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Designing geometrical learning activities assisted with ICT media for supporting students' higher order thinking skills

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Abstract

Students' mastery of geometry topics affects their ability to understand other mathematical topics. In addition, students are required to have higher-order thinking skills. Previous research shows that ICT media played an important role in improving students' higher-order thinking skills. This study was carried out to produce a cuboid volume learning trajectory in ICT-assisted learning that can support students' higher-order thinking skills. This research employed validation design which consisted of three main stages, namely preliminary, experiment, and retrospective analysis. It was held during two main cycles. Sixty-four students of the eighth-grade in Palembang, Ogan Ilir, Manado, and West Papua were involved as research subjects. Data were collected through validation sheets, observations, interviews, and documents in the form of student worksheets. Then, the data were analyzed qualitatively and described narratively. The learning design developed was able to help students use higher-order thinking skills where students analyzed, evaluated, and used their creativity in answering the problems given. The results of this study can inform the policy making for teachers in designing mathematics learning and for lecturers to carry out mentoring for teachers in designing mathematics learning based on Realistic Mathematics Education (RME) and ICT media.

Keywords: Design Research, Geometrical Learning, Learning Trajectory, ICT Media, Higher Order Thinking Skills

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Geometry is one of mathematical topics taught in the school. Students need to understand geometry to support their understanding of other topics such as algebra (Barana, 2021) and calculus (Zengin, 2021). A good understanding of geometry will help students understand algebraic topics such as an understanding of the root solution of quadratic equations (Fachrudin et al., 2014) and an understanding of Rieman's quantities on the topic of calculus (Jones, 2015). Thus, students' mastery of the geometry topics affects their ability to understand other mathematical topics.

Higher-order thinking skills (HOTS), as the top thinking skill levels in Bloom's taxonomy, become an important aspect in teaching and learning (Adams, 2015). They include the ability to think at the level of analyzing, evaluating, and creating ideas (Brookhart, 2010). These abilities are very important for the achievement of 21st-century competencies that consist of critical and creative (Setiawan et al., 2018), collaborative, and communicative thinking skills (Collins, 2014). Students with higher-order thinking skills can improve their performance (Tanujaya et al., 2017) and reduce their weaknesses (Ahmad et al., 2018). The importance of higher-order thinking skills for students affects the orientation and structure of the curriculum in Indonesia (Tanudjaya & Doorman, 2020). Therefore, teachers need to carry out HOTS-based mathematics learning in the classroom (Ariyana et al., 2018).

The Programme for International Student Assessment (PISA) measures students' mathematical abilities in the world including students' higher-order thinking skills (OECD, 2018). Achievement data in PISA results in 2018 shows that the score of Indonesian students in mathematics was still low (OECD, 2019). Indonesian students are only able to solve questions with Lower Order Thinking Skills (LOTS) and a few questions at the HOTS level (Tanudjaya & Doorman, 2020). These indicate that Indonesian students' HOTS needs attention. The low PISA results of Indonesian students raise the question "Why is that?", "Why is it difficult for Indonesian students to solve PISA questions in the form of questions at a high level?". One possible answer is the learning factor (Tambunan & Naibaho, 2019). In mathematics learning, in general, learning materials are delivered in a traditional way, where the teacher actively explains concepts to students and does not promote students' higher-order thinking skills (Tanujaya et al., 2017). In such as learning, students are not accustomed to solving HOTS problems. They tend to master routine problems, simple computations, which emphasize the memory aspect and do not train students' higher-order thinking skills (Pratama & Retnawati, 2018).

Considering the situation that the students' HOTS is low, the question "how to improve students' higher-order mathematical thinking skills" emerges. Teachers' efforts are needed in designing learning activities that contain teaching materials (Sofiyan et al., 2020), learning media (Komarudin et al., 2020) and even assessment tools that can be used to train higher-order thinking skills (Ahmad et al., 2018).

The development of science and technology requires that the learning process is no longer centered on teachers, but it should be student-centered (Neumann, 2013). One of the learning approaches is Realistic Mathematics Education (RME). In Indonesia, it is called PMRI (Pendidikan Matematika Realistik Indonesia). It is adapted from RME developed by Hans Freudenthal (Prahmana et al., 2012). It is a learning theory that emphasizes the process of learning mathematics as a human activity (van den Heuvel-Panhuizen, 2020). In this approach, the teacher facilitates students to build their mathematical knowledge through activities (Fitri & Prahmana, 2020). Therefore, PMRI is considered capable of supporting students in understanding mathematical concepts (Laurens et al., 2018).

Another factor that can support the success of mathematics learning in the classroom is the use of learning media (Ahern, 2016). Learning media can help students in improving their understanding. In addition, learning media are useful for presenting data attractively and reliably, facilitating data interpretation and condensing information (Darmawan & Suparman, 2019). One of the innovative mathematics learning media is Information and Communication Technology (ICT) media (Pereira et al., 2020). ICT refers to various forms of technology used to transmit, process, store, create, display, or share information electronically (Harsa, 2016). The use of ICT creates engaging mathematics learning because the emotional involvement of students will affect memory of the material they are studying (Zainil et al., 2018).

Several previous studies, especially related to ICT media, show that the use of ICT media contributes to the increase of student performance in secondary schools such as the use of applet improving students' performance in algebra (Jupri, 2015), symbol sense (Bokhove & Drijvers, 2010), and learning plane and solid figure (Zainil et al., 2018). Even the use of ICT media has a very good role in mathematics learning in elementary schools (Kolovou et al., 2011). Prior research shows that visual media can improve student performance in solving mathematical problems (Hoogland, 2016). However, it is only limited to discussion of the problem representation in the form of pictures, the effect of its use on students' problem-solving abilities, and its comparison to the problem representation given in a sentence description. Another study also shows that visual learning is able to improve students' higher-order thinking skills (Raiyn, 2016). In fact, besides visual media, there are also audio media and audiovisual media. Sometimes, using one picture is not enough for presenting the problem. Thus, it is possible to use other types of media such as audio-visual media in presenting mathematical problems in classroom learning. Considering the importance of students' higher-order thinking skills, the role of ICT media, and the design of the mathematics learning process in the classroom, this research is aimed at designing realistic mathematics learning assisted by ICT media that is able to support students' higher-order thinking skills.

METHODS

Validation study is employed as the research design to achieve the research objectives. There are three main stages in the research, namely the preliminary design, the design experiment, and the retrospective analysis (Bakker, 2019). This research was conducted in 2 main cycles. In each cycle, there are 3 stages of the design research.

Preliminary Design

In cycle 1, the researcher designed a sequence of learning activities that contained the alleged learning trajectories of students in ICT-assisted cuboid learning predicted to be able to help students develop higher-order thinking skills in learning the topic. The alleged learning trajectory is called Hypothetical Learning Trajectory (HLT) containing the learning objectives to be achieved, activities, and anticipation of how students think and the strategies used. It is dynamic and adjusted to the results of the implementation of the design experiment. In this stage, the researcher also conducted a literature study on geometry learning assisted by ICT media and learning-oriented to students' higher-order thinking skills. In addition, the researchers conducted a preliminary study on students related to abilities, difficulties, and strategies that students usually use to solve problems based on the students' higher-order thinking skills. This initial study was conducted to complement the literature study which aims to design a learning starting point. At this stage, the researcher also developed the learning tools used such as the learning plan, students' worksheets, and ICT media. The ICT media used are video media developed by researchers and other ICT media such as web-based media developed by Freudenthal Institute. The learning tools designed were then validated by several experts. After designing the HLT and preparing validated learning tools, the researcher then prepared the next stage, the design experiment.

Design Experiment

At this stage, the researchers implemented the sequence of activities and conjectures of students' thoughts designed at the preparation stage. This stage aims to improve students' learning trajectories in learning cuboid volume assisted by ICT media and find out the design of the cuboid volume learning trajectory that helps students develop higher-order thinking skills. The experiment tested five activities that emphasized mathematical ideas in learning the cuboid volume and students' learning processes. There are two types of design experiments, the pilot experiment in cycle 1 and the classroom experiment in cycle 2. In the pilot experiment, five activities were tested on several students to see how the small group of students worked in the sequence of activities designed in cycle 1. In the teaching experiment in cycle 2, the revised HLT was then re-tested to students in learning carried out in one class. Before carrying out each activity, the researcher and teacher discussed the upcoming activities and reflected at the end of each activity. During the experiment, all data including class observations, interviews, and student activity sheets was collected. This data was then analyzed in the next stage, namely the retrospective analysis stage.

Retrospective Analysis

After collecting data during the design experiment, the researchers analyzed all the data and obtained the results of the HLT evaluation. Based on the results of this stage, the HLT was developed and tested again in the next cycle. At the end of the second cycle, the researcher found the answer to the research question of how the learning trajectory of cuboid volume material in ICT-assisted learning can help students develop higher-order thinking skills.

The subjects of this research are junior high school students who are approximately 14 years old and in the 8th grade of junior high school. The research subjects were from several schools in Palembang, Ogan Ilir, Manado, and Papua. The research subject selection considered that the research was carried out offline and online. The offline part was carried out at SMP IT RU Sakatiga Indralaya because it applies direct learning. Since the study was also conducted online during the Covid-19 pandemic, the researchers involved research subjects outside South Sumatra. The research subjects involved are students whose schools were willing to allow their students to become research subjects. Data was obtained using validation sheets, interviews, observations, and documents in the form of student works. Then the data was analyzed and described descriptively.

RESULTS AND DISCUSSION

At the preliminary stage, the researchers conducted a literature study, developed learning tools (see Meryansumayeka et al., 2020), investigated students' difficulties in solving HOTS problems (see Meryansumayeka et al., 2021), designed the HLT and conducted expert validation.

Based on the results of the literature study and the preliminary research, the researchers then designed the HLT for learning the cuboid volume. The designed HLT consists of 5 activities as a series of learning cuboid volumes. These activities are structured with the aim of helping students overcome the difficulties that were identified during preliminary research. The designed HLT contains a series of learning objectives to be achieved, activities, and predictions of the student learning process. The HLT of cuboid volume learning assisted by ICT media is described in Table 1.

Table 1. The HLT of Cuboid Volume Learning

Activity	Main Goals	Conjectures
Connecting the visible and invisible parts	Through observation, students are able to connect the visible and invisible parts of the arrangement of 3-dimensional objects in determining the volume of the object	• Students make a picture of a box with objects that are only visible on the box • Students make a picture of a box by accompanying the pictures of objects in the box • Students are confused about what picture to make
Building based on different views of the cuboid	Through activities in the web-based media, students are able to form a building based on different views of the cuboid	• Students create 3-dimensional images of buildings that match the appearance of the building on web-based media • Students are confused in making pictures

Table 1. (continued)

Determining the cuboid volume	Through observation, students are able to see the multiplication relationship between sides of a cuboid in determining its volume	• Students count the number of boxes in a cardboard by counting the number of boxes in the first layer and multiply it for the second layer and so on • Students use multiplication to count the number of boxes in a cardboard
Determining the size of the cuboid sides	Through activities on web-based media, students are able to determine the size of the cuboid side that meets the criteria for the cuboid volume given	• Students determine the length of cuboid sides whose multiplication corresponds to a known volume • Students arrange unit cubes up to a known volume, then calculate the length of cuboid sides
Solving problems related to measuring the cuboid volume	Through observations and activities on the web-based media, students can solve problems related to measuring the cuboid volume	• Students determine the number of unit cubes by observing the visible and invisible parts • Students determine the number of unit cubes based on the visible part

Then, the designed HLT was validated by experts to see the suitability of the HLT designed with theories and topics of learning and language. In addition, HLT validation was also carried out by several teachers through Focus Group Discussions (FGD). The expert comments were used to revise the HLT so that there was a change in the sequence and number of activities in the HLT.

The HLT which had been validated and revised was then applied to a small group of students in this first cycle. The experiment was carried out to prove the designed HLT and compare it with the actual situation. The trial process was held on groups of students at SMP IT RU directly (face to face) involving six students in this cycle. In addition, HLT trials on small groups of students (approximately six students) were also conducted face-to-face via Zoom Meetings at SMPN 17 Palembang, SMPN Manado, and SMPN West Papua. The teacher model at the time of the HLT trial at SMP IT RU and SMPN 17 Palembang was a teacher at the school.

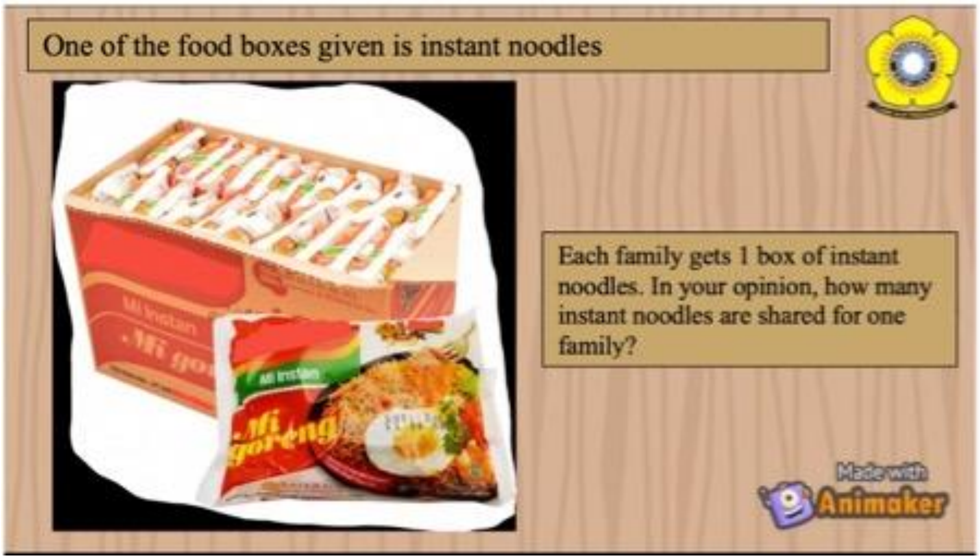
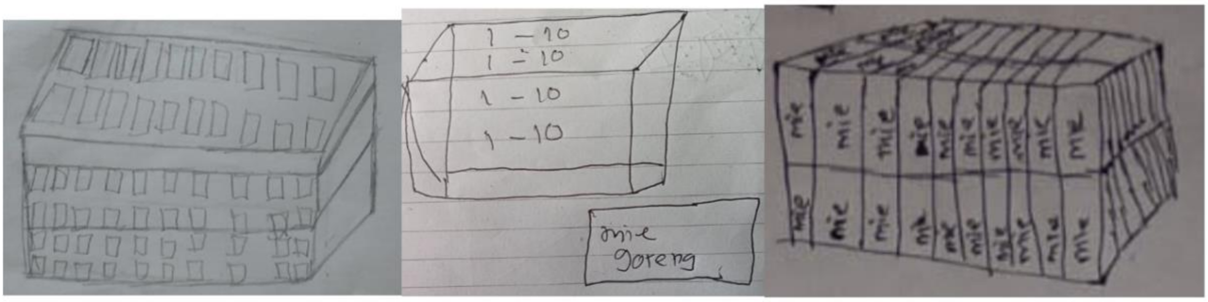


Figure 1. The mathematical problem served on the video

In the beginning of activity 1, the students watched a video containing a mathematical problem. The problem is about determining the number of packs of noodles on the box distributed for a family during pandemics (see Figure 1). After watching the video, students were given a question about the video. Then they were asked to draw the context on the video. Some of the students' drawings are as follows.

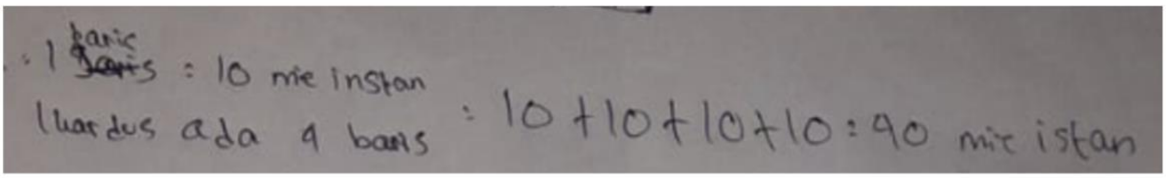


(a) (b) (c)

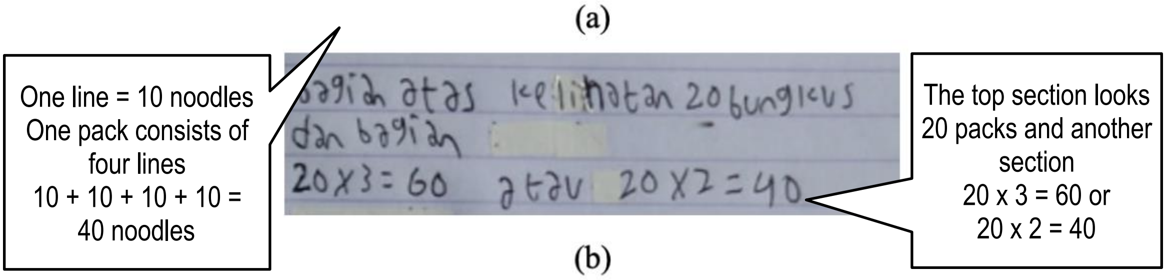
Figure 2. Students' Drawing of Context Given

Figure 2 contains some examples of pictures made by students when they were asked to describe the condition of the noodle box. Most of the students used a rectangular image as a representation of the shape of the noodles in the box and some of them depicted all the noodles in the box as shown in Figures 2 (a) and 2(c). Some students used numbers to mark the number of noodles in a row in a box as shown in Figure 2 (b).

After drawing a picture of the noodle box, the students were asked to determine the number of noodles in the box. Some of the results of students' calculations in offline learning are as follows.



(a)



(b)

Figure 3. Students' Answers in Determining the Number of Noodles

Figure 3(a) shows that the students counted each row and added up four times because there are four rows. Figure 3(b) shows that the students had doubts about the number of piles of noodles. Students estimated the probability that there are 2 or 3 piles, thus providing a probability calculation for two piles and three piles of noodles.

In addition to using video media in presenting mathematical problems, several activities used web-based media to encourage students to make a cuboid. The following is an example of a cuboid construction made by students.

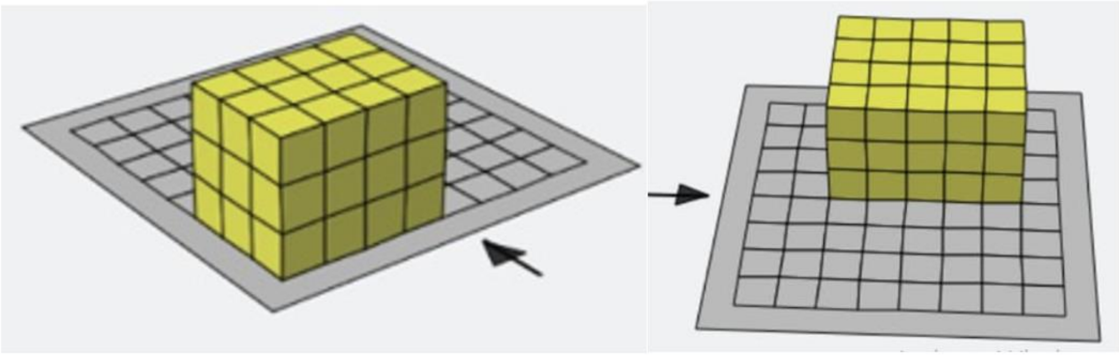


Figure 4. Students' Building Construction

In activities asking students to make cuboids, students were asked to explain the size and volume of the cuboid. Figure 4 shows the various possible cuboid constructions made by the students. The two examples of cuboid construction have different sizes and different volumes.

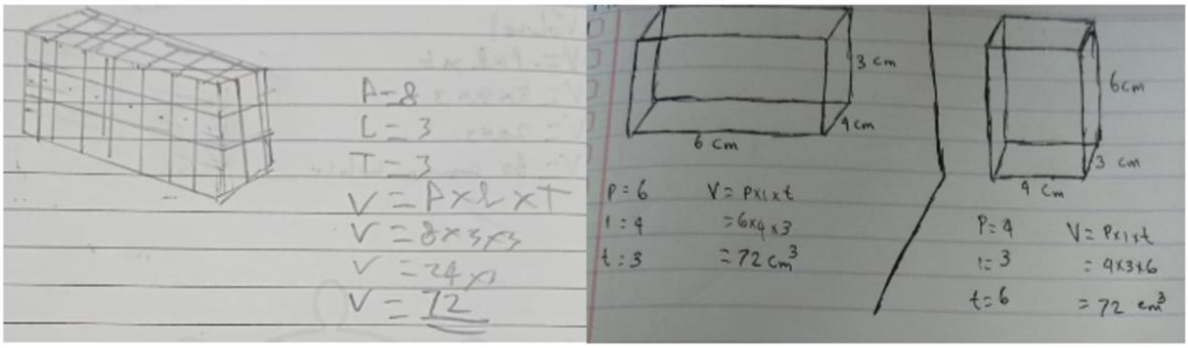
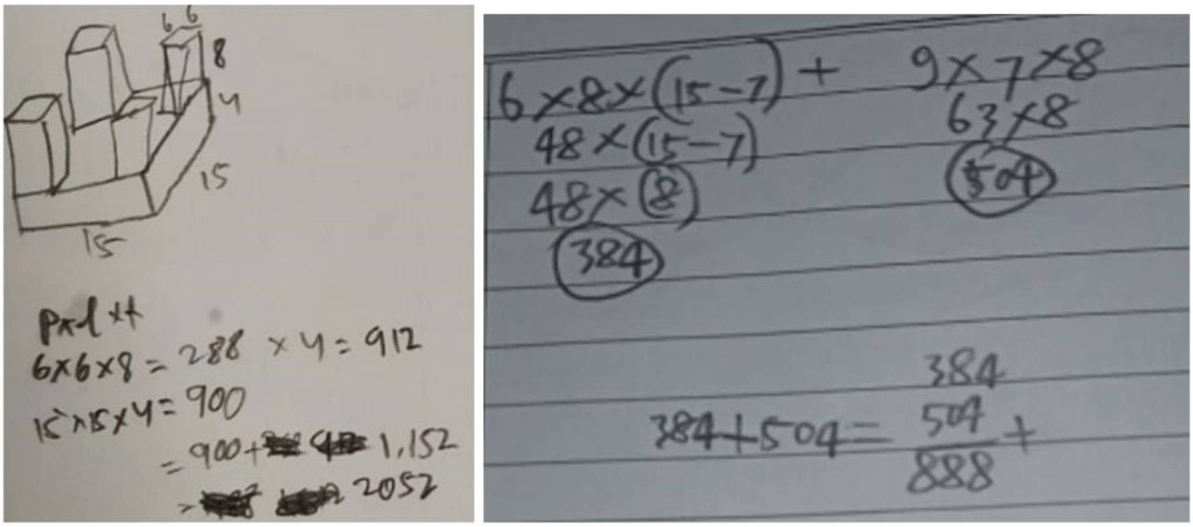


Figure 5. Students' Drawing of Cuboid Having Volume 72 unit

Figure 5 shows some of the students' works in the form of drawings of a cuboid having a volume of 72 units. The two pictures show different cuboid images with different possible cuboid sizes. Some of the cuboids made by students are higher and wider in shape.



(a) (b)

Figure 6. Students' Calculation in Determining Solution

In the last activity, the students determined the volume of the building. Figure 6 shows two students' answers to the given math problem. Figure 6 (a) shows that the students can determine the building volume by dividing the building into several cuboids and determining each cuboid volume. In figure 6 (b), the students present different answers. The final answer obtained is not correct. However, the teacher can take advantage of the differences to figure out how the students in Figure 6 (b) solve the given mathematical problem.

After the students discussed and completed student worksheets, they presented their work. Student G took the first opportunity to present.

T : Explain to us about problem number 1, what is it about, G?
G : About building volume
T : What is the volume of the building according to G?
G : 880
T : How did you get it?
G : (pointing to all the numbers in the picture) 15 x 15 x 4 x 8 x 6 x 6 = 880

As shown in the transcript above, student G tried to solve the problem by multiplying all numbers that appear in the picture. The student did not divide the building into cuboids. Therefore, he got the wrong result in determining the volume of the building. After trying out to the small group of students, the HLT was revised based on the results of the retrospective analysis in the first cycle. The revised HLT is presented in Figure 7.

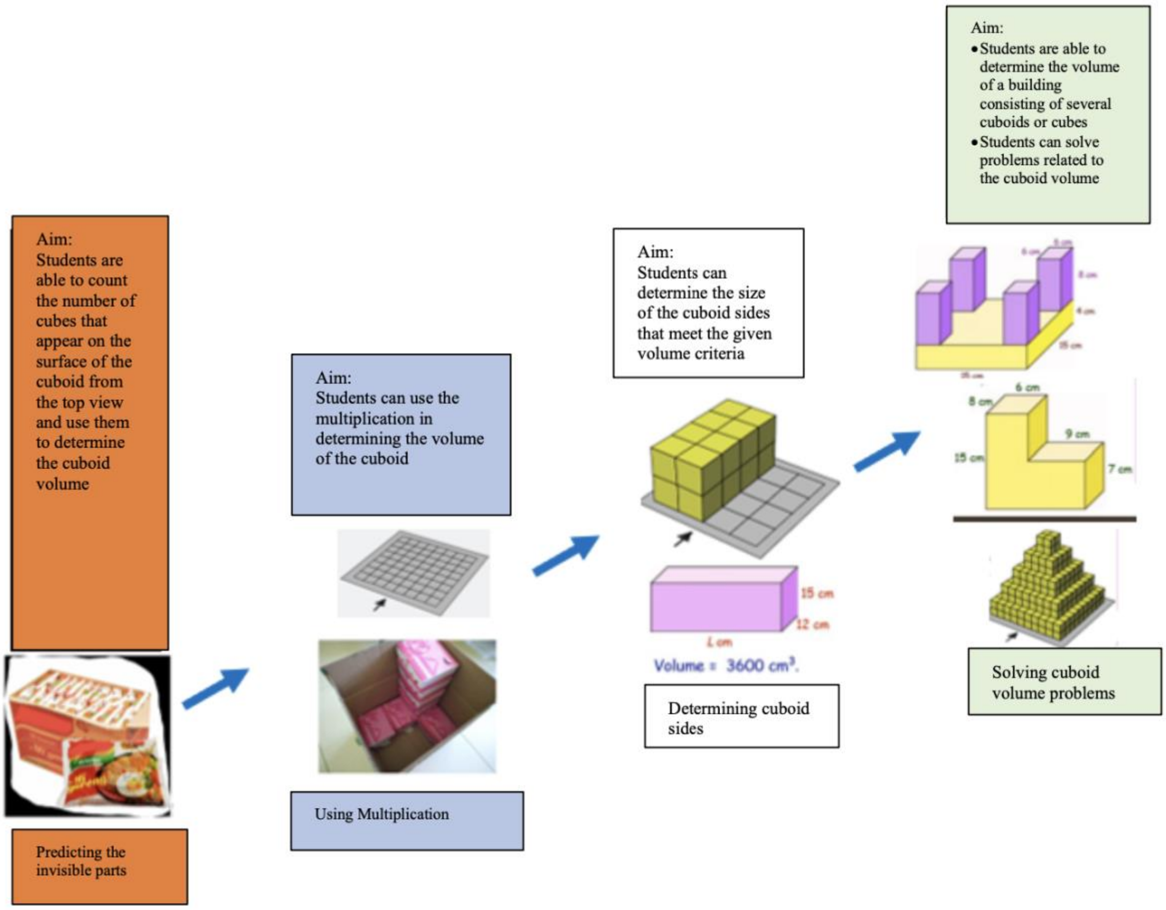


Figure 7. Learning Trajectory for Learning Cuboid Volume

There are no significant changes in the latest HLT. Improvements were only done in activities 1, 2, and 4. The images of the noodle box were deleted in the student worksheet in activity 1. In student worksheet 2, the image of a cuboid composed of unit cubes is replaced with an application display where students will make a cuboid and determine its length, width, and height. At the beginning of activity 4, similar problems were replaced with complex problems. The revised HLT was tested in the second cycle, namely in experiments in one class.

In activity 1, the students were given a problem video containing the context of the arrangement of noodles in a box. Then, the teacher tried to find out whether the students understood the given problem.

T : What is the video about, A?
A : It is about the government distributing groceries to the community during the pandemic. The groceries that were distributed included one box of noodles
G : What is the problem asked in the video?
A : How many noodles are in one box that is distributed?

From the conversation, the students understood the problems presented in the video. The students were able to explain the situation and the problem in the video. The students' answers to the problem given were varied. One of them is as follows.

T : How many noodles in a box?
F : 20, Sir
T : How do you get 20?
F : (counting one by one picture of noodles that appear) 1,2,3, ..20
T : (asking other students in one class) In your opinion, are noodles in a box 20? Who agrees with answer F?
(Some students raise their hands)
T : Is there a different answer? Is answer F correct?
J : It is not, Sir
T : why? How many noodles in a box should be?
J : 40, Sir
T : How do you get 40?
J : The top has 20, the bottom has 20 so they are 40
T : How do you know the bottom is 20?
J : The bottom is the same as the top
T : How do you know if there's a pile at the bottom?
J : There must be something that is piling on the top of the pile so that the position is here
T : How do you know there are 2 piles?
J : Take a look at this noodle, Sir (pointing at the picture of the noodles and estimating the height of the noodles), It's like two piles of noodles
T : What do you think is the correct answer F or J? There are 20 or 40 noodles?
T : Who agrees with answer F? Who agrees with J's answer?
(The majority of students raised their hands indicating agree with J's answer)

From the excerpt of the question and answer, the students' answers to the problems given were varied. Some students tend to count the number of noodles that appear in the picture for determining the number of noodles in the box. However, some students thought that there are 2 piles of noodles in the box. So, there were 40 noodles. The different students' answers were used by the teacher to listen to each student so that the student can use his analytical skill. In addition, the teacher facilitated the students to evaluate the answers of other students. With these two different answers, other students were asked to check and decide which answer was the solution to the given problem.

When students solved the mathematical problem presented in videos, they were enthusiastic about it. It happened because the video media can attract the students' attention (Wang & Antonenko, 2017) and direct students to focus on observing the contents of the video (Guo et al., 2014). In addition, students can retell and understand the problems asked in the video. Understanding the problem is an important part before students begin to take steps to solve the problem (Hoogland, 2016). When students are asked to draw a picture of the noodle box, some students will draw a picture that is like the given situation, make a rectangular symbol to represent the noodle image, and use number symbols representing the number of noodles in a box (Revina et al., 2011). Students can make models that they understand according to the given situation (van den Heuvel-Panhuizen, 2003). The models that students make are various models of the given situation (Sumirattana et al., 2017). The model of the situation made by students can be in the form of an image like the situation, a bar model because the shape of the noodle resembles a rectangular shape, even a number that represents the number of objects contained in the situation (van den Heuvel-Panhuizen, 2003).

In determining the number of objects, the students tend to count objects which are visible (Schindler et al., 2020). It takes students' analytical skills to count invisible objects that contain the capacity of a spatial structure. Another ability that can support students' understanding of the volume of cuboids is the ability of spatial visualization, which is one's ability to understand, process, and think in visual form (Revina et al., 2011). Because the picture of the noodle arrangement in the box did not show all the arrangements of noodles, it invited students to analyze and predict the number of all the noodles in a box. This analytical ability is one of the higher-order thinking skills in mathematics learning (Brookhart, 2010).

In addition, the different answers to the problems given, whether presented in videos or the results of student work when using web-based media, can be used by the teacher to invite students to use their evaluation skills. Students need to investigate the value the other students' answers, give good reasons. logically, and decide which student's answer is correct. Evaluation ability is also one of the students' higher-order thinking skills in learning mathematics (Anderson & Krathwohl, 2001).

In ICT-assisted activities using applications where students are asked to make a cuboid-shaped building structure that has a certain volume, there are various possible building arrangements made by students. Various student answers show various creations that are suitable to the problems given. In addition, students are required to recognize the size of the building and explain why the building they made is suitable for the problems asked. The ICT media used plays a role in encouraging students' higher-order thinking skills (Raiyn, 2016). In carrying out this activity, students are invited to hone their creative skills in constructing buildings that have a known volume. The creative ability itself is the highest level of students' higher-order thinking skills in learning mathematics (Brookhart, 2010).

CONCLUSION

The cuboid volume learning assisted by ICT media developed can support students in understanding the cuboid volume material and encourage students to use higher-order thinking skills during the learning process. The learning trajectory of the cuboid volume contains activities about the relationship between visible and invisible parts for determining the cuboid volume, the relationship between the sides of the cuboid, making cuboids with a certain volume size and determining the size of the sides of the cuboid, and activities to solve related problems with the cuboid volume. ICT media used in this study play an important role in supporting students' higher-order thinking skills. Video media can help students in understanding the problems given and the web-based media provided also play a role in encouraging students to use creative abilities in answering the problems given.

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Declarations

Author Contribution	:	M: Conceptualization, Software, Investigation, Formal Analysis, Writing-Original Draft, Visualization, Writing-Review, and Editing. Z: Resources, Data Curation, Validation, and Supervision. RIIP: Methodology and Supervision. CH: Supervision and Formal Analysis.
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