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Hypothetical Learning Trajectory for Ninth Graders' Understanding of Curved Three-Dimensional Shapes through Javanese Ethno-Realistic Mathematics Education

Farida Nursyahidah[1*], Irkham Ulil Albab[2], Maya Rini Rubowo[3]
[1*,2,3]Mathematics Education Department, Universitas Persatuan Guru Republik Indonesia Semarang
[1,2]PUI-PT Techno-Ethno-Realistic Mathematics, Universitas Persatuan Guru Republik Indonesia Semarang
Jalan Sidodadi Timur No 24, Dr. Cipto, Semarang, Indonesia
[1*]faridanursyahidah@upgris.ac.id; [2]irkhamulil@upgris.ac.id; [3]mayarini@upgris.ac.id

ABSTRAK

Geometri merupakan aspek penting dalam matematika yang mendukung perkembangan kemampuan kognitif siswa. Meski demikian, pemahaman terhadap konsep-konsep geometri, khususnya yang berkaitan dengan bangun ruang sisi lengkung, sering kali menjadi kendala bagi siswa. Artikel ini bertujuan untuk menyusun dan menyajikan sebuah lintasan pembelajaran hipotetik mengenai bangun ruang sisi lengkung dengan pendekatan Etnomatematika Realistik Jawa. Penelitian dilakukan menggunakan metode design research yang mencakup tiga tahap utama, yaitu perancangan awal, pelaksanaan eksperimen pembelajaran, dan analisis retrospektif. Penelitian ini melibatkan siswa kelas IX di salah satu SMP di kota Semarang. Fokus pembahasan artikel ini berada pada tahap desain awal, yakni pengembangan hipotesis lintasan pembelajaran yang meliputi empat aktivitas utama: (1) mengenali unsur-unsur bangun ruang sisi lengkung melalui pengamatan video berbasis konteks budaya, (2) menyusun pemahaman tentang luas permukaan dan volume tabung, (3) merumuskan luas permukaan dan volume kerucut, dan (4) menemukan rumus luas permukaan serta volume bola. Rangkaian aktivitas dalam lintasan pembelajaran ini dirancang untuk membantu siswa membangun pemahaman yang lebih mendalam terhadap konsep bangun ruang sisi lengkung, sekaligus menumbuhkan apresiasi terhadap budaya lokal dan keragaman dalam berpikir matematis. Lintasan pembelajaran hipotetik ini dirancang untuk diimplementasikan pada kelas eksperimen dan pengajaran berbasis penelitian menggunakan E-RME untuk meningkatkan kemampuan pemecahan masalah matematika siswa yang merupakan novelty dari penelitian ini.

ABSTRACT

Geometry plays a vital role in mathematics to foster students' cognitive growth. Nevertheless, grasping geometry concepts can be particularly difficult, especially when dealing with three-dimensional shapes with curved surfaces. This paper proposes a Hypothetical Learning Trajectory (HLT) for teaching such shapes, grounded in Javanese Ethno-Realistic Mathematics Education (E-RME). The study adopts a design research methodology comprising three key phases: initial design, experimental teaching design, and retrospective analysis. The participants in this research are ninth-grade students from a junior high school in Semarang. The article focuses on the outcomes of the initial design phase, specifically the development of an HLT that includes four learning activities: (1) recognizing components of curved surface solids through contextual video observation, (2) exploring the surface area and volume of cylinders, (3) deriving formulas for the surface area and volume of cones, and (4) discovering the formulas for the surface area and volume of spheres. This sequence of activities is intended to help students build a meaningful understanding of curved 3D objects, while also fostering an appreciation for their cultural background and encouraging diverse approaches to mathematical reasoning. The HLT developed in this study is intended for implementation in trial classrooms and experimental teaching through E-RME, with the goal of enhancing students' problem-solving skills, which is the novelty of this research.

Keywords: Design Research; Hypothetical Learning Trajectory; Curved Three-dimensional Shapes; Ethno-Realistic Mathematics Education (E-RME); Problem-Solving

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Kata Kunci: Penelitian Desain; Hipotesis Lintasan Pembelajaran; Bangun Ruang Sisi Lengkung; Etno-Pendidikan Matematika Realistik; Pemecahan Masalah

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1. INTRODUCTION

Geometry is a crucial mathematical topic to study. By mastering geometry, students will develop logical abilities and impart the knowledge needed to learn more about mathematics (Herawaty, 2020). Anugrah & Pujiastuti (2020) emphasize that geometry plays a fundamental role in achieving mathematical proficiency. Students who possess strong geometric understanding tend to exhibit advanced mathematical reasoning and are more capable of solving real-world problems effectively (Tanujaya, 2017; Wibawa, Nurhikmayati, & Kania, 2024). A key topic within geometry is the study of shapes with curved surfaces. The surface area and volume of these curved figures have numerous practical uses in daily life (Unan, 2016; Ali, Lestari, & Rahayu, 2023). According to Özerem (2012), learning about curved geometric shapes is an important aspect of mathematics education, as it helps students analyze and interpret various real-life phenomena and supports their understanding of other mathematical concepts.

However, several previous studies show students' mastery of curved-sided spatial figures is still relatively low (Marasabessy et al., 2021; Özerem, 2012; Pitriyani, Sundayana, & Maryati, 2024). Several difficulties students face in learning geometry include challenges in applying axiomatic deduction, perceptual misunderstandings, incorrect interpretations of visual processes and activities, improper use of procedures, concepts, and principles, as well as limited connections and weak reasoning skills in geometric thinking (Budiarto, 2019; Afhami, 2022). Students struggle with calculating volume, recognizing relevant information within a problem, and answering questions related to curved geometric shapes (Fitriani et al., 2018; Damayanti & Kartini, 2022). Additionally, they have difficulty identifying the components of a cylinder and the elements of a cone, recalling formulas for the surface area and volume of a cylinder, and applying these formulas—as well as those for cones and spheres—to solve problems (Abdullah & Nohseth, 2020).

To enhance the learning of curved 3D shapes, it is important to incorporate suitable approaches, relevant contexts, and innovative instructional media. One effective strategy is the use of Javanese Ethno-Realistic Mathematics Education (E-RME), which combines elements of Ethnomathematics with Realistic Mathematics Education (Prahmana, 2022; Prahmana et al., 2023). Ethnomathematics connects mathematical concepts to real-life practices and traditions, thereby increasing students' interest, understanding, and creativity (D'Ambrosio, 1999). It focuses on embedding culturally meaningful mathematical ideas into instruction, allowing students to engage with content that reflects their own cultural experiences (D'Ambrosio, 2018; Rosa & Orey, 2023).

Similarly, the use of RME in learning design can encourage students to become enthusiastic and actively involved in constructing knowledge during the learning process (Nursyahidah, 2020, 2021a; Nursyahidah, Albab, & Rubowo, 2023; Prahmana, 2021). Students more easily understand the concepts being studied (Hardiyanto et al., 2024; Hartono et al., 2023; Nursyahidah et al., 2025; Sari et al., 2023) and can come up with several models for solving problems through the context used (Andzin et al., 2024; Nursyahidah, 2021b; Wijaya et al., 2014).

One of the key features of Realistic Mathematics Education (RME) is the use of meaningful context in learning. In this study, the context applied to teach curved 3D shapes is the *Sesaji Rewandha* tradition practiced by the Semarang community in Central Java. This ritual is held annually by the Gunungpati community in Goa Kreo on the fifth day of Shawwal in the Islamic calendar. The ceremony is a tribute to the ancestral monkeys believed to have helped Sunan Kalijaga transport teak wood for the construction of the *saka guru* (main pillar) of the Great Mosque of Demak (Fauzia et al., 2022). The *Sesaji Rewandha* tradition was selected as a learning context to help students engage with the cultural heritage of Central Java and promote more meaningful learning. In this research, it serves as the starting point for exploring curved 3D shapes, as the ritual features symbolic objects such as teak wood replicas shaped like cylinders, *tumpeng* rice and fruit offerings arranged like cones, and round fruits resembling spheres.

The chosen context is presented in the form of a video. In the video, a narrator introduces the *Sesaji Rewandha* tradition while posing a series of questions and answers designed to activate students' prior knowledge within the learning context. Incorporating multimedia—such as videos—can enhance the learning experience. According to Er et al. (2022), interactive videos allow students to construct and understand concepts more effectively. Multimedia content, particularly videos, supports learners with varying abilities in grasping the material (Nursyahidah, Albab, & Rubowo, 2023; Vale & Falloon, 2024). Therefore, by observing the *Sesaji Rewandha* tradition through video, students are expected to better visualize objects, serving as a meaningful entry point for studying curved 3D shapes.

Research discussing mathematics learning utilizing RME on curved-3D shapes have been conducted using diverse contexts, such as sunflower seeds (Widiawati et al., 2019) and watermelon (Juwita et al., 2015) and did not yet specifically discuss specific mathematical abilities. However, the novelty of this study is the use of *Sesaji Rewandha* tradition context as a starting point in learning with E-RME focussed on problem-solving ability. Additionally, this research introduces video as a medium for initiating the learning process of curved 3D shapes.

This study employs a design research methodology, which involves three main stages: preliminary design, experimental teaching (including pilot and teaching experiments), and retrospective analysis. However, the current research is limited to the preliminary design phase. Its objective is to develop a Hypothetical Learning Trajectory (HLT) on curved 3D shapes for ninth-grade students using the *Sesaji Rewandha* tradition as context, supported by video to strengthen students' problem-solving skills.

2. METHOD

This study utilized design research as a framework for developing learning theories and educational tools (Bakker, 2018). The participants were 35 ninth-grade students from a public junior high school in Semarang. Data collection involved various methods, including classroom observations, video recordings, student responses on activity sheets, administration of pre-tests and post-tests, and interviews. The gathered data aimed to capture both the learning process and students' thought processes. Design research, as outlined by Gravemeijer and Cobb (Gravemeijer & Cobb, 2006), comprises three primary stages: (1) Preliminary design, which includes reviewing relevant literature, assessing students' problem-solving skills, formulating a Hypothetical Learning Trajectory (HLT), and designing appropriate learning media; (2) Design experiments, consisting of pilot and teaching experiments; and (3) Retrospective analysis, where all collected data are examined in relation to the HLT to refine and improve future instructional designs.

This article focuses solely on the outcomes of the first phase, namely the preliminary design. This phase involved identifying students' foundational abilities, determining their needs in learning curved 3D shapes, and constructing an HLT using the cultural context of the *Sesaji Rewandha* tradition, supported by instructional video. The video that will be used in this research is an animated video of the *Sesaji Rewanda* tradition using Canva which aims to provide students with a visualization of the traditions of this community and the various components of this tradition that can represent the material on curved-sided geometric shapes.

3. RESULT AND DISCUSSION

Several activities were conducted during the first design research stage, including a literature study, an examination of students' beginning abilities, and the development of a

Hypothetical Learning Trajectory. The literature review was conducted by collecting information about lines and angles from books, followed by a literature review on E-RME and research design. This was done to develop preliminary strategies for designing learning. Furthermore, pupils' talents must be assessed in order to identify their prerequisites. What was done above was used to create a dynamic hypothetical learning trajectory that could be adjusted during the teaching experiment (Bakker, 2018). In this article, the examination of student abilities and the HLT formulation are described as follows:

Examining the Basic Competencies Possessed and Needed by Students in the Material of Curved 3D Shapes

In studying the curved 3D shapes construction material for IX grade of junior high school, there are several basic competencies that students already have and competencies that students will acquire. Students already have competencies regarding curved 3D shapes, such as the basic competencies in I grade are: 1) recognizing spatial shapes and flat shapes using various concrete objects; 2) grouping spatial shapes and flat shapes based on specific properties using various concrete objects. Furthermore, several basic competencies are required in II grade, including 1) explaining flat shapes and spatial shapes based on their characteristics and 2) classifying flat shapes and spatial shapes based on their characteristics. Basic competencies in class III include 1) explaining and determining area and volume in non-standard units using concrete objects and 2) solving area and volume problems in non-standard units using concrete objects. Basic competencies in class V include: 1) Explaining and calculating the volume of geometric shapes using volume units (such as unit cubes) and cube connections using cube roots. 2) Solving volume issues for geometric shapes utilizing volume units such as cubes and cube roots. 3) Explaining and finding simple geometric nets (cubes and blocks), 4) creating simple geometric nets (cubes and blocks). Furthermore, the basic competencies that students in VI-grade already have include: 1) comparing prisms, cylinders, pyramids, cones, and spheres. 2) Identifying prisms, cylinders, pyramids, cones, and spheres. 3) Explaining geometric figures that combine several spatial figures and their surface area and volume. 4) Identifying spatial figures that are a combination of several spatial figures, as well as their surface area and volume.

Furthermore, the basic competencies that students in IX grade will master include: 1) generalizing the surface area and volume of various curved 3D shapes (cylinder, cone, and sphere) and 2) resolving contextual problems related to the surface area and volume of curved 3D shapes (cylinder, cone, and sphere), and a combination of several curved 3D shapes.

Developing Hypothetical Learning Trajectories

After carrying out literature activities and reviewing the students' abilities that students have and need, The next stage was to conceive and manufacture HLT material for making curved 3D shapes based on the *Sesaji Rewandha* tradition of the Semarang community in Central Java. This HLT offers a set of learning activity procedures consisting of four actions to help students understand the content under study, inspire students, and provide fun and meaningful learning with the help of video media. The four activities can be described as follows.

Activity 1: The aim of this initial activity is for students to identify the structural components of curved 3D shapes by observing a video that presents the *Sesaji Rewandha* tradition from the Semarang community. In this phase, students are first asked to watch the video. Following the observation, they complete an activity sheet based on what they have seen. The task requires them to recognize different curved 3D shapes represented in the *Sesaji Rewandha* tradition, identify the elements that make up these shapes, and describe their properties. The activity sheets are arranged systematically to guide students toward achieving the intended learning outcomes. During this process, the teacher's role is to facilitate and encourage students to further explore the cultural context, as well as provide additional insights as needed. Figure 1 illustrates the cultural elements from the *Sesaji Rewandha* tradition that students investigate during this activity.

Figure 1. *Sesaji Rewandha* tradition as a context

Students' thinking assumptions in Activity 1 are shown in Table 1.

Table 1. Conjectures of Students' Thinking in Activity 1

No	Activities	Conjecture
1	Engaging with a context-based video of *Sesaji Rewandha* tradition	Students can examine and define several types of curved 3D shapes
2	Doing activity 1	Students can determined elements of curved 3D shapes

Review of activity 1, in identifying various types of curved 3D shapes and determining the elements of curved 3D shapes, it is hoped that students can achieve the learning objectives. Some students who are likely to experience difficulties receive scaffolding assistance from the teacher. The teacher's responsibility is to present students with for the findings and information they obtain in constructing the concept of curved 3D shapes material.

Activity 2: the learning objective in Activity 2 is to calculate the surface area and volume of the cylinder. Activity 2 begins by observing videos of the context of the replica of teak wood and pictures. The aim of the activity is for students to be able to describe tube nets and then determine the tube surface area using assistance of a cylinder model. Figure 2 show the replica of teak wood.

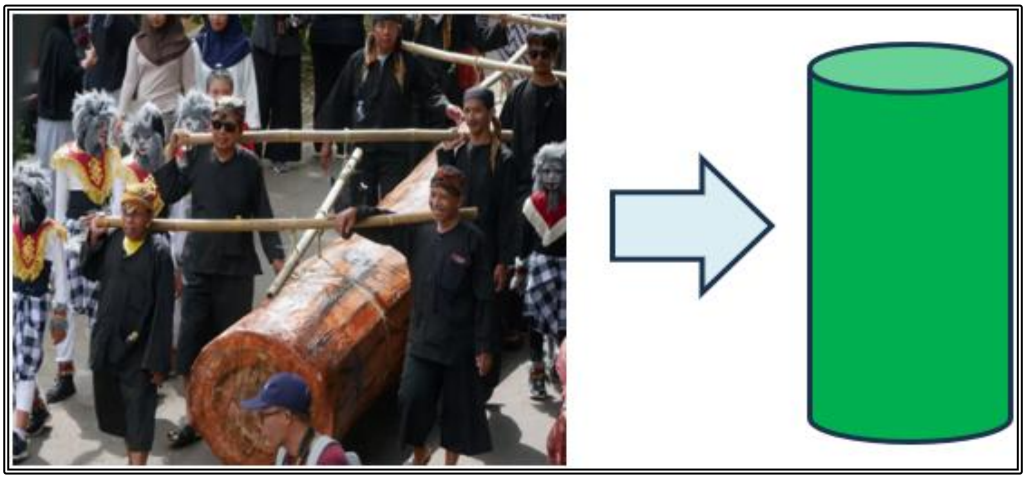

Figure 2. Replica of taek wood as a context for learning a cylinder

Students were asked to draw a tube net and then identify the shapes that form the tube. It is pretty easy for students to draw tube nets and determine their elements. Students can choose the formula for the surface area of a cylinder by adding up all the areas of the shapes that make up the cylinder consisting of 2 circles and one rectangle of a specific size.

After students determine the surface area of the cylinder, activity two also directs students to determine the volume of the cylinder. Students were asked to compare the volumes of blocks and prisms that have been studied previously, namely base area x height. Through this activity, students were expected to be able to find the formula for the volume of a cylinder with a circular base. However, if there were still students who experience difficulties in this activity, the role of the teacher as a facilitator is needed, someone who could provide scaffolding so that students can discover the concepts being studied.

Throughout the lesson, the teacher provides guidance and poses challenging questions to encourage students' higher-order thinking and enhance their problem-solving skills related to cylinders. This approach aims to foster active participation and a sense of contribution among students. Table 2 also explains the students' conjectures.

Table 2. Conjectures of Students' Thought in Activity 2

No	Activities	Conjecture
1	Engaging with a context-based video of the replica teak wood in S*esaji Rewandha* tradition context	Students can examine and define elements of a cylinder
2	Doing activity 2	Students can calculate the cylinder surface area and volume Students can solve contextual problems involving the cylinder

Reflection on activity 2, in identifying elements of a cylinder, drawing a cylinder net, and finding a formula for a cylinder's surface area and volume, it is hoped that students can achieve the learning objectives in activity 2. Some students who have difficulties will receive scaffolding assistance from the teacher. The teacher plays to stimulate students with the findings and information they obtain when constructing the concept of a cylinder.

Activity 3: the learning objective in Activity 3 is to determine the surface area and volume of the cone. This activity starts with students watching a video that features the context of the food and fruit arrangement shaped like a mountain, along with related images. The purpose is to help students visualize and describe the net of a cone, and then use a cone model to determine its surface area. An example of the food and fruit mountain used as context is shown in Figure 3.

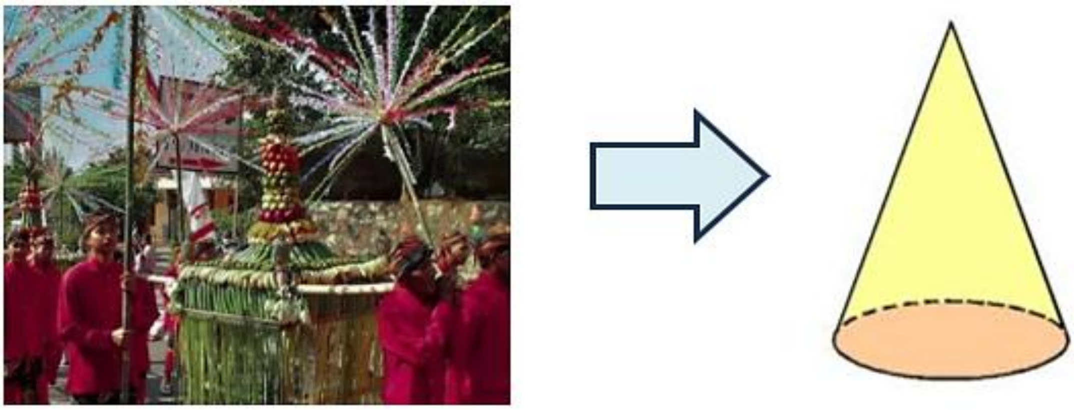

Figure 3. Food and fruit mountain as a context for learning a cone

Students were asked to draw a cone net and then identify the shapes that form the cone. It is quite easy for students to draw cone nets and determine their elements. Students can determine the formula for the surface area of a cone by adding up all the areas of the shapes that make up the cone, consisting of one circle and one segment of a specific size. However, some students may make mistakes in drawing a cone net by drawing one triangle and one circle, and the teacher can give scaffolding for them.

After students determine the surface area of the cone, activity 3 also directs students to determine the volume of the cone. Students are asked to experiment to measure the volume of a cone by using a cylinder. The students filled seeds from cones to cylinders of a specific size. They will find that 3 times the cone volume will be the same as the volume of a cylinder.

During the learning process, the teacher supports students by posing thought-provoking questions aimed at enhancing their higher-order thinking skills in relation to cone-related problems. This approach also encourages students to be more interactive and actively contribute to the learning environment. Additionally, students predicted thought processes are outlined in Table 3.

Table 3. Conjectures of Students' Thinking in Activity 3

No	Activities	Conjecture
1	Engaging with a context-based video of food and fruit mountain in *Sesaji Rewandha* tradition context	Students can examine and define elements of a cone
2	Doing activity 3	Students can calculate the cone surface area and volume Students can solve contextual problems involving the cone

Reflection on activity 3, in identifying elements of a cone, drawing a cone net, and finding a cone formula for volume and surface area, it is hoped that students can achieve the learning objectives in activity 3. Some students who have difficulties will get scaffolding assistance from the teacher. The teacher plays to stimulate students to construct the concept of a cone.

Activity 4: The objective of Activity 4 is for students to find the surface area and volume of a sphere. This activity starts with students watching a video featuring the *gunungan* of fruits, along with related images. The goal is for students to be able to visualize and describe a net representation of a sphere and then use a sphere model to calculate its surface area. An illustration of the fruit *gunungan* used in this context is shown in Figure 4.

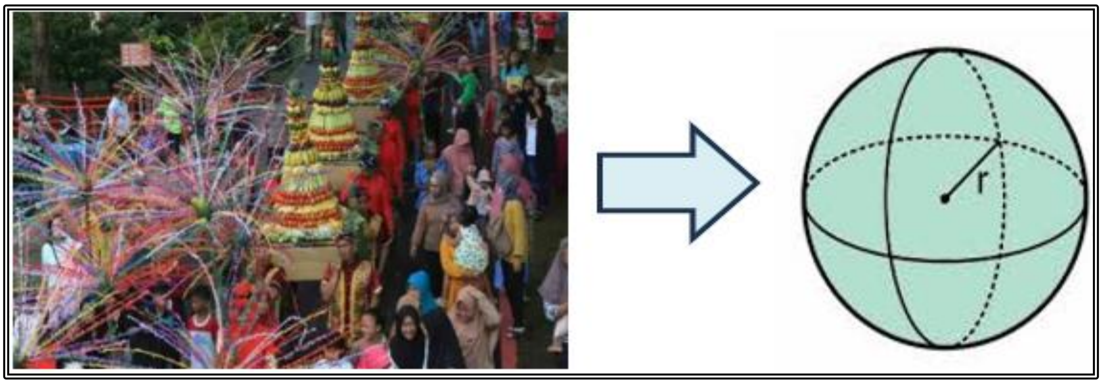

Figure 4. Fruits mountain as a context for learning a sphere

Students were asked to draw a sphere net and then identify the shapes that form the sphere. It is quite easy for students to draw sphere nets and determine their elements. Students can choose the formula for a sphere's surface area by experimenting with orange peel. They will prove that orange peel will cover four circles with the same radii as the orange. However, some students may make mistakes in determining the surface area of a sphere, and the teacher can give scaffolding for them.

After students calculate the surface area of the sphere, activity four also directs students to determine the volume of the sphere. Students were asked to experiment to measure the volume of a sphere by using a cone. The students were filling seeds from cone to sphere with a specific size. They will find that 4 times the cone volume will be the same as the volume of a sphere if the radii and height of a cone are the same as the radii of a sphere.

Throughout the learning activity, the teacher guides students and poses challenging questions to encourage higher-order thinking related to sphere problems. This approach is intended to foster students' engagement and promote active participation. Additionally, students' anticipated thought processes are presented in Table 4.

Table 4. Conjectures of Students' Thinking in Activity 4

No	Activities	Conjecture
1	Engaging with a context-based video of the fruit mountain tradition	Students can examine and define elements of a sphere
2	Doing activity 4	Students can calculate the surface area and volume of a sphere Students can compute contextual problems related to the sphere

Reflection on activity 4: in identifying elements of a sphere, drawing a sphere net, and finding a formula for a sphere's surface area and volume, it is hoped that students can achieve the learning objectives in activity 4. Some students who have difficulties will get scaffolding assistance from the teacher. The teacher plays to stimulate students to construct the concept of a sphere and solve related contextual problems.

Based on the findings presented, the initial phase of design research involves preparing for the experiment through several key activities. These include conducting a literature review, analyzing the competencies students currently possess and the competencies they need to acquire, selecting a relevant ethnomathematics-based context, formulating a Hypothetical Learning Trajectory, and creating innovative instructional media. These activities serve as the foundation for developing early instructional strategies. According to Nursyahidah & Albab (2021b), literature reviews play a crucial role in identifying effective starting strategies for formulating HLTs. This preliminary design stage is essential to help students progress in understanding curved 3D shapes—from informal ideas to formal mathematical concepts. The use of cultural contexts within Ethno-Realistic Mathematics Education provides a meaningful entry point and valuable learning resources for studying these concepts. Previous research (Andzin et al., 2024; Hardiyanto et al., 2024; Nursyahidah et al., 2023; Nursyahidah et al., 2023), supports the idea that contextual learning enhances student engagement, comprehension, and problem-solving skills.

The instructional design aligns with the five core characteristics of RME outlined by Putri & Zulkardi (2018): 1) Use of context – This study utilizes the ethnomathematical context of the *Sesaji Rewandha* tradition from the Semarang community in Central Java. 2) Use of models – Instructional models help guide students from informal understanding toward formal mathematical concepts. 3) Student contribution – Each activity encourages student input and participation as a pathway to achieving learning goals. 4) Interactivity – Learning involves interaction through discussion, explanation, feedback, collaboration, and evaluation. 5) Intertwinement – Activities integrate related mathematical concepts such as surface area, volume, circle segments, and cultural traditions to promote a holistic understanding.

Using ethnomathematics as a learning context can stimulate students understanding and problem-solving ability (Nursyahidah, 2021b; Nursyahidah, Albab, & Rubowo, 2023). Each learning activity is designed to address real-life problems involving curved 3D shapes, reinforcing the relevance and meaningfulness of RME. Students are encouraged to actively participate and apply what they learn in practical contexts. Studies by Nursyahidah et al. (2021a) and Silva et al. (2022) affirm that RME enhances the learning experience, while Laurens et al. (2018) highlight its success in improving mathematical achievement.

Finally, employing Ethno-Realistic Mathematics Education provides a comprehensive method for teaching curved 3D shapes. This practice improves students' conceptual knowledge by blending cultural backgrounds and realistic events. It also increases engagement, concept understanding, and problem-solving skills. These outcomes are supported by prior studies, which highlight the effectiveness of E-RME as a forward-thinking and impactful teaching strategy.

4. CONCLUSION

This research successfully developed a Hypothetical Learning Trajectory for teaching curved 3D shapes through Ethno-Realistic Mathematics Education, using the *Sesaji Rewandha* tradition of the Semarang community as the cultural context to support students' problem-solving skills. The HLT created during the preliminary design phase can be implemented in the next phase, the experimental design stage. The HLT includes four key activities: observing a contextual video of the *Sesaji Rewandha* tradition to identify the components of curved 3D shapes, determining the surface area and volume of cylinders, cones, and spheres. These sequential activities are structured to guide students in developing a conceptual understanding. The findings underscore the potential of combining local cultural knowledge through ethnomathematics with the RME framework to enhance the teaching and learning of curved 3D geometry.

Despite these promising outcomes, the study has several limitations. First, it focuses on a specific cultural context—the Javanese *Sesaji Rewandha* tradition—which may not be directly applicable to students from different regions or cultures. Second, the study only examines understanding and problem-solving in the context of curved 3D shapes and does not explore other learning dimensions. Furthermore, the limited duration of the intervention and a relatively small sample size may affect the broader applicability and long-term impact of the findings. Addressing these limitations in future research could provide a deeper and more comprehensive evaluation of the approach.

Future studies are encouraged to build on this work by implementing the developed HLT in broader contexts. To develop a varied learning trajectory that considers a variety of cultural and geographic backgrounds, it is then necessary to investigate integrating additional ethnomathematics contexts and extending the E-RME method's reach to encompass other mathematical subjects and proficiency. Through such efforts, researchers and educators can continue advancing mathematics education using culturally meaningful and technology-enhanced instructional strategies.

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AUTHOR BIOGRAPHY

	**Farida Nursyahidah, S.Pd., M.Pd.** Born in Rembang, on 18 January 1988. Faculty member at Universitas Persatuan Guru Republik Indonesia Semarang. Completed undergraduate studies in Mathematics Education at Universitas Negeri Semarang, Semarang, in 2010; Completed graduate studies in Mathematics Education at Universitas Sriwijaya, Palembang, in 2013.
	**Irkham Ulil Albab, S.Pd., M.Pd.** Born in Kendal, on 10 April 1988. Faculty member at Universitas Persatuan Guru Republik Indonesia Semarang. Completed undergraduate studies in Mathematics Education at IKIP PGRI Semarang, Semarang, in 2011; Completed graduate studies in Mathematics Education at Universitas Sriwijaya, Palembang, in 2014.
	**Maya Rini Rubowo, S.Pd., M.Si.** Born in Semarang, on 21 Mei 1974. Faculty member at Universitas Persatuan Guru Republik Indonesia Semarang. Completed undergraduate studies in Mathematics Education at IKIP Semarang, Semarang, in 1997; Completed graduate studies in Mathematics at Universitas Gajah Mada, Yogyakarta, in 2003.