STEM-based 2D Shapes Learning Design in Parachuting Context to Support Student's Flexibility Ability

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STEM-based 2D Shapes Learning Design in Parachuting Context to Support Student's Flexibility Ability

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Abstract

This research aims to produce STEM-based 2D shapes learning trajectories in the context of parachuting to support students' flexibility ability. The method chosen was design research type validation studies consisting of three stages: preparation for experiment, design experiment, and retrospective analysis conducted for two cycles. The research subjects were 7th grade junior high school students selected by purposive sampling. Data were collected through observation, written tests, and interviews, then analyzed qualitatively and presented in text narratives. The result of this study is a learning trajectory consisting of three activities, namely 1) making three square-shaped canopy designs with different sizes and the same suspension rope length, 2) making three square-shaped canopy designs with the same size and different suspension rope lengths, and 3) making three canopy designs in the form of different quadrilateral with the same canopy area and suspension rope length. The learning trajectory developed is able to support students' flexibility ability where in the learning process students are directed to realize the existence of alternative strategy choices or varied solutions, utilize various knowledge possessed, determine the most effective and efficient way or strategy, and believe in the truth of the answers used in solving problems.

Keywords: 2D Shapes, STEM, Flexibility Ability, Parachuting

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INTRODUCTION

Human life in the 21st century has experienced significant changes, especially in the field of education, so this era requires quality human resources (Mardhiyah et al., 2021). Improving the quality of human resources through education from primary to tertiary levels is the key to keeping up with the development of the Industrial Revolution 4.0 in the 21st century (Lase, 2019). 21st century learning focuses on learners with the aim of providing skills in thinking skills and being ready to learn throughout life (Santyasa, 2018). 21st century learning requires students to have thinking skills known as "The 6C skills" including (1) character, (2) citizenship, (3) critical thinking, (4) collaboration, (5) communication, and (6) creativity (Choo et al., 2022).

Learners with creative skills can apply their knowledge and potential to generate new ideas that are unique and diverse (Ernitasari et al., 2022; Montessori et al., 2023). Using creative skills when solving problems will create ideas that are useful in finding solutions, which indicates flexibility (Haylock, 1997; Ladayatmoko et al., 2022). Flexibility is the ability to connect various knowledge and procedures to produce varied approaches and conclusions (Basuki et al., 2023). One of the materials that has the potential to bring up problems with various answers or solutions is flat building material (Sujarwo & Yunianta, 2018).

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Understanding a learning theory is necessary when studying geometry material on 2D shapes. One of them is van Hiele's theory, which is specifically used in the context of geometry and is divided into five levels ranging from level 0 to level 4, according to the level of abstraction possessed by students (Nihayah, 2021; Nuraini et al., 2021). These levels of geometry thinking include visualization, analysis, informal deduction, deduction, and rigor (Herawati, 2021; Yanuar et al., 2022). Each level of thinking has certain criteria that reflect differences in students' understanding of solving problems (Handayani et al., 2020). This difference is influenced by the information received and processed by students during the learning process (Nurhaolida et al., 2022). Therefore, thinking skills are needed, which are the basis for student' to understanding and ability to solve problems.

One of the abilities that students must have in solving problems is the ability to be flexible. Flexible thinking is the ability to produce a variety of ideas, answers, or questions, as well as being able to see situations from various points of view (Vylobkova & Heintz, 2023). This allows us to better adapt to everyday challenges and find alternative solutions. However, the facts in the field show that flexibility skills are still lacking. Basuki et al. (2023) found that students' flexibility ability was low, and they only answered as needed. Other research results show that students with medium and low abilities are unable to present a variety of ways to solve problems (Rozi & Afriansyah, 2022). In addition, research by Islami et al. (2018) found that only about 20.69% of students were able to generate diverse ideas. According to Christofel et al. (2022), students cannot use more than one way to solve geometry problems. Meanwhile, Monisa et al. (2023) found that students still have difficulty in providing diverse answers because they are not used to and do not understand the problem. Students with low mathematical thinking skills tend to rely on procedural methods learned during learning, without using flexibility skills (Rohmawati, 2022).

An alternative that can be considered is Science, Technology, Engineering, and Mathematics (STEM) based learning. STEM is an idea that combines the four fields of science into education in an interdisciplinary manner, encouraging students to think more integrated (Mu'minah & Suryaningsih, 2020; Yasifa et al., 2023). This approach creates an interesting and meaningful learning atmosphere, helping students to develop knowledge, creativity, and flexibility skills (Hassan et al., 2018; Marta et al., 2023; Nasrah et al., 2021; Wakhid et al., 2023). Through the application of STEM, students are actively engaged and acquire integrated knowledge with cross-disciplinary skills in a real-world context (Davidi et al., 2021; Lee, 2020). Learning can also be enriched by utilizing sports contexts such as skydiving, which presents mathematical elements in circular and rectangular canopies (Pratama & Herisman, 2019). The use of these contexts can be an innovative starting point in learning.

Previous research has developed learning media with a STEM approach (Aprilia et al., 2021; Arifin et al., 2020; Salmah et al., 2021; Sari et al., 2022; Utami et al., 2018). In addition, the development of learning pathways using STEM allows students to be actively creative (Susanti & Kurniawan, 2020). Some developments used real-world contexts or phenomena (Efriani et al., 2023; Pratiwi et al., 2023). Sports contexts, for example, provide various materials that can be utilized in mathematics learning (Listiwikono, 2018). Other studies highlight students' abilities such as critical thinking, problem solving, cooperation, and creativity (Nur Sopa et al., 2023; Prajoko et al., 2023; Suardi, 2020; Sukmawijaya et al., 2019). However, a study conducted by Widiastuti & Indriana (2019) showed that the use of the STEM approach to improve student creativity still has limitations in generating a variety of ideas or ideas in solving a problem that shows a lack of flexibility. The learning trajectory designed in this research consists of learning activities for students that offer various ideas or suggestions for solving problems. This is the novelty of this research. Given the importance of flexibility ability and the design of the mathematics learning process in the classroom, this study aims to design a STEM-based 2D shapes learning trajectory in the context of parachuting that can support students' flexibility ability.

METHODS

This study used design research method of validation studies type. The main purpose of this research is to support students' flexibility ability based on STEM context parachuting by designing Hypothetical Learning Trajectory (HLT) on 2D shapes material. HLT contain learning objectives, learning activities, and conjectures that arise during the learning process to predict the extent to which learners' thinking and understanding develop (Abrika et al., 2023; Putrawangsa, 2019).

The research subjects consisted of 15 grade 7 students of Srijaya Negara Junior High School Palembang in the pilot experiment and 25 grade 7 students of SMP Negeri 1 Indralaya in the teaching experiment. The subjects were selected using purposive sampling technique based on academic ability, subject teacher recommendation, and student availability. This study also involved a mathematics teacher who acted as a source of information related to the curriculum, materials, and classroom conditions and one researcher colleague acted as an observer.

The stages in validation studies include the preparation for the experiment, design experiment, and retrospective analysis (Gravemeijer & Van Eerde, 2009). At the preparation for experiment stage, a literature review was conducted related to the difficulty of 2D shapes material, flexibility ability, and the use of STEM. Then, designing HLT and research instruments. In the HLT, a series of learning activities based on STEM in the context of parachuting on 2D shapes were arranged.

Two cycles were conducted in the design experiment, namely cycle 1: pilot experiment and cycle 2: teaching experiment. The pilot experiment was conducted with the aim of testing the HLT that had been designed to evaluate its effectiveness and how the prepared instrument could be implemented. All data obtained from the pilot experiment was collected and analyzed to adjust and improve (if needed) the HLT to be used in the next cycle. Whereas teaching experiment became the core stage of validation studies where HLT that had been adjusted and improved in the previous cycle was tested in the actual class that became the subject of the study.

Data obtained from teaching experiment was collected and analyzed to see the learning trajectory in the actual learning process (ALT). Before carrying out the learning, a discussion was held with the teacher regarding the activity plan that would be implemented. Each learning session ended with a reflection to identify aspects that need to be improved. During the learning process, conjectures were refined into Local Instructional Theory (LIT). The data obtained from the retrospective analysis provided answers to the research questions.

Data in this study were collected through observation, written tests, and interviews. Activities during the learning process were collected through observation sheets and video recordings. Students' attitudes and skills were observed, and assessments were given based on predetermined descriptions. Written test data was collected through student worksheets (LKPD). The LKPD was analyzed to see students' conjectures and solution strategies as feedback from the learning that took place and to see the achievement of learning objectives. LKPD analysis is given a text narrative that explains student answers. Interviews used semi structured interview guidelines that were adjusted to the development of student answers. Data from the interview results were analyzed and presented in the form of text narratives. Data from observation analysis and interviews were used to provide a clearer picture of the results of the LKPD that had been done by students. All data were analyzed using descriptive method to describe students' thinking during the learning process and the emergence of flexibility ability. The flexibility ability indicators used according to Yamsy (2021) are presented in Table 1.

Table 1. Indicator of Flexibility Ability

No.	Indicator of Flexibility Ability
1.	Realizing the existence of alternative strategy options or varied solutions
2.	Determining the most efficient and effective way or strategy
3.	Utilizing various knowledge possessed
4.	Believing in the truth of the answers used in solving problems

RESULTS AND DISCUSSION

The result of the research conducted is a STEM-based flat building learning trajectory in the context of parachuting to support the flexibility ability of grade 7 junior high school students.

The Preparation for Experiment

The researcher conducted several preliminary steps in the preparation experiment, including a literature review, HLT design, and research instrument development. The designed HLT consisted of three STEM activities with a parachuting context that aimed to help students understand the concept of 2D shapes learning and improve their flexibility ability in the learning process. In addition, the researcher also developed research instruments such as LKPD, question grids, assessment rubrics, and lesson plans. The HLT and all research instruments were then validated through discussions with three relevant experts. The HLT is designed into 3 activities used in 3 meetings that have been validated and presented in Figure 1.

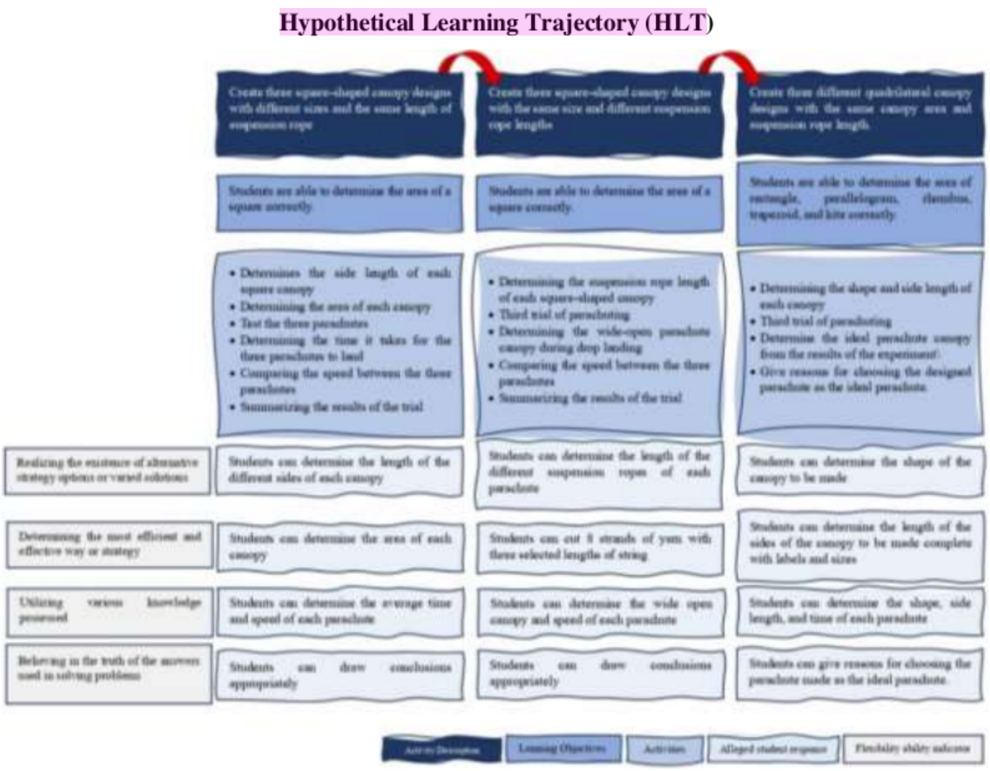


Figure 1. HLT on 2D shapes material using STEM

Design Experiment

The design experiment process was conducted through two cycles, namely cycle 1: pilot experiment and cycle 2: teaching experiment. The learning design at the preparation for experiment was implemented in cycle 1 and the results were used to improve the HLT that would be implemented in cycle 2.

Pilot Experiment

In the learning stage of cycle 1, the HLT was tested on 15 non-subject students from grade 7 of Srijaya Negara Junior High School Palembang. The trial process was conducted over three meetings with three activities. The first activity aimed to introduce the concept of square area through the context of a parachute. Students were asked to make three square canopy designs with different sizes, but the same length of suspension rope. After that, they calculated the area of each canopy and did a test parachute plunge to determine the landing time. Next, students compared the speed of the three parachutes and drew conclusions. The second activity was a continuation of the previous activity with the same objective. Students were asked to make three square canopy designs of the same size, but with varying suspension rope lengths. They again conducted parachuting trials to determine landing times, compare plunging speeds, and draw conclusions. The third activity aims for students to understand the concept of area of a rectangle, parallelogram, trapezoid, rhombus, and kite through the context of parachuting. Students were asked to create three different quadrilateral canopy designs with the same canopy area and suspension rope length. They determine the length of the sides of the canopy, design the parachute plunges, conduct trials, compare plunging speeds, and determine the best and safest parachute plunge.

The three activities involved students' understanding of the concepts of speed and gravity in science, the use of technology such as the stopwatch application on smartphones to measure time, and the application of engineering principles in designing a parachute plunge. After the series of cycle 1 activities were completed, researchers and teachers conducted observations and analyzed the findings for future improvements. Some aspects that need to be improved for the next cycle include the importance of direct delivery and explanation by the teacher related to the initial material not only students watching the video provided independently at home, the sentences on the LKPD need to be improved to make it easier for students to understand so that there is no misinterpretation, and emphasizing that the making of the parachute in stages according to the instructions given and the prohibition of its use before the trial is complete. Figure 2 shows student activity in completing the learning activity in Cycle I.

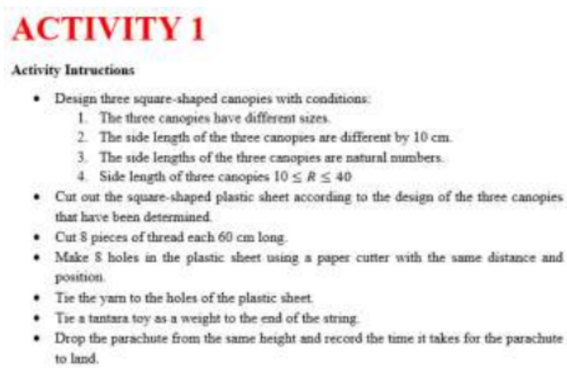
Figure 2. Students' activity in cycle 1

Teaching Experiment

The learning trajectory on 2D shape material at the teaching experiment stage is described as follows.

Activity 1: Create three square-shaped canopy designs with different sizes and the same length of suspension rope

The teacher gave LKPD activity 1 to students consisting of 25 people divided into 8 groups. Learning began with the delivery of learning objectives to be achieved and exploring students' prior knowledge of 2D shapes material and parachuting sports. Furthermore, students were motivated by showing a video of parachuting that has various canopy shapes where there are elements of mathematics, especially geometry, and showing the process of landing a parachute (https://shorturl.at/euHW1). Details of LKPD activity 1 of the first meeting are shown in Figure 3.



ACTIVITY 1

Activity Intructions

- Design three square-shaped canopies with conditions:
  1. The three canopies have different sizes.
  2. The side length of the three canopies are different by 10 cm.
  3. The side lengths of the three canopies are natural numbers.
  4. Side length of three canopies $10 \le R \le 40$
- Cut out the square-shaped plastic sheet according to the design of the three canopies that have been determined.
- Cut 8 pieces of thread each 60 cm long.
- Make 8 holes in the plastic sheet using a paper cutter with the same distance and position.
- Tie the yarn to the holes of the plastic sheet.
- Tie a tantara toy as a weight to the end of the string.
- Drop the parachute from the same height and record the time it takes for the parachute to land.

Figure 3. LKPD Activity 1

The problems in LKPD activity 1 are structured in such a way that STEM disciplines and flexibility ability indicators are combined. Each group was asked to make three square-shaped canopy designs of different sizes and the same length of suspension rope. Figure 4 is an example of the results of group 4 students' answers to the LKPD given.

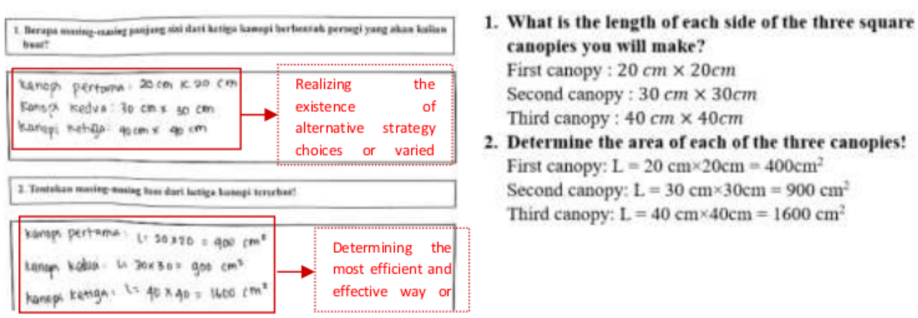
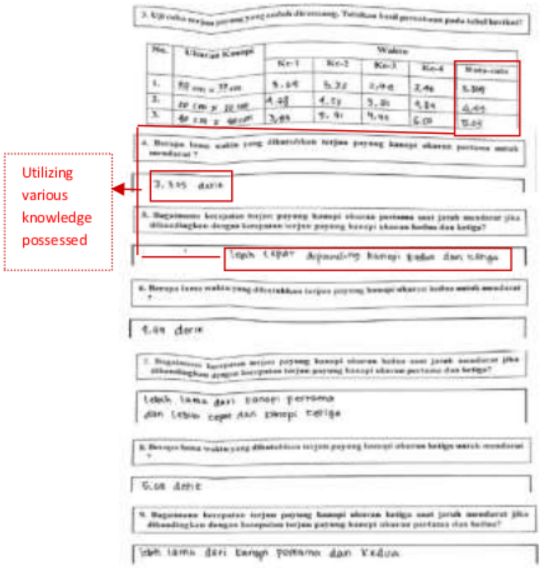


Figure 4. Completion of point 1 and 2 activity 1

Based on the answers shown in Figure 4, students can determine each side length of the three-square canopies to be made correctly. Students choose the length of the square side based on the size of the canopy with the length of the suspension rope which is 60 cm. They stated that the reason why they did not choose the canopy size of 10 cm was that the canopy was too small, and that the length of the suspension rope was a consideration. Answers from student work are included in realizing the existence of alternative strategy options or varied solutions where students can determine their choices from 11 varied solutions. Furthermore, students can determine the respective areas of the three canopies so that students fulfill the process of determining the most efficient and effective way. Students determined the area of the three canopies using the square area formula $s \times s$ completely and correctly. However, there are students who do not determine the area of the three canopies, determine only one of them, and are wrong in the calculation operation.



3. Test the designed parachute plunge. Write down the results of the experiment in the table below!

No.	Canopy size	Time				
		1st	2nd	3rd	4th	Avarange
1.	20cm x 20cm	3,84	3,33	2,79	3,46	3,305
2.	30cm x 30cm	4,78	4,53	3,81	4,84	4,49
3.	40cm x 40cm	3,96	5,71	4,45	6,00	5,03

4. How long does it take the first size canopy parachute to land?
3,305 sec

5. What is the parachuting speed of the first-size canopy on landing when compared to the parachuting speed of the second and third-size canopies?
Faster than the second and third canopy

6. How long does it take for the second size canopy parachute to land?
4,49 sec

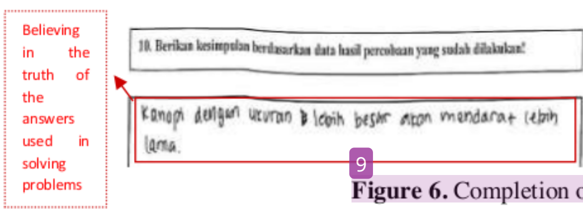
7. What is the parachuting speed of the second-size canopy on landing when compared to the parachuting speed of the first and third-size canopies?
Longer than the first canopy and faster than the third canopy

8. How long does it take a third size canopy parachute to land?
5,03 sec

9. What is the parachuting speed of the third-size canopy at drop landing when compared to the parachuting speed of the first and second-size canopies?
Longer than the first and second canopies

Figure 5. Completion of points 3 to 9 activity 1

Parachuting is tested, and students utilize a variety of knowledge to solve the problem as shown in Figure 5. Based on four trials, students can calculate the average time it takes for the parachute to land. Furthermore, students can determine the time it takes for each parachute to land. In addition to determining the time required, students also compare the speed between the first size parachute and the second size parachute, the second size parachute and the third size parachute, and the first size parachute and the third size parachute. However, there were students whose parachutes failed or were damaged during the trials, affecting the average time, landing time, and speed comparison of the three parachutes to be less precise.



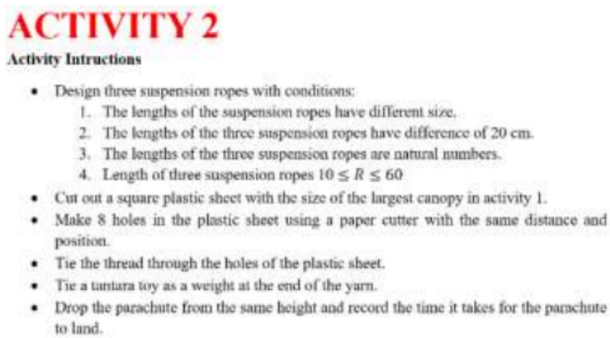
10. Draw conclusions based on the data from the experiment!
Canopies with larger sizes will land longer

Figure 6. Completion of points 10 activity 1

Based on Figure 6, after the process of designing parachuting and testing, students believe in the correctness of the answers used in solving the problem. Students can draw the conclusion that the larger the canopy, the longer the parachute landing time or the smaller the canopy, the faster the parachute landing time. Some students give conclusions that are not in accordance with the results of the experiments conducted.

Activity 2: Create three square-shaped canopy designs with the same size and different suspension rope lengths

Similar to the learning carried out in activity 1, at the beginning of learning the researcher conveys the learning objectives to be achieved and recalls the previous learning. Details of LKPD activity 2 of the second meeting are shown in Figure 7.



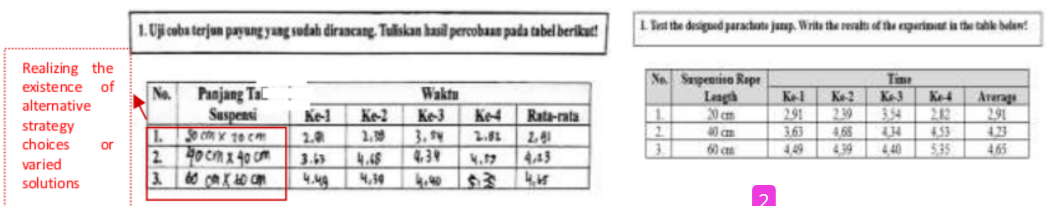
ACTIVITY 2

Activity Intructions

- Design three suspension ropes with conditions:
  1. The lengths of the suspension ropes have different size.
  2. The lengths of the three suspension ropes have difference of 20 cm.
  3. The lengths of the three suspension ropes are natural numbers.
  4. Length of three suspension ropes $10 \leq R \leq 60$
- Cut out a square plastic sheet with the size of the largest canopy in activity 1.
- Make 8 holes in the plastic sheet using a paper cutter with the same distance and position.
- Tie the thread through the holes of the plastic sheet.
- Tie a tantara toy as a weight at the end of the yarn.
- Drop the parachute from the same height and record the time it takes for the parachute to land.

Figure 7. LKPD Activity 2

In LKPD activity 2, each group was asked to make three square-shaped canopies with the same area and different suspension rope lengths. The following is an example of group 7 students' answers to the activity 2 LKPD given.

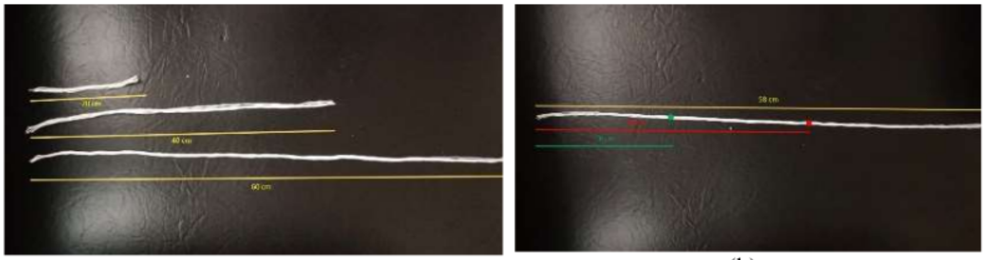


No.	Suspension Rope Length	Time Ke-1	Ke-2	Ke-3	Ke-4	Average
1.	20 cm	2.91	2.39	3.54	2.82	2.91
2.	40 cm	3.63	4.68	4.34	4.53	4.23
3.	60 cm	4.49	4.39	4.40	5.35	4.65

Figure 8. Completion of Points 1 Activity 2

Based on the answers shown in Figure 8, it can be seen that students can determine the length of each suspension rope of the three parachutes to be made correctly. Students chose the length of the suspension rope based on the size of the suspension rope with the largest canopy size in activity 1. They stated that the reason why they did not choose the 10 cm rope length was because the length of the rope was too short, and the size of the canopy was the largest so it was taken into consideration. These answers are realizing the existence of alternative strategy choices or varied solutions where students can make their choices from 11 varied solutions.

In the indicator of determining the most efficient and effective way or strategy in solving problems, where students can cut 8 strands of yarn each with three selected lengths as shown in Figure 9a. Some students can cut the yarn with the longest size and then marked for the second and third size yarn then tested and cut afterwards shown in Figure 9b.



(a) (b)

Figure 9. Cutting Yard as Suspension Rope Activity 2

Parachuting was tested, students utilized a variety of knowledge to solve the problem as shown in Figure 10. Students can calculate the average time of the three parachutes when they land through four trials. After that, students can compare the speed between the first suspension rope length parachute and the second suspension rope length parachute, the second suspension rope length parachute and the third suspension rope length parachute, and the first suspension rope length parachute and the third suspension rope length parachute.

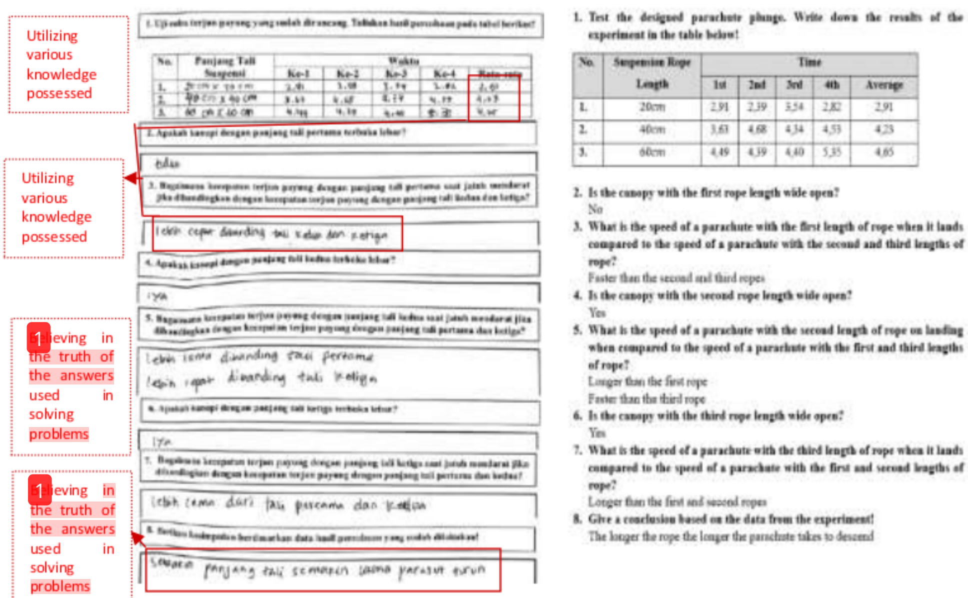


Figure 10. Completion activity 2

However, there were students whose parachutes failed or were damaged during the trials, affecting the average time, and speed comparison of the three parachutes to be less precise. Students can draw the conclusion that the larger the canopy, the longer the parachute landing time or the smaller the canopy, the faster the parachute landing time. This shows believing in the truth of the answers used in solving problems. There were some students who give conclusions that were not in accordance with the results of the experiments conducted.

Activity 3: Create three different 2D shape canopy designs with the same canopy area and suspension rope length.

Not significantly different from activity 1 and activity 2, the researcher conveyed the learning objectives to be achieved at the beginning of learning and recalls the previous learning. Details of the LKPD for activity 3 of the last meeting are shown in Figure 11.

Figure 11. LKPD Activity 3

In LKPD activity 3, each group was asked to make three different 2D-shaped canopy designs with the same canopy area and suspension rope length. The following is an example of group 8 students' answers to the activity 3 LKPD given.

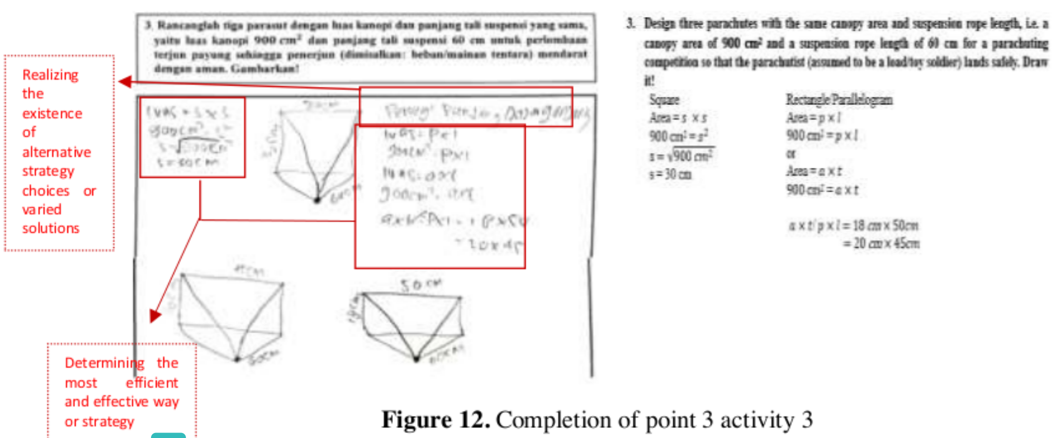


Figure 12. Completion of point 3 activity 3

Based on the answers shown in Figure 12, it can be seen that students realize the existence of alternative strategy options or varied solutions by choosing square, rectangle, and parallelogram. There were students who are aware of the options but only used two different types of quadrilaterals. Furthermore, students determined the length of the sides of the rectangular canopy from the known area based on its properties which are included in determining the most efficient and effective way or strategy. However, there were students who did not consider the length and width of the parachuting canopy so that the resulting parachuting is not ideal to be less precise.

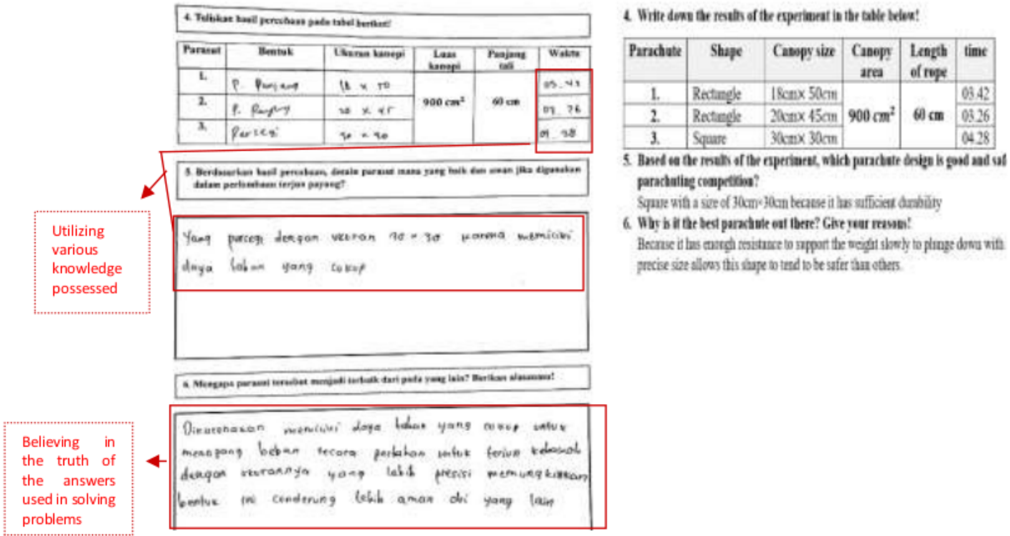


Figure 13. Completion Activity 3

The parachute had been designed and tested, students utilized the various knowledge they had and believed in the truth of the answers used to solve the problem as shown in Figure 13. Students can determine the shape and size of the canopy they will make. After that, students determine the parachuting time to land. Based on the results, students can determine a good parachuting design appropriately. Finally, students provide conclusions in the form of reasons why the parachute is the best of the others. Students can provide reasons for choosing a parachute based on the longest landing time and considering the precise size of the canopy so that the landing is safe, but there are students who are less precise in providing reasons related to the criteria of the ideal parachute.

Activities involving a parachuting context have the potential to attract student interest in learning. This aligns with Mahardika et al. (2023) opinion that parachuting context activities make learning more interesting and not monotonous; help clarify the concepts taught, facilitate understanding of the material, and provide variations in learning methods so that students are actively learning. Agusta (2021) also stated that the use of context can encourage students to explore situations that involve identifying relevant elements, creating schemes, and visualization to find patterns, to develop conceptual models that are in accordance with concrete circumstances.

STEM-based learning integrates science, technology, engineering, and math through a project or activity to solve problems (Allanta, 2021). In line with research conducted by Hardani (2020) when implementing it, mathematics acts as a foundation that connects or unites other sciences in STEM. Mathematics provided the methods and techniques used to calculate the surface area of the parachuting canopy. 2D shapes concepts are used to measure the shape and area of the canopy. Science provides knowledge of gravity and speed. The area of the parachuting canopy causes resistance to the wind (the frictional force of air against the force of gravity) which can reduce the speed of the fall (Asmianto et al., 2016). When students do a parachuting trial, they measure the speed of their landing. However, students made errors in determining the speed by using the average time the parachute landed as a substitute for the actual speed. According to Purwati & Jazuli (2023), this can happen because each STEM component in schools is still taught separately. Students may not always see the connection between concepts in STEM components, as they are separated into different subjects.

Technology is used to see the making of the parachute, the process of the parachute landing, and the tools used to calculate time. Rahmaniar & Abdul Latip (2021) argued that using technology as a supporting medium helps students gather information. Engineering is shown where students play the role of parachuting designers. Relevant to Sastradiharja & Febriani's (2023) opinion, engineering activities are used to encourage students to design, make decisions, increase knowledge and skills and provide opportunities to expand knowledge through creative problem solving and investigation. The activities carried out involve real situations that require the application of various strategies in solving them. In line with Machmudah & Siswono (2019) research, students will adapt to changing situations and try various strategies to solve problems. Wijaya et al. (2020) findings explain when students make a parachute showing the product in an effort to solve real-life situation problems. Ishak said that implementing STEM can develop students' ability to build flexible thinking habits. Students are able to adapt to new situations and ideas (Vylobkova & Heintz, 2023), generate many varied ideas (Hermawan et al., 2019), see problems from various points of view, and apply concepts with diverse approaches (Rahmawati, 2021).

CONCLUSION

Based on the research results, it can be concluded that the STEM-based 2D shapes learning design in the context of parachuting that has been designed and tested is able to support students to understand 2D shapes material and encourage students to use flexibility ability during the learning process. The 2D shapes learning trajectory contains activities to create three square canopy designs with different sizes and the same suspension rope length, activities to create three square canopy designs with the same size and different suspension rope lengths, and activities to create three different quadrilateral canopy designs with the same canopy area and suspension rope length. Activities with a parachuting context are able to help students understand the problems given and can lead students to realize the existence of alternative strategy options or varied solutions, utilize various knowledge possessed, determine the most effective and efficient way or strategy, and believe in the correctness of the answers used in solving the problem. This finding confirms that the resulting learning trajectory contributes to a positive learning experience as it involves active participation and increases students' motivation to learn. There was a hitch in this study where there was damage to the parachute that students made before it was tested. Therefore, it is important to manage time and discipline students in the process of making the parachute.

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