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Students' informal strategy on calculating the volume of three-dimensional shapes in STEM learning project: design bakpia carton

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Abstract

The problem of learning on surface area and volume of solid shapes that often arises is that learning is always carried out deductively mechanistically, meaning that students teach definitions, formulas, practice questions, then applied questions from the formula. The negative impact is that many students understand the concept of volume and surface area as a rigid tool, which cannot be used in different situations, such as when calculating the volume of a box containing solid food, dividing the volume of the container by the volume of one food to calculate its quantity even though solid food leaves empty space, so the formula cannot be used just like that. This article aims to describe how flat shape learning design in STEM learning projects: The design of a bakpia container helps students understand the concept of Volume and surface area by bringing up various flexible calculation strategies, and not only focusing on formulas but gaining a more complete understanding of volume and surface area. A research technique called design research is used to create the design. The Gravemeijer research design model is assessed in terms of the learning trajectory of hypotheses on 3D volume objects in the initial design, experimental design, and retrospective analysis. This study contributes to learning theory and useful tools based on an approach that supports student learning and adds to the instructional theory of volume of flat shapes, namely, the meaning of volume and surface area of geometric shapes through informal strategies such as filling layers. This learning design can help teachers provide better learning volume and surface area of geometric shapes.

Keywords: Design Research, RME, STEM, Three Dimensional Shapes, Informal mathematics

Mathematics emerged as a science due to human activities (Albab, Hartono, & Darmawijoyo, 2014). Mathematics develops from various activities such as counting the number of livestock, buying and selling, accounts payable, and so on. Along with the development of human activities, mathematics also develops in the world which includes things that are very detailed, one of which is Three-dimensional shapes. These various activities require people to master mathematics so that mathematics becomes a science that is neatly arranged deductively. Mathematics consists of a collection of definitions, theorems, postulates, and so on. Mathematics learning to the community is carried out using a deductive approach as mathematics is a structured and ready-to-use science (Gazali, 2016). However, competence is now starting to develop towards a higher cognitive level. Learning mathematics that is ready to use becomes irrelevant considering the situation of the development of human activities is very complex so rigid mathematics cannot be used just in that manner.

Not without reason, but learning mathematics in schools that focus on the finished form of a mathematical formula brings many bad effects. Students focus more on using formulas and tend to memorize procedures without understanding the relationships between concepts (Mytra, P., & Christi, S. R. N., 2024). For example, when calculating the volume of a box containing solid food, student directly dividing

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the volume of the container by the volume of one food to calculate its quantity. This drive to misconception of the volume formula as solid food leaves empty space. This is massively occurred on mechanistic mathematics setting class. Then, how do you set up learning about volume and surface area that provides a whole understanding of the concept?

Mathematics is a human activity, so it is highly recommended to use activities to teach it. Freudenthal (Gravemeijer & Terwel, 2000) suggested that mathematics learning be returned to its context through activities that are close to students. Learning mathematics requires a didactic context that leads to the formation of formal knowledge from students' intuitive knowledge. Intuitive knowledge or what is called informal knowledge has the advantage that it is original knowledge from students, is flexible according to students' cognitive development, and can be generalized according to needs after going through the process of comparing, testing, and associating in collaborative activities with other students. There are many activities in everyday life that can be used as a context for learning mathematics. One mathematician education expert suggested context criteria. Van den Heuvel Pan Huizen (Nursyahidah, & Albab, 2021) emphasizes that context must meet the criteria of 1) making it easier for students to solve a problem or get a concept, 2) describing the problem in detail and be literate, and 3) provide instructions solution to the problem. Interestingly from the context criteria, the context must provide extensive information and provide literacy to students. Whereas literacy and numeracy are the basic needs of students in 21st-century learning. One of the powerful activities that contain literacy and numeracy context relevant to support understanding of volume and learning area is STEM.

STEM (Science, Technology, Engineering, and Mathematics) is a form of learning that combines at least two of the knowledge included in STEM. According to Kelley & Knowles (2016) STEM is an approach to the learning process in form of STEM that connects two or more types of subjects that are included in STEM. What is interesting here, Sagala (2019) states that STEM involves various learning domains such as skills, knowledge, and values through problem-solving activities in the context of life. STEM in solving a problem uses problem-solving steps by inviting students to think as an engineer. The thinking step in solving the problem is called the Engineering Development Process (EDP).

EDP in STEM has various models (Cunningham, 2018). One of the best models to show an advanced thinking picture of an engineer's thinking pattern is the Jaime Back model. EDP steps in STEM learning are as follows: Identify & define problems, gather information, Identify possible solutions, Create prototypes, Evaluate tests, Refine, and Communicate.

Although learning about volume and surface area of geometric shapes has been done with STEM settings, the learning is still limited to making nets and calculating volumes as in the formula (Rahmawati, P., Adamura, F., & Apriandi, D., 2022; Suryaningsih, W., Sukriadi, S., Arafah, A. A., Muhlis, M., Septika, H. D., & Rahmi, R. P., 2024). For example, there is, namely using a unit cube whose container volume fits and leaves no remaining space. The contents of a container are not always boxes that fit the container. Forms of STEM learning can be in the form of problem-solving activities in the Project format. In the competence of building a flat side space, the STEM project can be started from the problem of packaging cartons for Bakpia Patok which are usually made of paper. Paper as a consumable natural material creates problems, namely the limitations of materials and the need for efficient use of packaging materials. The tighter the bakpia peg container, the more economical the use of materials. The description of the Wadah Bakpia Pathok project in STEM elements is as follows in the Table 1.

Table 1. Project Bakpia Pathok Carton of STEM Learning

Stem Elements	Description
Science	The Bakpia Pathok cardboard design project is right for class VII science learning about environmental conservation
Technology	The materials and tools used in the project to design the bakpia pathok container include letter-size cardboard, styrofoam bakpia media, solatip, adhesives, and stationery.
Engineering	Manipulation of bakpia containers in the form of cube models, prisms, pyramids, etc.
Mathematics	Calculating the volume and surface area of flat-sided shapes by looking at the nets of flat-sided shapes, and filling them in.

METHODS

This study used the research design technique as its research methodology. The goal of research design research, according to Barab and Squire (Kamsurya, 2019), is to provide new ideas, artifacts, and useful models that explain and maybe have an impact on learning using natural laws. A study design that strives to generate and validate the educational theory, particularly learning theory, was employed as the methodology for the research design. The three steps of implementation for the research design research technique are preliminary design, experimental design, and retrospective analysis (Gravemeijer and Cobb, 2006).

Table 2. Step of Design Research Methods

Design Research	Activity
Preliminary design	The stage before performing research is the preliminary stage. At this point, the researcher has studied a number of publications and is getting ready materials including lesson plans, syllabus, Worksheet, pretests, and posttests, constructing HLT, creating instructional videos, and working on the strong bridge project. The researchers' participants, including classroom teachers and lecturers from the mathematics education study program, validate the created instruments. Next, categorize the study's participants into large and small groups.
Design Experiment • **Pilot Experiment** • **Teaching Experiment**	At this, the researcher with model teacher, make a STEM setting class in the two phases. In pilot experiment, Design was taught a small group student. The pilot experiment aimed to review from the student perspective, and to improve the design. Then, in the teaching experiment, we were involving larger amount of student using improvement design
Retrospective Analysis	This stage serves as a conversation stage for sharing learning outcomes, communicating results, transmitting messages, and evaluating future learning with the model teacher and other observers. Next, with the aid of an observer, evaluate the outcomes of the model teacher's student work.

The initial design was a single challenge task to make a container that could hold a cake “bakpia patok” in the shape of a tube using A4 paper. The design did not change much from what was shown in the results. This study used student activity sheets, power points, learning booklets for teachers as teaching guidelines.

We involved several students in the pilot teaching experiment, and students in one class in the teaching experiment. Research data were collected through student work results on activity sheets, video recordings of learning, focus group notes, and open interview sheets. The results of the study were processed by comparing the findings of student strategies during learning, with the results of LAS to reveal the thinking strategies that emerged in developing the concept of volume and surface area of geometric shapes, followed by confirming students' thinking methods through interviews.

RESULTS AND DISCUSSION

There are three activities in this mathematics learning, however, what we will emphasize is learning that uses how students' informal understanding of mathematics appears in the STEM learning project Designing the Bakpia Pathok Wadah project on the topic of volume and surface area of flat-sided shapes. In this activity, students get a situation when a bakpia pathok company asks students to design some good and efficient container designs in function and efficiency as can be seen in Figure 1.

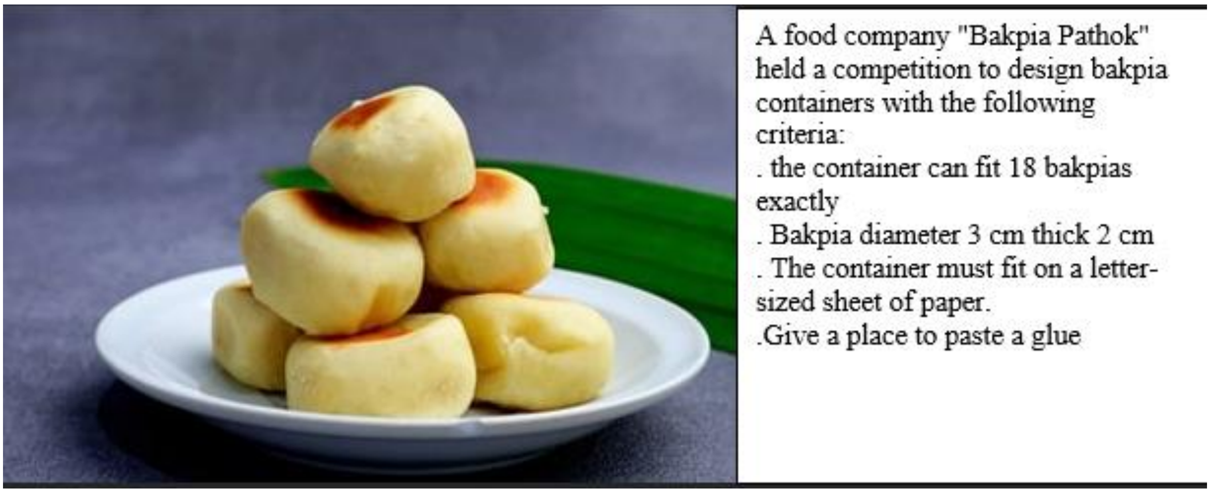

Figure 1. Bakpia Pathok Container Design Competition

Students make a project to design a “bakpia pathok” cardboard project in a STEM learning scheme with several students in one group. Student groups can contain up to three students. We have prepared student activity sheets by following the engineer's line of thinking, namely the Fish Engineering Design Process (EDP) as follows:

Identify & Define Problems

Students identify a contest advertisement for making bakpia pathok designs with certain prizes. Students then identify the container requirements proposed by the company where the container contains 18 bakpias, the diameter of 1 bakpia is 3 cm thick 2 cm. The container is made of letter-sized cardboard.

Figure 2. Students Identify STEM Project Problems

Then the teacher asked the students about the problems contained in the advertisement.

Researcher : "What task should we do if we take up the challenge?"
Student : "Designing a bakpia pathok container appropriate, economical and beautiful"
Researcher : "Good. What information do we have?"
Student : "The container holds 18 where the size of 1 bakpia is 3 cm in diameter and 2 cm thick and fits on letter-size paper.. But we don't understand what letter paper means."
Researcher : "Try to find out on Google".

Based on the results of the interviews above, it appears that students have been able to identify and define problems that must be solved, namely by designing an efficient and effective bakpia pathok container to minimize paper use.

Gather Information

In this section students then look for shapes of bakpia containers that they might use in completing the competition. From this information-gathering activity, students also discovered the meaning of letter-size cardboard. Students list several shapes of containers that they will choose as a bakpia peg container design consisting of cubes, blocks, prisms, and pyramids. Meanwhile, letter size paper is identified as paper measuring 21.59 x 27.94 cm.

Identify Possible Solutions

The number of contents of bakpia in a container is 18 pieces. This means that students must arrange the 18 bakpias in a configuration that makes packing easier. Students design the container by experimenting with variations in the arrangement of bakpia pathok which can affect the shape of the bakpia pathok container that will be made. The following is an example of the arrangement of the pathok bakpia that will be packaged.

Figure 3. Students Arrange Bakpia Models in a 3 x 3 x 2 Configuration; 3 x 2 x 3; 3 x 6; Pyramid

Figure 3 shows the possible solution forms as an informal, original volume concept strategy owned by students. Students do not involve cubic units such as cm3 or m3 to show volume. The shape also appears on the student activity sheet when they determine the configuration of the bakpia arrangement that might be used to make the container.

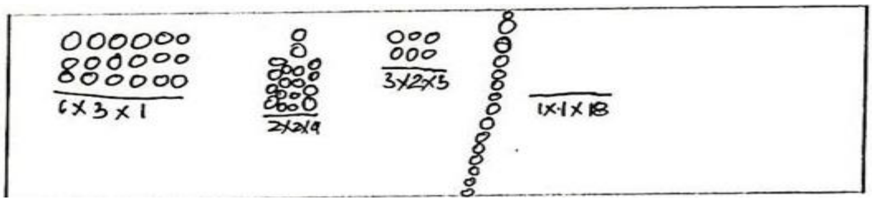

Figure 4. Students Form a 6 x 3 x 1 Configuration; 2 x 2 x 4; 3 x 2 x 3; 1 x 1 x 18

Figure 4 shows clearly how students show the volume of the container from the area configuration times the height of the tool in a 6 x 3 x 1 arrangement; 2 x 2 x 4; 3 x 2 x 3; 1 x 1 x 18. For example, the arrangement of 6 x 3 x 1 shows the capacity of the bakpia container (volume) arranged across 6, longitudinally 3 by 1 layer. This means that bakpia only consists of one layer without being stacked whereas one layer consists of 6 x 3 bakpia. This layer is called the base for calculating the volume of formal mathematics.

Create Prototypes

This EDP section is the stage where students realize the arrangement design in the form of a concrete container in the form of a bakpia pathok container that can take the form of various flat-sided shapes. One group makes a container in the form of a flat-sided shape with instructions from the teacher. The difficulty for students is when converting the contents of the container in informal units (many bakpia) to formal units of cm. Figure 5 shows one of the student's work.

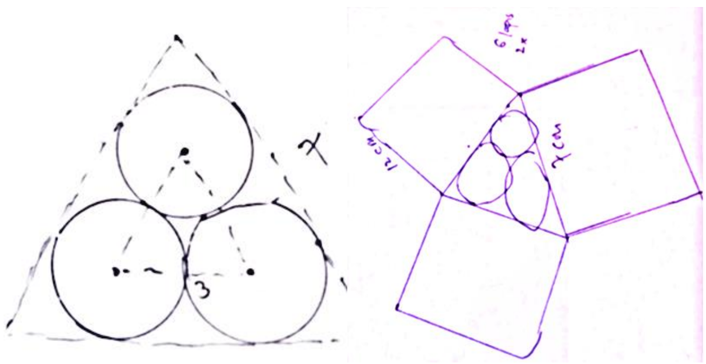

Figure 5. One of the Shapes of the Nets Sketched by Students

Figure 5 shows a sketch of the bakpia container nets that were chosen by students. The nets are triangular prisms. We can see again one of the arrangements in Figure 2 which is an arrangement of bakpia with 6 layers where each layer consists of 3 bakpia. Students have difficulty converting bakpia to cm as shown in Figure 4 on the left. Students calculate the side of the triangle to be 7 cm. while the height of the prism is 2 x 6 layers = 12 cm (*sisi 2x* on the right picture). Of course, if this calculation is wrong, the bakpia cannot fit in the container. Another way that students do is to arrange 3 bakpia directly on the cardboard and then draw an equilateral triangle that contains three bakpia.

Evaluate of Test

After the prototype of the Bakpia Pathok container project is finished, the next step is to carry out testing and evaluation. The pilot stage is the part to test efficiency, precision, and innovation. In the efficiency test, students test whether the container is able to fit the bakpia properly, not too tight, nor does it leave empty space. The student's precision test assesses the prototype in the use of cardboard, indicated by the size of the nets in cm, and should not require additional cardboard.

Refine

After conducting trials and evaluations, the next stage is revising the project design. Improvements to the design of each project are carried out after finding project weaknesses. Weaknesses can be seen in the empty space, inaccurate size precision, or the wrong design. Students make revisions by changing the model/design of the container, adding or subtracting the required materials, and changing the size. Consider the case of the following cube-shaped bakpia container:

Figure 6. An Example of a Container Design Showing a Weakness

Figure 6 shows a student presenting the design of a cube-shaped bakpia container. He obtained the design from the 2 x 2 x 4 +2 configuration. This means that in each layer of the stack, there are 2 x 2 = 4 bakpia, as many as 4 layers. But left 2 bakpia, so he added the height of the container for the remaining 2 bakpia. Consequently, there is an empty space that can fit two bakpias. This inaccuracy in the design of the container prevents the bakpia from being loaded tightly so that it can wobble and cause the bakpia to crumble

Communicate

This stage is the last stage of EDP in the STEM approach. Each group communicates or presents to other groups related to the result of their project.

Student Informal Strategy in Developing the Concept of Volume

Mathematics emerged as a science due to human activities such as counting the number of livestock, buying and selling, accounts payable, and so on. Along with the times, the human need for mathematics has become a necessity. Mathematics then develops into a ready-made form, consisting of a collection of definitions, theorems, postulates, and formulas that are ready to be swallowed by the community. However, 21st-century competencies no longer require mathematics as a tool to calculate but develop as a problem solver. The mathematics needed is no longer rigid mathematics and memorizing formulas, but rather a mastery of concepts (Wijaya, Zakiah, & Sunaryo, 2018).

Learning mathematics through activities fosters student creativity to develop their own mathematical knowledge naturally. Intuitive knowledge/informal knowledge is owned by every human being, it's just a matter of how the teacher guides students to use it in various contexts (Albab, Hartono, & Darmawijoyo, 2014). Learning designs that contain various didactic contexts help students develop formal mathematical knowledge that can be used in all situations. Natural knowledge grown by students has various advantages including flexible knowledge (van Galen & van Eerde, 2013) according to students' cognitive development, and can be generalized according to needs after going through the process of comparing, testing, and associating in collaborative activities with other students. In addition, students have a broad and thorough understanding of mathematics, are flexible to the volume and surface area of flat-sided shapes, and gain other skills such as creative, innovative, and critical thinking (Hedayani, 2018).

STEM learning with a bakpia container design project gives students the opportunity to use their intuitive understanding of volume. Informally, students show the strategy of calculating the contents (volume) is the amount of space that can contain the exact contents that will be put in the container. Calculate the volume can be done by multiplying the number of layers by the number of contents of the arrangement in one layer. For example, a block container can contain 3 x 2 bakpia in 1 layer whereas the container can accommodate 2 layers (pile of bakpia). This is in accordance with the concept of the volume area of the base times the height. In addition, students can also concretize the shape of the bakpia container design through nets with precise sizes. This shows that students in this study do not have difficulty abstracting or concretizing the situation of the volume of flat-sided spaces in the form of nets as in the study of Fitriani, Suryadi, and Darhim (2018).

In the case of the incorrect bakpia container (Figure 6), the students showed us clearly that volume is not just a matter of calculating V= p x l x t. Calculate for sure this shape gives rigidity. Students who are already studying formal mathematics can easily calculate the size of the volume of a container by multiplying the volume of 1 bakpia x 18. In the STEM learning project above, the size of bakpia is 3 cm in diameter, 2 cm thick. The volume of the container becomes.

$$V = \pi \, r^2 t \; .18$$

$$V = \; \pi \; (1.5)^2 .2 \; .18 \qquad \text{............(1)}$$

where V is the volume of the container
r is the radius of 1 *bakpia*,
t is the thickness of the *bakpia*

The calculation is indeed not wrong, but it does not make sense because the cylindrical bakpia cannot fit together properly when arranged in a container. This kind of ready-made mathematics learning creates problems in students' lives later.

CONCLUSION

Design learning on volume and area of 3D flat shape helps student to understand whole understanding of the concepts. Student uses intuitive understanding of volume as content. The strategy of calculating volume informally using multiple contents and layers helps students understand the concept of volume thoroughly. It is highly recommended for teacher to design or use this design because in real-world situations, formula is not always applicable as content of container not always be fits to the container.

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