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Curiosity: A game-based early mathematics case

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Abstract

This research aimed to generate a learning trajectory in an introduction to early mathematics, precisely to measure learning using educational games and Realistic Mathematics Education (RME) and to describe young children's curiosity in learning early mathematics. Children need to have an understanding to take a measurement and use a learning trajectory to learn how to differentiate measurable and countable quantities and to tell the longer and the greater in number. The design of this research involves three phases, namely, preliminary design, experimentation, and retrospective analysis. A Hypothetical Learning Trajectory (HLT) using educational games was developed by collecting data from documentation, observations, and interviews. The results obtained from the implementation in the classroom showed that the educational games were able to help young children get to know early mathematics, particularly on measurements of lengths and volumes. There is an association with several factors in the selection of realistic problems. Communications during the game could stimulate an introduction to measurement. The use of objects in students' vicinity also contributed to their experiments relating to measurement. The results of this research inform policymaking for teachers in designing learning in the classroom in introducing early mathematics based on educational games and Realistic Mathematics Education (RME).

Keywords: Design Research, Early Childhood, Early Mathematics, Educational Game, Learning Trajectory

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Multi- and interdisciplinary early childhood learning is comprised of numerous interconnected, holistic, integrated disciplines. One of the aspects developed in the learning development of young children is the cognitive (intellectual) aspect. As stated by Tedjawati and Sari (2017), the development of intellectual abilities must be based on the science of pedagogy and mathematics for children. Meanwhile, Cross et al. (2009) and Duncan et al. (2007) state that the mathematics knowledge of young children predicts their success in taking further steps to the elementary and secondary school levels. Many researchers have remarked on the importance of introducing early mathematics. According to Baroody et al. (2006), Bassok et al. (2016), Bozick et al. (2017), and Clements et al. (2013), it is important to introduce young children to early mathematics for the following reasons: young children are significantly capable of learning mathematics, which is often surprising, and they can take a considerable interest in mathematics learning; young children have an important background for learning mathematics that they derive from their informal knowledge (daily experiences, mostly verbal and manipulative) that has been accumulated from an early age, with differences on individual and group levels that may significantly influence their school achievements; and early interventions have been proven to be effective at closing the gap between individuals in an early stage and at evenly reducing difficulties in formal mathematics learning. In addition, according to the survey by the Trends in International Mathematics and Science Study (TIMSS), which is an international study measuring developments in mathematics and science, the cognitive abilities of Indonesian students in mathematics were weak, as shown by Indonesia's 45th position among 48 countries with a score of 397 (Mullis et al., 2015). Beloglovsky and Daly (2015) explain that mathematics learning for young children aims to train logical and systematic thinking and to introduce the basics of mathematics as a preparation into higher complexity levels. However, other general goals of education are not to be overlooked. "Thinking habit", including curiosity, is one of the components of the chief objective of productive predisposition, promoting self-confidence and scientific thinking (Clements et al., 2013; Kashdan & Silvia, 2012; Klahr et al., 2011; Raharja et al., 2018). The curiosity of young children is high and natural (De Lange, 2019; Trundle et al., 2013). Therefore, it is necessary to design learning that can facilitate their curiosity promotion (Akkas & Suryawati, 2021).

The educational games in this research are Android-based and are developed based on Realistic Mathematics Education (RME). The games facilitate the introduction to early mathematics with measurement materials content. The learning trajectory generated was developed based on the said educational games and RME. It was reported by previous works (Clements et al., 2013; Pramudiani et al., 2011; Wijaya et al., 2021) that learning trajectories were able to assist and direct students in understanding materials. Meanwhile, the research by Papadakis et al. (2021) and Peirce (2013) reported that the use of a game was able to motivate and raise the curiosity of young children. Therefore, this research aimed to figure out children's curiosity and generate a learning trajectory on measurement in introducing young children to early mathematics based on educational games.

METHODS

This research used the method of a design research type validation study as it aimed to develop a theory on the learning process on a given concept along with the instructional design to support such learning. Gravemeijer (2004) explain that this method is composed of three phases, namely preliminary design, experimentation, and retrospective analysis. The first phase involved literature study and interviews with teachers. While literature study was conducted for the authors to go deeper into theoretical perspectives, interview was conducted with one teacher from each school during the research data collection process.

The aims of interviewing a teacher in a classroom were to figure out the characteristics, to identify the barriers faced by students throughout the learning process in the field, and to formulate the students' assumed thoughts. As stated by Schneider and Gowan (2013), teacher's understanding of the learning process during elementary development serves as a consideration aspect in solving pedagogical problems. The combination of literature study theories and the truth in the field lays a foundation for designing hypothetical learning trajectories (HLTs).

In the next phase, that is, the experiment phase, a hypothetical learning trajectory was carried out in two experiment stages: pilot experiment and teaching experiment. The pilot experiment involved five students from each school and was set as a bridge between the preliminary design phase and the teaching experiment phase. The focus of the pilot experiment was to find out the feasibility of the preliminary design on the HLT and to collect data that were probably needed to revise the HLT. After the pilot experiment, a teaching experiment was conducted with an involvement of 10 students from each school. This teaching experiment was aimed to investigate how the revised HLT helped the students learn probability. Students' thoughts were observed from their works and from interviews with three students. An interview was conducted at every end of an activity, involving three students who were representative of active, moderately active, and passive students. These interviews were intended to explore students' learning opportunities and barriers using a game. The final phase was retrospective analysis. In this phase, all the data obtained from the experiment phase were analyzed with a focus on the comparison between the HLT and the actual students' learning process. This analysis covered possible causes and synthesized possible measures to be taken to have an improved HLT.

RESULTS AND DISCUSSION

Preliminary Design

In this phase, the authors conducted a literature study on the measurement material for young children as well as on the curriculum related to the relevant competence based on the research objective. Other than conducting a literature study on the material and curriculum, the authors also designed mini games relevant to the curriculum studied and the research objective. Prior to being tried in a classroom context, the game went through an expert review process and several prototype stages. In this phase, the authors also designed a hypothetical learning trajectory (HLT) with the teacher to guide the development of activities in the classroom. This HLT is critical in the design process as a guide to learning in the classroom and to an analysis of subsequent learning activities development. The HLT is highly useful in the learning process (Marion, Zulkardi, & Somakim, 2015). As pointed out by several experts, an HLT consists of learning activities, learning objectives, and expectations (Clements et al., 2004; Simon & Tzur, 2004). The HLT may change in the teaching experiment phase (Bakker & van Eerde, 2015). The following is an illustration of the HLT designed here with the classroom teacher (see Figure 1).

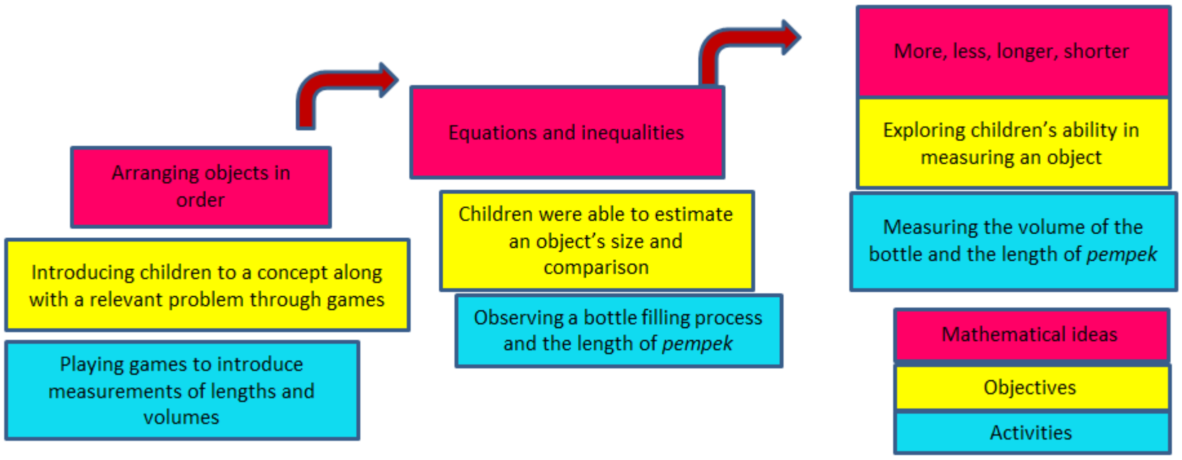

Figure 1. The hypothetical learning trajectory on measurement (volumes and lengths)

Teaching Experiment in the Classroom

In this phase, the HLT designed was tried out in a pilot experiment. It was found that the HLT designed contained three activities for the measurements of lengths and volumes materials. In the pilot experiment, the HLT designed together with the teacher was completed and followed by a retrospective analysis, according to which not many modifications were made to the activities designed for the next stage. Meanwhile, in the teaching experiment, the following activities were carried out.

Length Measurement Material

Activity 1. Playing a game

This activity is one in which children were introduced to measuring the length of *pempek* through a game. The children were given a problem through the game and were commanded to listen to the instruction given by Arjuna (the game's icon). The children were guided by the teacher in using their handphones as learning media, in which case the children received information from the teacher regarding how to use the handphones as well as explanation regarding early mathematics. In this activity, the children exhibited considerable enthusiasm and posed questions on how to press the buttons on the game. They enthusiastically completed the game, where they arranged *pempek* in the order from the longest to the shortest following the direction from the teacher. This activity is not only a matter of playing a game; it also allowed the children to think and to use their reasoning in choosing *pempek* from the longest to the shortest (see Figure 2).

Figure 2. The teacher giving the children an explanation prior to the game

In this game, the children were very quick at answering and choosing *pempek* from the longest to the shortest. They directly and quickly answered the question, saying that the longest *pempek* was the one at the bottom (see Figure 3).

Juna has four different sized of pempek lenjer. Pempek lenjer is usually long. This pempek will be sold from the longest to the shortest size. Please help Juna sort the pempek from the longest to the shortest length.

Figure 3. The game of arranging *pempek* in the order from the longest to the shortest

The children's curiosity was characterized in how they completed the game by measuring the length of the *pempek*, repeating what they were doing out of curiosity to find the answer, and their excited expression when they discovered the answer (Litman, 2005; 2008). Below is the dialog between the teacher and one of the children during the game.

Teacher: Which one is the longest to you?
Child : This one (pointing at the bottommost)
Teacher: What do you think is the length of it?
Child : 1 (one).
Teacher: Oh 1 (one). Then, which one is the longest of all other than 1 (one)?
Child : This one (pointing at the topmost)
Teacher: How long is it do you think?
Child : 2 (two)
Teacher: 2 (two), what?
Child : 2 (two) meters
Teacher: So, which one is longer, 1 (one) or 2 (two)?
Child : Two
Teacher: Anything else?
(The child went on answering to the end of the game and gave correct answers.)

From the dialog above, it can be concluded that the child had not understood how to measure something, and neither had they understood the numerals to be used in measuring. This was because the child had yet to enter the age at which they could construct the concept of measurement formally. Children at this age have an egocentric tendency in thinking, in which case they are unable to differentiate between the perspectives of their own and those of others. This case was proven by the child simply answering "this one" when they were asked which one was the longest. In the dialog above, when asked to choose which one was longer between 1 and 2, the child plainly answered 2. The child understood and imagined the objects to be 1 m and 2 m long, although they uttered the unit of length arbitrarily. The child was familiar with the word "meter", so when they were asked "2, what?" they promptly answered, "2 meters." It could be concluded from this activity that although the child was mistaken in thinking that the *pempek* that measured 1 unit of length was the longest, in the end they managed to complete the question without measuring the *pempek*. The child was able to directly answer by comparing the *pempek* from the longest to the shortest without measuring the actual lengths. This is in line with Realistic Mathematics Education characteristics, in which case the Realistic Mathematics Education activity could build children's knowledge using their reasoning and thinking (Bustang et al., 2013).

Activity 2. Comparing *pempek* lengths

This activity is one in which children compared long and short *pempek*. The children were given *pempek lenjer* of varying lengths and asked to measure them from the longest to the shortest. They were then asked to arrange the *pempek* from the longest to the shortest, or from the shortest to the longest. A preliminary activity of comparing two objects or more was conducted first. It was shown from this activity that the children were able to measure an object by first recognizing the object to be measured and comparing it against another object (Walle, 2008). This activity is a real activity in children's world; thus, it was extremely easy for them to solve this problem. Below is how the children solved the problem in arranging *pempek* from the longest to the shortest (Figure 4).

Figure 4. The children's strategy in comparing lengths

In this activity, unlike what the authors and teacher expected, the children solved the problem of size comparison not by directly comparing sizes, but by referring to the classroom's walls from which they saw shapes and sizes that to them had similarity with lengths. The children solved the problem by applying their reasoning regarding their environment, which added a conjecture in the learning trajectory in solving a problem by considering the environment.

Activity 3. Measuring *pempek* lengths

The children were given a ruler in the introduction to measurement. The authors and the teacher then guided the children in using the ruler as a simple medium of measuring and gave them a problem through the game where the children were instructed to compare longer and shorter *pempek*. The children looked at the ruler and observed the numerals on the ruler. They asked about the function of the ruler and how to measure the *pempek*. In this activity, the children were introduced to the ruler as a means of measuring an object. The children showed enthusiasm about using a tool like a ruler and were engrossed in the activity. The children's strategy is depicted in Figure 5.

Figure 5. An introduction to the ruler as a measuring tool

As shown in Figure 5, the children arranged the *pempek* by placing one *pempek* close to another *pempek* (see the bottommost of the picture). The children compared the lengths of the *pempek* and arranged them from the longest at the top to the shortest at the bottom. They posed a lot of questions, such as, what the ruler is for, took the ruler and observed the small numerals on the ruler. Below is the dialog recorded when the children used the ruler to measure the *pempek*.

Teacher: You did a great job arranging the pempek, it makes me hungry. How did you do it?
Child 1 : (Silent while concentrating before finally giving an answer) Here is how I did it.
Child 2 : We place them close to one another in a neat arrangement, the shortest being the latest.
Child 3 : Is it a ruler, Ma'am? (Taking the ruler)
Teacher: Yes, it is. What is it usually used for?
Child 3 : For measuring.
Teacher: Great. Now please measure the pempek. Help me measure the one that you think is the longest.

The children tried to take a measurement using the ruler eagerly and run their finger over the numerals on the ruler as shown in Figure 4.

Child 3 : Like this, Ma'am?
Teacher: Now let me know how long is it?
Child 3 : 11 (eleven)
Teacher: What about the other one?
Child 4 : 6 (six)
Teacher: Another one?
Child 4 : 9 (nine)
Teacher: How long is the last one?
Child 4 : 5 (five)
Teacher: So, please arrange 11, 6, 9, and 5 in the order from the longest.
Children 3 and 4: (arranging the pempek in the order 11, 9, 6, 5) The longest is 11, followed by 9, 6, and 5.

From this activity, the children figured out how to take a measurement using a ruler. They recognized the object that they were to measure using the ruler. They seemed correct in their measuring way, although in fact they did not know how to measure formally and accurately. They did not know that they must measure from 0 on the ruler since they did not understand the number 0. The measurements that they took as shown in the dialog above were not accurate. However, the eagerness that they exhibited in using the ruler to take a measurement reflected their attempt to find out how to use the measuring tool. A high level of curiosity about early mathematics was reflected by their diligence and attention to their assignment (Shah et al., 2018). The children built their own concepts in measuring an object using comparison. When they were allowed a freedom to arrange objects from the longest to the shortest, the children compared the objects against one another. The children reasoned and measured informally using a comparison of objects.

Volume Measurement Material

Activity 1. Playing a game of arranging vinegar bottles in an order by volume

In this stage, using their handphones the children arranged *pempek* vinegar bottles from the lowest to the highest in volume. This stage was easy as the children had explored this game in the previous activity using an actual model. Below is the dialog that took place when a child played this game:

Child 1 : Ma'am, I'm done.
Teacher: So fast. What do you think about the game?
Child 1 : Piece of cake, Ma'am.
Teacher: How did you choose among the vinegar bottles?
Child 1 : I chose by size, Ma'am. The bigger, the higher the volume. The smaller, the lower the volume.
Teacher: I see.

The Figure 6 depicts how the children solved the game of arranging vinegar bottles. It shown that the children had a serious expression during the game. Not only were they motivated to learn, but the children were also curious about the next activity and game. Other than in games, children also take pleasure in challenges. The challenges that they overcome in a game and the rewards earned are the source of joy for children when solving a problem or discovering an answer. A pleased expression is a sign of children's curiosity about mathematics learning (Litman, 2005).

Figure 6. The children's expression when solving the game

Activity 2. Observing water filling into vinegar bottles

In this activity, the children were asked to observe two same-shaped bottles. They asked to give a sign to stop filling the bottles with water when they saw the water levels in the bottles were the same (see Figure 7), with dialog as follows.

Teacher : Please remind me to stop when the volume is the same.
Children 1 and 4: Stop.
Child 2 : Stop.
Child 3 : Stop.

Teacher : Okay, is the volume the same?
Children 1 and 2: (thinking for a moment)
Child 2 : I think this one has more volume.

Figure 7. The children observing the water filling process

In this activity, the children were focused on the water filling into the bottles, in which case the water level in the first bottle had to be the same as that in the second bottle. Some children said the volumes were equal, but some other said otherwise. They saw that something was off. This had increased their curiosity about what was right and what they had to do next.

Activity 3. Measuring the highest volume

The next activity was comparing two bottles of the same size and shape, one of which was filled with water and the other was also filled with water in the same volume. The children were instructed to tell the teacher to stop filling the bottles when the water volumes of the two bottles were equal. The children followed this instruction enthusiastically and looked very curious about whether the volumes were truly equal. They inspected the volumes directly. Then, one bottle was replaced by another that was of a different size and the water inside the first bottle was poured to the second bottle. The children were asked to measure which bottle had more content. The children then compared the contents of several vinegar bottles and decided which bottle had more content than the other. This activity is depicted in Figure 8.

Figure 8. The children measuring the bottle with the most content

Figure 8 shows how the children measured the water contents of the two bottles. Below is the dialog when they were doing this activity. The teacher replaced one bottle with another bottle that was of a different shape but the same in height. The water was removed from the old bottle to the new bottle.

Teacher : *Could you tell which one has the most water and which one has less?*
Child 1 : *(measuring the content of the bottle by hand)*
Child 2 : *(taking the bottles closer to each other and started to express their argument) This bottle had a little more content than the other, but the difference is very small.*
Childre 3 and 4 : *(taking the bottles closer to each other and inspecting the water contents of the bottles to find out whether they were equal, then they started to discuss) They are the same, aren't they? I think the heights are the same, so the contents are also the same.*

As shown in the recorded dialog of the four children above, the children were able to represent their ideas of which bottle had more content, which one had less content, or whether the two bottles had equal contents in their own language. Being curious, the children inspected by taking the bottles next to each other and measured the contents of the bottles using their hand. Directly involving children in the learning process allows for a meaningful learning process where the children can explore and build their concepts while developing their cognitive abilities (Joubish & Khurram, 2011; Piaget, 1983). This learning activity was highly interactive. The children were able to develop their ideas together and express their opinions on the objects under observation. Given this interactive nature, Realistic Mathematics Education is extremely useful in a learning process (Putri, Dolk, & Zulkardi, 2015; Zulkardi, 2002).

The children also had an opportunity to develop their cognitive abilities through the language that they used. According to the research results, the children were of varying levels of curiosity about the game-based mathematics learning. They were able to understand the concept of measurement and express their thoughts regarding the learning and the game. Some curiosity characteristics were observed during the learning activity, such as, the joy when discovering the answer, showing curiosity when trying to find the answer, and performing the task diligently (Kashdan et al., 2018; Kashdan & Silvia, 2012; Litman, 2005, 2008; Shah et al., 2018). This research revealed that children's interactions during a game opened a pathway for them to get to know about early mathematics concepts of measurement and attracted their curiosity. For instance, the terms *more* or *less* and *long* or *short* directed the children toward the ideas of comparison and measurement. The children's curiosity was reflected in the following questions: "What is it, Ma'am?", "What is it for?", "What are we going to do next?", and "Is there another game?". The introduction to early mathematics and the curiosity generated from playing games were transformed to a higher level but still in game activities. On a higher level, educational media such as ropes, yarns, and rulers can be used to present ideas of early mathematics.

CONCLUSIONS

The learning trajectory resulted in this research can be considered as an alternative way for the teacher to design learning activities in support of children's curiosity about early mathematics. However, to make use of ICT-based game media, it requires a more careful guidance as children give enthusiastic reactions in using the game media as learning media and as they are also curious about other games that are available. Therefore, the challenge for future research is to develop a learning trajectory in greater depth to manage learning in the classroom. Another challenge is for the teacher to manage the classroom and develop a learning trajectory to fit children's curiosity.

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Declarations

Author Contribution	:	CR: Conceptualization, Methodology, Writing - Original Draft, Formal Analysis, Writing - Review, and Editing Revised Version. RIIP: Conceptualization, Data Gathering, Formal Analysis, Review, Validation, and Supervision. Z: Review, Editing, and Formal Analysis, and Supervision YH: Methodology, Review, Editing, and Formal Analysis, and Supervision
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