significant increase in students' mathematical thinking abilities. The table shows a significant increase in students' mathematical thinking abilities, with a more homogeneous distribution of scores compared to the pretest. The lowest score on the post-test was 75, while the highest score reached a perfect score of 100. Meanwhile, the control class that did not receive the 4C-based PBL treatment actually showed a decrease in the average score from 40 on the pre-test to 30.44 on the post-test, with standard deviations of 19.419 and 23.817, respectively. This decline indicates that without the 4C-based PBL learning intervention, students' mathematical thinking skills tend to decline. Overall, these descriptive data indicate that the implementation of 4C-based PBL in Peusangan SDIT students effectively improves mathematical thinking skills, both in terms of an increase in average scores and a narrowing of score variation, compared to the control class that did not receive similar treatment.

3.3.2. Result of Mathematical Self Concept

Based on the results of descriptive data analysis of students' self-concept in flat shape material, an overview of the differences between the experimental class and the control class was obtained.

Based on the results of descriptive data analysis, these results show that the average mathematics self-concept score of students in the experimental class was higher than that of the control class. The difference in the average reflects a clear difference between the two groups. The data variation in the experimental class was also slightly greater than in the control class, as seen from the difference in standard deviation values, although the difference was not very significant. This indicates that students' self-concept perceptions in the experimental class were more varied than those in the control class. This difference can be interpreted as a positive impact of using a problem-based learning model combined with 4C skills in the experimental class. This model enables students to be more active, engage collaboratively, and develop self-confidence and understanding of their potential.

Table 8. Descriptive Statistics for Mathematical Thinking in SDIT Peusangan

DESCRIPTION	CLASS EXPERIMENT	CLASS CONTROL
Mean	52,346	48,280
Standard Deviation	4,270	3,680
Minimum	41	41
Maximum	59	55
N	26	25

Conversely, the control class that used PBL without 4C integration tended to have lower average scores, indicating that although the PBL approach also had a positive impact, the integration of 4C skills could strengthen students' self-concept development more optimally. Thus, this descriptive data provides an initial picture that the use of the 4C-based PBL model in flat shape learning at SDIT Peusangan can have a

better influence on the formation of students' self-concept compared to the conventional PBL model. These results form an important basis for further in-depth analysis through inferential testing to confirm the significance of the differences between the two groups. This improvement indicates that 4C-based PBL not only improves academic learning outcomes but

also increases self-confidence, independence, and positive attitudes towards mathematics.

4. Discussion

Overall, the results of the study in the three schools showed the following patterns, first, 4C-based PBL was effective in improving mathematical thinking, but the degree of effectiveness depended on student readiness, the quality of teacher scaffolding, and the collaborative culture of the class. Second, self-concept improved consistently in all schools, indicating that the affective dimension was easier to improve through collaborative interaction than higher-order cognitive abilities. Third, the highest variation in results among students occurred in schools with high heterogeneity, such as SD Negeri 3 Peusangan. And the last, the highest effectiveness occurred in schools with mature classroom management, clear discussion structures, and group work habits (SDIT Peusangan).

4.1. The Development of Student Mathematical Thinking through 4C-Based PBL

The results of the study indicate that the application of Problem-Based Learning (PBL) combined with 21st-century 4C skills can develop students' mathematical thinking in flat shape material. This development can be seen from the increase in students' ability to perform mathematical representations, identify patterns, develop problem-solving strategies, make generalisations, and provide logical mathematical arguments.

Empirically, students showed a shift in thinking patterns from simply identifying shapes based on visual characteristics to a conceptual understanding of the properties of shapes, the relationships between shapes, and the use of formulas. These findings are consistent with Van Hiele's theory, which asserts that progress in geometric thinking moves from visualisation to analysis and deduction through concrete learning experiences and structured discussions. The integration of 4C reinforces this developmental trajectory, particularly through mathematical

communication activities that help students negotiate and clarify their understanding.

Cross-school analysis results show that the use of concrete media and teacher scaffolding plays an important role in improving mathematical thinking. In schools where teachers consistently ask guiding questions, students can give a better reason and show significant progress in problem solving. These findings are in line with Hmelo-Silver (2004), who asserts that the success of PBL is largely determined by the quality of scaffolding that guides students in independently constructing knowledge structures. Schools with a strong culture of collaboration see more equitable development of mathematical thinking. Collaboration allows students to share strategies, test ideas, and correct misunderstandings directly through group discussions. This activity supports Vygotsky's concept of the Zone of Proximal Development (ZPD), in which social interaction plays an important role as a bridge for students' cognitive development.

Thus, the findings of this study reinforce empirical evidence that a problem-based learning model integrated with 4C not only encourages academic achievement but also develops holistic mathematical thinking skills at the primary school level.

4.2. Variation in Implementation and Contextual Factor Affecting the Mathematical Thinking

Although 4C-based PBL is generally effective, the development of mathematical thinking between schools shows significant variation. This variation is related to contextual factors such as students' cognitive readiness, classroom management, the quality of teacher-student interactions, and the availability of learning media.

Schools that provide concrete media, such as shape cut-outs, measuring tools, or geometric objects, show the most stable development. Concrete media serve as a bridge from visual to symbolic representation, making it easier for students to understand the concepts of area, perimeter, and classification of flat shapes. These findings are in line with Bruner (1966), who

emphasised the importance of the enactive–iconic–symbolic stages in mathematics learning. In addition, classroom discussion patterns also influence students' thinking development. In schools with a strong discussion structure, students are able to present mathematical arguments more coherently. Meanwhile, in schools where discussions tend to be dominated by high-ability students, the development of other students becomes less than optimal. This confirms the findings of Anthony & Walshaw (2007) that quality mathematical interaction is an important prerequisite for creating inclusive and productive learning.

4.3. The Development of Student Mathematical Self-Concept through Collaborative Learning

Students mathematical self-concept also showed positive development during the implementation of 4C-based PBL. Mathematical self-concept includes self-confidence, belief in one's abilities, self-perception of success in learning mathematics, and a sense of involvement in learning activities. Through problem-based learning that emphasises collaboration and communication, students have more opportunities to actively participate, ask questions, and express their reasoning.

In schools that clearly divide group roles (e.g., writer, speaker, question reader, measurer, and shape drawer), the development of self-concept becomes more evenly distributed. Students who were initially passive become more involved because they feel a sense of responsibility within the group. This is consistent with Bandura's (1997) theory, which states that mastery experiences are the most decisive factor in increasing self-efficacy. Even simple successes—such as successfully explaining how to calculate the perimeter or sticking shapes on a group poster—become a powerful stimulus in building mathematical self-confidence.

4.4. The Effectiveness of 4C-Based PBL Learning Trajectory

The learning pathway analysed in this study consists of several phases: problem orientation, group organisation, investigation, presentation of

results, class discussion, contextual problem application, reflection, and formative assessment. The results of the study indicate that this learning pathway is effective in improving students mathematical thinking and self-concept, especially in the investigation, presentation, and reflection phases.

Thus, the 4C-based PBL pathway applied in this study can be viewed as a more comprehensive revision syntax than classical PBL. This syntax accommodates both cognitive and affective development, making it suitable for mathematics learning in primary schools.

4.5. Theoretical and Practical Implication of the Research

Theoretically, this research contributes to the expansion of the PBL model into a 4C-based PBL with more detailed syntax. These findings confirm constructivist theory regarding the importance of problem-solving activities and social interaction in developing mathematical understanding. In addition, this research reinforces the literature on the relationship between collaborative learning and the formation of mathematics self-concept.

In practical terms, this research offers a learning model that can be implemented by primary school mathematics teachers, especially in geometry. Teachers need to ensure the availability of concrete media, division of group roles, regular scaffolding, inclusive class discussions, and formative assessment throughout the learning process. This implementation has been proven to improve the quality of learning, equal participation, and students' confidence in learning mathematics.

The research findings show that the implementation of 4C-based Problem Based Learning (PBL) consistently contributes to the improvement of primary school students' mathematical thinking and mathematics self-concept in geometry material. Cross-context analysis in three schools shows that students are involved in guided investigation activities. Based on these findings, this study offers a theoretical contribution in the form of a revised 4C-based PBL syntax consisting of seven principal stages:

1. Problem orientation using concrete media, the learning process begins with the presentation of a contextual problem supported by concrete or visual media, providing students with a clear and meaningful foundation for understanding the task.

2. Group organisation and role allocation, students are organised into collaborative groups, with explicit division of roles to promote responsibility, participation, and effective teamwork.

3. Guided investigation with structured scaffolding, During group inquiry, the teacher provides systematic and gradual scaffolding to support students' reasoning, problem-solving processes, and conceptual development.

4. Class discussion and conceptual clarification, whole-class discussions function not merely as opportunities to report group findings, but as academic forums for argumentation, comparison of strategies, and collective construction of conceptual understanding.

5. Application to contextual problems, students apply the concepts they have developed to new contextual situations, reinforcing transfer of learning and deepening conceptual mastery, through a presentation.

6. Reflection and evaluation, the learning cycle concludes with structured reflection, guiding students to synthesise key ideas and formulate general principles derived from their investigative experience.

5. Conclusion

The findings of this study indicate that the application of 4C-based Problem Based Learning can improve primary school students' mathematical thinking and mathematics self-concept in geometry. The development of mathematical thinking is reflected in students' ability to measure, classify, prove, and generalise flat shapes. Students at SDIT Peusangan showed the most consistent and even improvement, while MIN 1 Bireuen and SD Negeri 3 Peusangan showed improvement but with variations in ability among students.

Furthermore, students' mathematics self-concept also experienced a significant increase, especially in terms of self-confidence, courage to express opinions, and active participation in group discussions. Teacher support, a collaborative atmosphere, and opportunities to reflect on the thinking process proved to be important elements in strengthening students' self-concept in mathematics.

The learning trajectory (Hypothetical Learning Trajectory) developed within the framework of 4C-based PBL has also proven to be effective in supporting the development of students' mathematical thinking processes. The investigation and presentation phases are the most decisive parts, as they allow students to build conceptual understanding independently before discussing it in class. Meanwhile, the reflection phase helps students reassess the strategies used and interpret the relationships between the geometric concepts studied. Thus, the 4C-based PBL approach not only contributes to improving learning outcomes, but also to shaping learning experiences that are process-oriented, collaborative, and strengthen mathematical dispositions.

6. Recommendation for Future Research

Further research is needed to examine the applicability of 4C-based Problem-Based Learning (PBL) across different grade levels and mathematical topics, including measurement and algebra. Expanding the scope of implementation would provide a clearer understanding of the model's consistency and effectiveness in diverse learning contexts. In addition, studies involving larger and more heterogeneous samples, supported by rigorous experimental or quasi-experimental designs, would strengthen the generalisability and empirical validity of the findings.

In-depth qualitative studies are also recommended to explore the dynamics of group interaction within 4C-based PBL classrooms. Detailed examination of communication patterns, collaborative engagement, and peer influence may contribute to a more

comprehensive understanding of the social factors shaping students' mathematical self-concept. Moreover, future investigations should address the integration of digital technologies and examine the influence of teacher-related factors, particularly teacher mindset and scaffolding practices, on the effective implementation of 4C-based PBL. Such research would support the continued refinement of both the theoretical framework and its pedagogical application in mathematics education.

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Credit Authorship contribution statement

Marzuki: Writing the original draft, conceptualization, and analysis. **Hasratuddin:** Writing-Review and Editing, **Sumarno:** Writing-Review and Editing. All author

Declaration of competing interest

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