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Learning design of quadrilateral STEM-based through lesson study

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Abstract
Understanding quadrilateral and triangle material is still a problem for students. These problems occur because teachers did not design learning trajectories before they tough in the classroom, or they still did not apply innovative approaches and media in the learning process. Designing and developing a learning trajectory for the quadrilateral and triangle material as an activities series based on science, technology, engineering, and mathematics (STEM) using rubber-powered car projects through lesson study is the aim of this study. This design is referred to as a hypothetical learning trajectory in teaching quadrilateral and triangle material. This study used design research as a research method, which consists of three stages: preliminary design, design experiment, and retrospective analysis. The subject of this research was seventh-grade students at a state junior high school in Semarang City. Data were collected from various sources: pre- and post-test, student worksheets, interviews, documentation of photos, and video recording of the learning process. Data analyses through qualitative research about validity and reliability refer to the quality of the observation. This study result described the learning trajectory consisting of three activities, namely creating a rubber-powered car project, identifying the property and relation among quadrilaterals, and solving a contextual problem in the area and perimeter of quadrilaterals. This research indicated that a series of activities STEM-based designed through lesson study can make students understand material actively, joyfully, and meaningfully.

Keywords: design research, quadrilateral, STEM, lesson study

INTRODUCTION

Geometry is a crucial learning mathematics branch. The goals of studying geometry include developing creative thinking skills, intuition, conceptual understanding, and giving an understanding of reading and interpreting mathematical concepts (Dan & Xie, 2011). It is possible to connect mathematical concepts with everyday life by learning geometry (Irsa et al., 2017). Moreover, concepts learned in geometry can train students to think creatively in solving mathematical problems.

However, according to several studies, it is stated that there are still many students who have difficulty in learning geometry. Furthermore, seventh-grade students got misconceptions and a lack of understanding in learning geometry topics, because geometry topics are more complex than algebraic operations (Ozerem, 2012). In addition, students' geometrical thinking level was still at level 2 (Lutfi & Jupri, 2020). Thus, geometry is still a problem that is often encountered in the mathematical teaching and learning process. One of them is the difficulty of students in learning the material of quadrilaterals and triangles. Students have difficulty analyzing, evaluating, and forming the stages of solving quadrilateral and triangle problems (Guo, 2023).

Some forms of student difficulties in learning quadrilaterals and triangles are caused by several factors, including students who are less interested in learning the material, students who are less accustomed to solving problems in the material, and students who tend to depend on help from teachers (Youkap, 2020; Žakelj & Klančar, 2022). Furthermore, the problem was caused by the direct delivery of mathematical concepts as finished products so students' understanding of the mathematical context was limited. If mathematical concepts are conveyed to students directly as finished

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Contribution to the literature

- Designing STEM-based quadrilateral instruction can help students understand the concepts learned and more actively engage in learning through designed projects by integrating science, technology, engineering, and mathematics.
- Hypothetical learning trajectory in learning quadrilateral STEM-based results in this study can inspire the teacher to design another material using appropriate context.
- Integrating Lesson study and design research can result in better instructional design, teaching-learning process, and reflection of the conjecture of students in learning quadrilateral STEM-based.

products, it causes students to experience difficulties in learning mathematics (Thapa et al., 2022). Therefore, mathematics should not be seen as a ready-made product, but as a human activity. So, the focus of learning mathematics is not only on the ready-made product but on the process of forming the mathematical concept itself.

Therefore, we need an approach to make the students active in the learning process and support students' understanding of concepts, namely through STEM-based learning. STEM learning is seen as an approach that is able to provide significant changes in the 21st century (Asrizal et al., 2023; McMaster et al., 2023; Yakob et al., 2021). With STEM learning, scientific literacy skills, which are part of 21st century skills can be achieved (Knowles et al., 2018; Zainil et al., 2023). In line with this, STEM approach can give greater chances to get various experiences by involving students in real-world problems that are authentic, open, and structured, to enhance the content meaning (Furner, 2018; Thibaut et al. 2018). Several studies also show that learning with STEM framework in Indonesia can positively improve students' abilities in a subject (Pahrudin et al., 2021; Tomperi et al., 2022; Wisudawati, 2020).

One of the materials that can be taught using STEM approach is quadrilaterals and triangles in class VII SMP through the spring car project. Aspects of science can be found in material force and motion. The technological aspect can arise from the use of equipment to design a spring car, the winding aspect arises from the way in which a spring car is designed, and the mathematical aspect arises from the material of quadrilaterals and triangles or the planar shape. Integrated aspects of STEM in the designed project are hoped to stimulate students' literacy and skill of creative thinking through learning STEM-based.

However, STEM-based learning implementation in schools is still relatively new for teachers, some teachers are still experiencing problems in implementing it (Suprapto & Ku, 2019). Therefore we need a learning community to help them to share in the design, implementation, and evaluation of learning. Lesson Study is one of the learning community models that can build teachers' optimum ability (Mahardika & Putri, 2020). Teachers will learn from each other how to optimize the use of STEM-based digital classroom platforms. Although lesson study has proven to be very good as a guide for the learning community, designing lesson study materials requires teaching materials design techniques and learning approaches.

By designing learning trajectories, it is expected that students can comprehend the concepts learned meaningfully. This article reveals the design of the learning trajectory of quadrilateral by using the PjBL STEM-based learning through lesson study.

METHODS

To examine the learning design helps to facilitate students in getting an understanding of a concept and problem-solving, a design research model can be used (Gravemeijer & Cobb, 2006). There are five characteristics in the design research method: the character of the intervention, orientation to a process, a component of reflection, the nature of the cycle, and orientation to theory (Gravemeijer, 2004; Prahmana, 2017). In addition to these reasons, this study used design research because design research is a systematic strategy and can be flexibly adapted to enhance the process and learning outcomes quality through positive collaboration between instructors and researchers to construct a plan for studying (Gravemeijer, 1994).

Design research consists of three stages, namely preliminary design, design of the experiment (pilot experiment and teaching experiment), and retrospective analysis (Bakker, 2004; Gravemeijer & Cobb, 2006). Each of these stages can be explained, as follows.

Preliminary Design

The first phase is preliminary design. This phase focuses on enhancing activities of learning and instruments to assess the process of learning. In this study, a review of the literature was conducted on the concepts of quadrilaterals and triangles, STEM projects, and material analysis of quadrilaterals and triangles in the Indonesian mathematics curriculum, which were used to design students' thinking assumptions, and designing instruments (lesson plan, worksheet, teacher guide, pretest-posttest). In addition, at this stage, the design of hypothetical learning trajectory (HLT) as an instrument and design was also carried out. HLT as a design contains three main components, namely the

Table 1. Design research integrated with lesson study framework

Design research	Lesson study	Activity
Preliminary design	Plan	• Literature review • Designing HLT • Designing lesson plans, worksheets, teacher guides, & pre- & post-test • Designing project STEM based • Preparing for design experiment • Discussing HLT & project with lesson study community
Design experiment Pilot experiment Teaching experiment	Do	• Pilot experiment - Students prior knowledge will be investigated - Make a draft of an HLT or revise an HLT by collecting data • Teaching experiment - Plan of HLT will be adjusted - Activities designed will be observed in classroom
Retrospective analysis	See	• Analysis of data • Plan improvement of a possible design for next lesson • Reflecting on implementation of HLT • Discussing all findings about students' activities during learning process • Evaluation & redesign for next learning

objectives of the activity, a series of activities, and the alleged possible responses of students that appear to the activities carried out during class learning. There were three activities in understanding the concept of quadrilateral and triangle in this study. Furthermore, the important role of HLT is to be able to indicate the analysis of research direction and focus (Alim et al. 2020). A thought experiment was used to improve HLT during this step, an experiment in which we predict and examine the possible thought processes of students from the teacher's perspective who have more experience in the field. At this stage, it can also be adjusted from the student's responses at every stage (Nuraida & Amam, 2019).

Design Experiment

The second stage is the experimental design consists of the phases. The first phase is the pilot experiment, and the second one is the teaching experiment phase. A learning trial using HLT, which has been designed in the previous stage will involve six students with heterogeneous abilities in the pilot phase. Furthermore, at the teaching experiment stage, a trial will be conducted on HLT, which was revised in the previous stage in the real class condition as the research subject, conduct observations, interviews, and give tests.

Retrospective Analysis

Retrospective analysis is the third phase. At this phase, several steps will be carried out, including

(1) data gotten from the teaching experiment phase is analyzed then the analysis results were used to plan activities and improve activity designs for the next lesson and

(2) comparing HLT with actual student learning.

To answer the formulation of problem using the study result. The record received at some stage in the design experiment stage is assessed by way of evaluating conjecture and HLT to be learning trajectory application results all through the test phase's design (Gravemeijer & Cobb, 2006).

Furthermore, it is combined with lesson study consisting of three phases including plan, do, and see (Masaaki, 2012). Moreover, an overview of the design research integrated with the lesson study framework in this study is given in **Table 1**.

Several data collection techniques were used to answer research problems, namely by means of observation, interviews, and documentation. The purpose of the observation is to get ideas related to the mathematical social norms that apply in the classroom, the use of teaching approach and methods, the implementation of the engineering design process (EDP) in STEM, class organization, rules in class, student responses, and allocation of time during the process.

Interviews were carried out with several parties, including experts in mathematics education, teachers, and students. Interviews with the experts aim to look for content and relevance that is suitable, context application, the practicality of the instrument, language that easy-to-understand, and sufficient time. The purpose of the interview was to obtain in-depth information regarding the problems that teachers might face in teaching, the level of student's understanding, the level of student's creative thinking skills, the experiences of teachers and students in using STEM approach, and the process of using interactive media in learning. The role of the researcher in this learning activity is to help accommodate students who ask some additional questions, have a look at activities in the learning process, coordinate activities, and modify activities

Table 2. STEM analysis on a quadrilateral & triangle

STEM elements	Explanation
Science	Project a rubber-powered car can apply science concept of energy change, motion, displacement, & spring force
Technology	Tools & materials used in creating a rubber-powered car project include scissors, glue, a ruler, rubber, & bottle cap
Engineering	Design or model in creating a project is to make a rubber-powered car project
Mathematics	Students can find mathematical concepts by creating project rubber-powered cars: quadrilateral & triangle

needed to be able to furnish all forms of applicable data about the implementation of the study.

Furthermore, in the observation stages will get documentation to know how the implementation of the process of learning from beginning to end, student discussion activities, student strategies, and student thinking processes from the informal to the formal phase in mastering the material being studied through the designed project. Documentation of data is collected through photos and video recordings.

The technique of data analysis was carried out qualitatively. In the retrospective analysis stage, an analysis was carried out on the data that had been collected at the preliminary design, pilot experiment, and teaching experiment stages. The initial HLT was designed using guidelines from the analysis results of the observation sheet, the interview result, and the pre-test results in the stage of the pilot experiment. In addition, the student's written tests result will be analyzed, and data analysis on the research design method was carried out by comparing the results of observations during the learning process in the teaching experiment with HLT that had been designed.

In addition, STEM analysis of the quadrilateral and triangle material is described in **Table 2**.

RESULTS

As a study finding, we acquired a learning trajectory description of the quadrilateral and triangle material utilizing a rubber-powered car STEM project through lesson study. Furthermore, in this chapter, the researchers describe the effects acquired at some point in every learning stage, as follows.

Preliminary Design

In this stage, the researchers implemented the initial idea of learning the quadrilateral and triangle utilizing STEM project of a rubber-powered car. Because a rubber-powered car can represent a quadrilateral and triangle concept and it is familiar and easy to be constructed by the students, it could be picked as the context in this research. Also, it can enable students to grasp the ideas of the quadrilateral and triangle. Additionally, there is an exciting aspect to the situation of creating a rubber-powered car STEM project. Because the shape of the rubber-powered car was made differently based on the

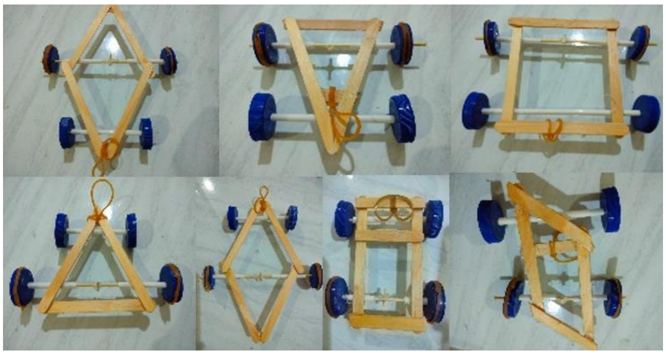


Figure 1. Design of rubber-powered car project STEM based (Source: Authors' own picture)

kinds of quadrilaterals and triangles, also the technique in designing and the way of operating the rubber-powered car, the variation that arises is that the path and the length of time have different results. To keep each rubber-powered car having the same result, the students made a few strategies. The variations involve making the wheels designed for rubber-powered cars and the frequency of the rubber rotation. It will be an intriguing topic to be discussed by the students in the classroom. Furthermore, the illustration of the rubber-powered car project can be seen in **Figure 1**.

Furthermore, HLT development in the learning activity series is the most important stage of the designing stage of learning activities of the students sequent. The design is inseparable from the learning trajectory, containing a lesson plan for teaching the material. In this case, the learning trajectory is a concept map that students will pass during the learning process. In addition, HLT planning process used to be achieved by conducting a literature review, designing a learning trajectory for the quadrilateral and triangle as a series of learning activities, and observation. Also, a curriculum overview to make certain that lessons based on the mathematical standards were appropriate for students in the seventh grade based on the *merdeka* curriculum. The analytical system involves setting up learning materials, the aims of the lesson, and indicators of learning. The learning process developed by HLT includes three things to do. Every activity is simple and makes students actively participate in the process of learning. For detail, **Table 3** illustration of the series of activities and the student's conjectures in this research.

Table 3. Activities series & conjectures of students

Activity's name	Purpose	Student response conjecture
Creating a rubber-powered car project	To introduce kinds of quadrilaterals & triangles	Students are familiar with & capable of creating a rubber-powered car project with their team Students make a different design on shape of quadrilateral & triangles Students can evaluate their design & redesign it to be a better one
Identifying property & relation between quadrilaterals	To identify properties & relationships among quadrilateral	Students are able to determine properties of quadrilaterals Students are able to find relationship between quadrilaterals
Solving a contextual problem related to area & perimeter of quadrilaterals	To find perimeter of quadrilaterals To find quadrilateral's area	Students can investigate whether different designs of rubber-powered car have same length of a path Students can find quadrilateral perimeter Students can determine quadrilateral's area

This stage is also a planning stage in lesson study. The researcher discussed HLT, students' worksheets, lesson plans, and media with the teacher partner who has already familiar with the material and the student's character. So that they can give suggestions for the instructional design to be better and applicable.

Design Experiment

At this phase, a learning trajectory designed for seventh-grade junior high school students on the quadrilateral and triangle using a rubber-powered car STEM project has been implemented. The findings of this research established an HLT description of quadrilateral and triangle material using a rubber-powered car project. The learning series is divided into three activities: creating a rubber-powered car project, identifying the property and relation among quadrilaterals, and solving a contextual problem related to the area and perimeter of quadrilaterals and triangles. Learners might comprehend the idea of quadrilaterals and triangles by employing the rubber-powered car project in STEM learning. It can be seen from the activity sequence results and positive feedback from learners.

Concerning this study, the feedback indicates that students feel more at ease with the quadrilaterals and triangles material after being taught through activities STEM project-based and activities series designed. The findings of the study revealed that the learning design of quadrilaterals and triangles material based on the rubber-powered car is significant as a starting point and can help enhance student motivation during classroom activities. The researchers explain the study's findings in the design experiment stage.

Activity 1: Creating a rubber-powered car project

The learning process commences with the teacher providing apperception content, about the benefit of energy and changing energy, asking about kinds of quadrilaterals found in everyday life, and using a question-and-answer technique to ensure that students have no doubts concerning the previous topic and related topic. Following that, students observe a simulation of two kinds of cars that use different energy resources, namely battery-powered cars and spring cars. Additionally, the instructor inquired about the rubber-powered car. The teacher gives some clarifying questions to some students about the energy used to make the car move, which will be a context in the project done by them. Students can make some references to the rubber-powered car. It can be shown in dialogue 1.

Dialogue 1:

Teacher: Have you ever played with toy cars as a child?

Students: Yes, I have.

Teacher: What car do you play? Can it move?

Student: Truck car, police car, yes it can.

Teacher: How do these toy cars run?

Students: Pulled using a rope, using batteries sir

Teacher: Good, if the battery runs out, do you think the car can run or not?

Student: No, Sir.

Teacher: So, how can a car run without a battery?

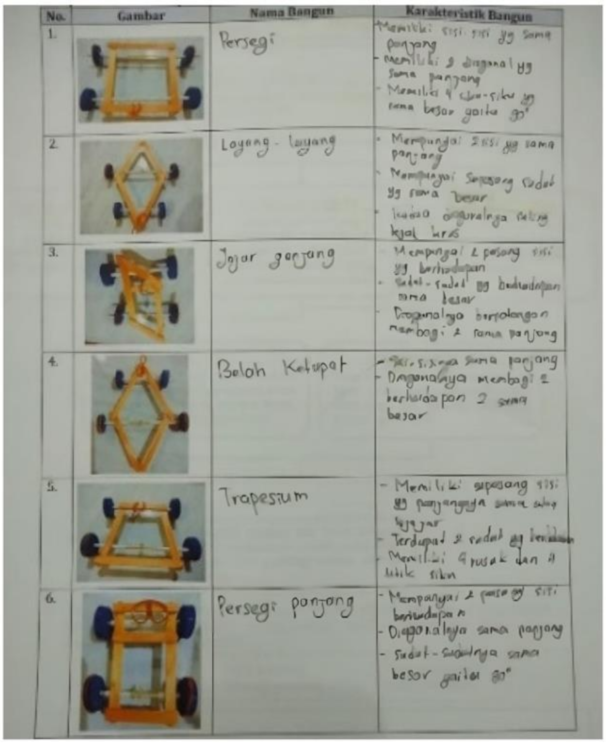
Student: By being pushed, or using a spring, Sir.

Teacher: Good, with spring power, we can make the car run. Well, now we will try to make a spring car project using rubber.

Dialogue 1 demonstrates that students were familiar with the energy changes making the car move. So, it was expected that students can create rubber-powered cars easily by using equipment provided by the teacher. The teacher informed students about classroom activities by doing projects, discussions, and presentations. The teacher then divided the students into several small groups of four students. Then the teacher instructs them to create a STEM project.

The students can design rubber-powered cars with EDP step. The first is to define the problem, the students

Figure 2. Students' activity in creating a rubber-powered car project & testing it (Source: Authors' own picture)



Shape	Characteristics
Square	• has 4 same-length sides • has 2 same-length diagonals • has 4 right angles
Kite	• has 2 pairs of equal sides • has a pair of equal angles • has 2 different diagonals & are perpendicular to each other
Parallelogram	• has 2 pairs of opposite sides, each pair is parallel & same length • opposite angles are equal • diagonals intersect bisecting same length
Rhombus	• sides are same length • diagonals bisect each other & are same length
Trapezoid	• has a pair of parallel sides • has 4 edges & 4 vertices
Rectangle	• has two pairs of sides that are same length • diagonals are same length • angles are same size that is 90o

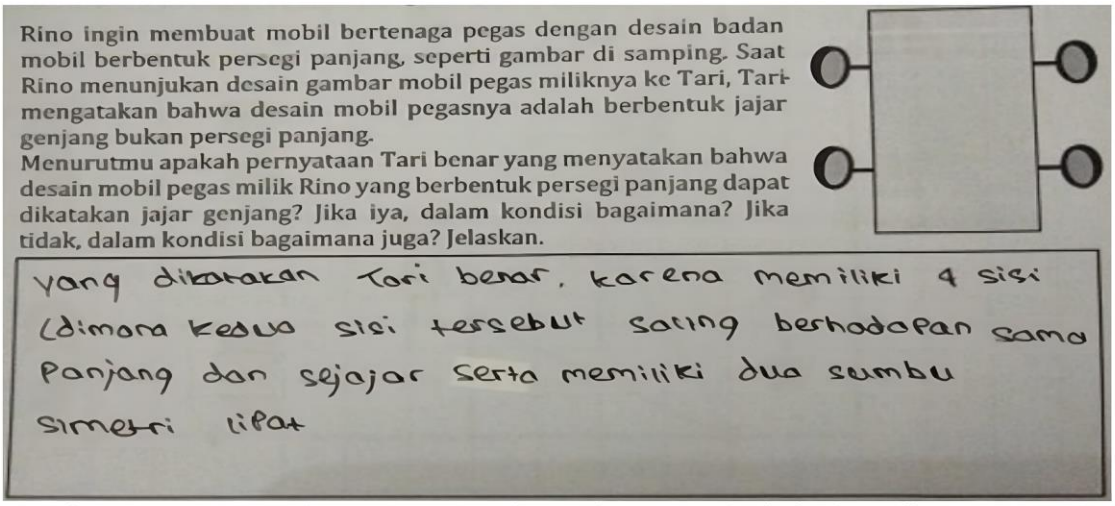
Figure 3. Sample of students' results in determining name & properties of quadrilateral (Source: Authors' own picture)

were given a challenge by the teacher to create a car design with various shapes quadrilateral and triangles, and then investigate whether the different shapes of the rubber-powered car give different lengths in moving. The second is research, students did research on what shape that will give the most effective one for moving. The third is development; the students then develop the shape model and create the rubber-powered car project. The fourth is to choose; then they will choose the most effective shape model predicted in the previous step. The fifth is to create the project; the students create a project based on the model designed together with their team. The sixth is to test and evaluate the project; after finishing creating the project they test it and evaluate whether it can run well or not if the car design did not work they tried to find the cause and solution. The last is to communicate the project; after they tested and evaluated the project, they could present it in front of the class and compare it to another team cars project result.

Also, activity of students in creating STEM project is seen in **Figure 2**. When teacher observed student discussion activities in classroom, students engaged actively and attempted to create various types of rubber-powered cars. After successfully creating a car project, students were asked to identify kinds of shapes in quadrilaterals and triangles. In this activity, students may find that there are some quadrilateral shapes namely: square, rectangle, rhombus, trapezoid, kite, and parallelogram quickly.

Activity 2: Identifying property & relation between quadrilaterals

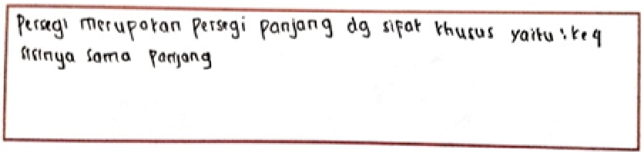
In activity 2, students could determine the properties of quadrilaterals after creating STEM projects in various shapes. Students were given student activity sheets, which were arranged to help them understand the concepts of quadrilaterals and triangles. Students are instructed to determine the properties of a quadrilateral based on a project that has been made previously and determine the relationship between the properties of the quadrilateral. Then, students write the name of each car project model that has been designed in the previous



Question: Rino wants to make a spring-powered car with a rectangular body design like picture on side. When Rino showed his spring car design to Tari, Tari said that his spring car design was in form of a parallelogram. Do you think that Tari's statement is correct, which states that Rino's rectangular spring car design can be said to be a parallelogram? If so, under what conditions? If not, under what conditions? Explain your answer.

Answer: What Tari said is correct, because it has four sides (where two sides are opposite same length & parallel & have two-fold axes of symmetry)

Figure 4. Students' results in determining relationship between rectangles & parallelograms (Source: Authors' own picture)



A square is a rectangle with special property that all four sides have same length.

Figure 5. Students' results in determining relationship between square & rectangle (Source: Authors' own picture)

activity and determine its properties. The results of student work in this activity can be seen in **Figure 3**.

In this activity, students were also given the problem of determining the relationship between quadrilaterals. For example, students were asked to determine whether a rectangular rubber-powered car model can be said to be a parallelogram and give the conditions when it can be said to be like that. Responses to this activity vary, but most share ideas that a rectangle can be said as a parallelogram and give the condition.

Figure 4 explains the student's argument about this problem.

Then, students were asked about relationship between a square and a rectangle, and whether a square shape is a rectangle. From this problem, after analyzing each property of quadrilateral, students could find answer. A student's answer is seen in **Figure 5**.

From this problem, as shown in **Figure 4**, some students could give the right answer and some of them still gave the incorrect answer. But, after interviewing the students who still did incorrect answers, they could realize the correct one.

Activity 3: Solving a problem related to perimeter & quadrilateral's area

In this activity, the teacher gave three problems about finding the perimeter and area of given shapes to stimulate students' understanding of the perimeter and the area of a quadrilateral. The first problem is finding the shape with the longest perimeter among the different shapes given. The second problem is about determining whether the given pictures have the same area. The third problem is that students were given an open problem, which was asked to design a shape consisting of nine unit squares having the longest perimeter.

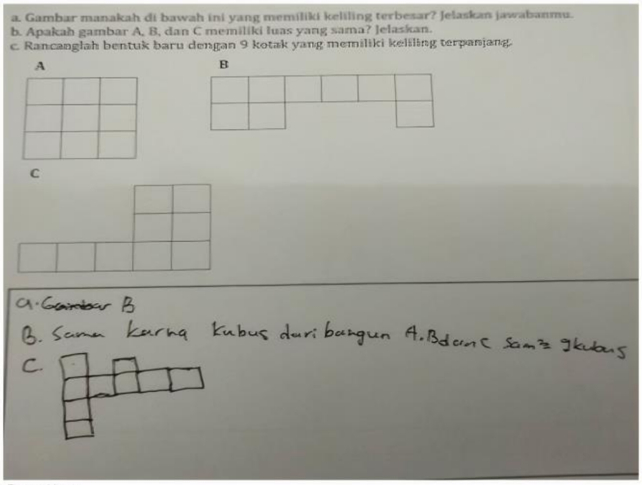
Figure 6 gives an illustration that the students can determine from the different shapes given that shape B has the longest perimeter. Although they did not write the reason why they choose it, from the interview with the teacher they can explain that reason. Parts of the dialogue between the teacher and students from this problem can be shown, as follows.

Dialogue 2:

Teacher: Why do choose shape B, which has the longest perimeter?

Students: Yes, Sir, because I calculate all of the perimeters of the given shapes.

Teacher: So, can you mention the perimeter of each given shape?



Question:

a. Which of following images has the greatest circumference? Explain your answer

b. Do pictures A, B, & C have same area? Explain your answer

c. Design a new shape with nine squares that have the longest perimeter

Solution:

a. Picture B

b. Same, because building blocks of shapes A, B, & C are same, which is nine squares

Figure 6. Students' results in solving problems related to quadrilaterals (Source: Authors' own picture)

Student: Yes, I can. The perimeter of A is 12, B is 18, and C is 16.

Teacher: How did you get it?

Students: I count all the sides of each given shape.

The second problem students can determine that all the different shapes have the same area. The reason for this problem is almost the same as the previous one. They count all the square units given for each shape, and all the given shapes have the same number of square units, that is nine units. Then, the third problem is the open problem. some students can find several different shapes consisting of nine-unit squares that have the longest perimeter.

Retrospective Analysis

Reflecting on the experience of conducting research in schools combined with the experience of teachers in teaching, the researchers conducted various forms of anticipation aimed at demonstrating a deeper understanding of the material (Nickerson & Whitacre, 2010). Seeing the first goal, students are actively involved in a project, this thinking can have an opportunity to have a positive effect. Some students in the group showed good results after carrying out a project designed by the teacher, namely the project of making a rubber-powered car with various rectangular and triangular shapes, then testing it, measuring the distance traveled by the car, and the travel time. This activity can foster motivation, creativity, and innovation in creating a technology (Mereli et al., 2023; Rohimah et al., 2022).

To be able to bring up this second goal, students begin to be given contextual problems to enable students to be able to imagine, calculate, and estimate in authentic situations (Winarni et al., 2022). The activities carried out by students were discussing the problems in the student activity sheets related to the properties of quadrilaterals and triangles and the relationship between quadrilaterals. Students were asked to identify whether certain types of quadrilaterals are part of other types of quadrilaterals based on their properties and relate them through the projects that have been made in the previous activity. The development of student understanding from informal to formal makes the learning process meaningful (Nursyahidah & Albab, 2021; Saraswati et al., 2016).

The third objective can be achieved by presenting open problems that arise naturally as an alternative way to solve problems in the context of written procedures. The activities carried out at the third meeting were solving the problem to find the perimeter and area from some different shapes. Students were presented with several shapes then determine which one is having the longest perimeter, determine the area, then they are allowed to design the shape that had the longest perimeter. The activity of giving open problems like this can stimulate students' creative thinking skills.

CONCLUSIONS

The design learning developed in this research consisted of three activities, namely creating a rubber-powered car project, identifying the property and relation among quadrilaterals, and solving a problem related to the area and perimeter of quadrilaterals and triangles. Besides using STEM approach with the project, this study also integrated with lesson study guiding students in comprehending material actively, joyfully, and meaningfully.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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