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Didactic Design of Cube Nets based on Ethnomathematics of Engklek Game in Elementary School : An Educational Innovation

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Abstract: The purpose of this research is to develop a didactic design for cube nets based on the ethnomathematics of the Engklek game in elementary schools. This study uses a design research approach using the Didactical Design Research (DDR) method. The participants in this research are 5th and 6th grade students at an elementary school in Serang-Banten. The research goes through three stages: 1) prospective analysis, 2) metapedadidactic analysis, and 3) retrospective analysis. Data collection techniques included tests, observations, interviews, and documentation. Data analysis techniques employed qualitative descriptive analysis based on Miles & Huberman's data triangulation model. The results of this research show that: 1) In the retrospective stage, obstacles such as conceptual errors, principle errors, and verbal errors were identified, which became the basis for creating the hypothetical didactic design, 2) In the metapedadidactic stage, the initial didactic design was developed by integrating the cultural elements of the Engklek game and resulted in a new 2-2-2 pattern, and 3) In the retrospective analysis, the revised didactic design based on the ethnomathematics of the Engklek game with the new 2-2-2 pattern can be used to teach the concept of cube nets in mathematics education. This research aims to develop a meaningful didactic design by incorporating local cultural contexts into mathematics learning in elementary schools. This research has significant implications for education, especially in improving the quality of mathematics learning with didactic designs that utilize cultural context in teaching materials.

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Introduction

Mathematics is a branch of natural science that is included in various curricula and is taught from elementary education through higher education (Klien, 2003., Subrahmanyam, 2021). Mathematics has contributed significantly to human life (Arisetyawan et al, 2021). Mathematician Freudenthal (1971) explained the concept of mathematics as a human activity. This indicates that mathematics instruction is not only focused on numbers and operations (content) but also on teaching various skills such as thinking, building relationships, reasoning, estimating, and problem-solving (Onal et al, 2017). This view aligns with Baykul's (2009) statement that mathematics is used to solve problems in science. Additionally, mathematics can encourage students to think creatively and critically, thereby helping them understand the complexities of life.

Early mathematicians viewed mathematics as a form of beautiful art. However, students in schools often do not seem to perceive this beauty. Misunderstandings about mathematics among students, parents, and educators are considered one of the root causes of this problem (Rohman et al, 2023). This perspective is also consistent with Fauzi & Chano's (2022) assertion that mathematics is very difficult to understand for students, parents, and teachers alike. One factor contributing to this difficulty is the phenomenon of mathematical anxiety (Siaw et al, 2020), which arises because mathematics is often taught in an unengaging manner (Suci et al, 2014). This results in boredom, and students tend to be less responsive in their learning (Rohmah & Sutiarso, 2018). Teachers need to understand this reality and create innovative and meaningful learning experiences to increase students' interest in mathematics, as interest in learning is one of the keys to success in mathematics education (Rellensmann & Schukajlow, 2020).

In mathematics education, three key areas are essential: numbers and algebra, geometry and measurement, and statistics, data, and probability. According to Fauzi & Arisetyawan (2020), geometry is a branch of mathematics (Fachrudin et al, 2014) and is one of the crucial topics in mathematics education, taught from elementary through higher education (Trimurtini et al, 2022). Learning geometry promotes the development of critical thinking and problem-solving skills in students, making it an integral part of human life (Sunzuma et al, 2020). This is evident as geometric concepts and their applications are widely used in various fields, such as industry, architecture, and interior design (Burns, 2000). According to Grunberg & Clements (2014), students need a foundational understanding of geometry and measurement from an early age to support their comprehension of more complex mathematics in life.

Geometry is defined as the discovery of patterns and standard principles within and among shapes, contributing to the overall learning of mathematics (Sahinkaya & Kilic, 2021). According to Crompton & Ferguson (2024), geometry is one of the foundational topics in mathematics education. However, this subject is often overlooked by curriculum developers and teachers in schools, leading to students lacking critical skills in geometric reasoning. Essentially, geometric reasoning involves the creation and use of 'conceptual systems' adopted to explore shapes and space (Alghadari & Noor, 2021). On the other hand, students often face difficulties due to low spatial reasoning skills (Wahidah et al, 2020). According to the National Council of Teachers of Mathematics (NCTM, 2020), spatial reasoning is one of the essential skills that students must master to understand geometric concepts. Strong spatial reasoning skills make it easier for students to comprehend relationships and properties in geometry. One of the topics in geometry education is cube nets, which are fundamental for understanding three-dimensional shapes (cubes). However, as Obide (2009) notes, at the elementary level, students often struggle with distinguishing size, shape, and generating geometric forms.

The issues faced by students need to be anticipated by teachers during the learning process, one of which is by preparing a didactic design. According to Annizar & Suryadi (2016), a didactic design is an instructional plan developed based on the learning obstacles that arise, with the goal of overcoming these obstacles so that the learning objectives can be achieved. Didactic design is derived from the steps of Didactical Design Research (DDR), which includes the analysis of didactic situations, metapedadidactic analysis, and retrospective analysis. Didactical Design Research (DDR) was first introduced by Professor Didi Suryadi from Universitas Pendidikan Indonesia in 2010 (Fauzi & Suryadi, 2020) as a method to generate educational innovations. This didactic design also serves as a form of preparation for teachers in their teaching practice. According to Callahan & Clark (1983), teaching without preparation leads to ineffective learning, as it means the teacher has not thoroughly considered what will be done and how to do it. In the learning process, teachers need to incorporate contexts that are close to students' lives, known as contextual learning. According to Hutagaol (2013), contextual learning is based on the constructivism approach, which allows students to construct the knowledge they learn and give it meaning through real-life experiences. One way teachers can do this is by incorporating ethnomathematics into the learning process.

According to D'ambrosio (2001), ethnomathematics is the relationship between mathematics and culture. This means that mathematics is experienced, practiced, or integrated into cultural practices (D'Ambrosio & Rosa, 2017) such as activities of categorizing, counting, measuring, and designing tools. In another view, Barton (1996) emphasizes that ethnomathematics is the study of how different cultures understand, articulate, and use concepts and practices that originate from their own culture and are described by researchers as mathematical. According to Rosa & Orey (2013), the study of ethnomathematics essentially consists of three important components: cultural anthropology, mathematical modeling, and mathematics. Sirate (2015) argues that ethnomathematics is an effective solution for conveying formal mathematics to students through the mathematical values found in everyday life. Ethnomathematics has a significant impact on the development of positive character that reflects the cultural values of a nation while also enhancing the cognitive aspects of students (Arisetyawan et al, 2014).

Games are a type of activity that is part of the cultural context within society. These games are highly favored by children. According to Fauzi et al (2023), children should be accustomed to engaging in thinking processes without losing their inherent playfulness. Therefore, teachers should recognize the characteristics of children who need to play and integrate this into the learning process. Burdette & Whitaker (2005) state that games create excitement due to the physiological and natural tendencies to try new things, explore, solve problems, and engage in enjoyable activities.

A traditional game frequently played by children is Engklek, which involves hopping on one foot from one field to the next following a specific pattern. According to Kamid et al (2021), Engklek is highly beneficial for children's development, honing their skills, and maintaining physical balance. In this game, one type of Engklek pattern that can form a cube net is the "airplane" Engklek pattern. According to Solekhah (2014), an Engklek board resembles the faces of a cube, with six identical square fields arranged as a net of a three-dimensional cube. Aprilia (2019) Aprilia (2019) notes that the Engklek game incorporates mathematical concepts, one of which is the net of three-dimensional shapes.

Based on observations at an elementary school, students showed significant confusion when confronted with cube nets and their relevance to everyday life. Children also did not realize that the pattern of the Engklek game tracks is part of a cube net. This represents a learning obstacle related to cube nets. Given these issues, it is essential to develop an engaging and meaningful didactic design that addresses students' needs and the obstacles found in the classroom.

This study aims to develop a didactic design for cube nets based on the ethnomathematics of the Engklek game in elementary schools. The goal is to address the obstacles students face related to cube nets. These obstacles serve as the foundation for creating a didactic design that incorporates the Engklek game. Several reasons highlight the importance of incorporating culture (Engklek game) into mathematics learning: 1) Mathematics is a cultural product, and each individual's creativity is influenced by cultural principles (Supriadi, 2017), 2) a mathematics teacher should integrate ethnomathematics-based learning activities into their teaching plans (Brandt & Chernoff, 2014), and 3) didactic designs using an ethnomathematics approach effectively address higher-level thinking obstacles in mathematics education, as they include cultural elements, allowing students to learn in a more real and meaningful way (Imswatama & Lukman, 2018). Additionally, relevant studies include Fauzi et al (2023), which investigated the integration of culture

(Engklek game) in teaching fraction concepts in elementary schools, and Febriyanti et al (2018), which explored mathematical elements within the Engklek game. This research will focus on developing a didactic design for cube nets using an ethnomathematics approach (Engklek game) to address students' epistemological obstacles.

Research Method

This study uses a research design approach with the Didactical Design Research (DDR) method. This study employs a pragmatic paradigm, which involves more than one paradigm. According to Suryadi (2018), Didactical Design Research (DDR) is based on two paradigms: interpretive and critical. The ontological study of the interpretive paradigm in DDR relates to the impact of didactic design on learners, particularly regarding the reality of meaning that emerges from a didactic situation or series of situations. The ontological study of the critical paradigm in DDR relates to understanding the meaning of something from an individual or group perspective (learners) and the structured and functional meanings generated from specific viewpoints. This means that the interpretive paradigm is used to uncover learning obstacles experienced by students, while the critical paradigm involves the iterative process of developing didactic design.

Didactical Design Research is created to provide a framework for teachers' ideas to achieve efficient learning outcomes and enhance teachers' comprehensive knowledge in addressing classroom issues (Suratno, 2016). DDR involves three stages: 1) Prospective Analysis, which includes repersonalization, recontextualization, and didactic design development. In this study, the focus is on analyzing the epistemological obstacles encountered by students and developing an initial didactic design, 2) Metapedadidactic Analysis, which focuses on implementing the hypothesis didactic design to observe the didactic triangle phenomenon, creating appropriate didactic-pedagogical situations, observing student responses to didactic-pedagogical actions, and conducting further didactic-pedagogical actions to achieve learning goals, and 3) Retrospective Analysis, which focuses on reviewing the results of the initial didactic situation analysis in conjunction with the results of the metapedadidactic analysis and revising the didactic design.

The research was conducted at an elementary school in Serang-Banten, involving 28 sixth-grade students to identify epistemological obstacles related to cube nets and 28 fifth-grade students for the implementation of the didactic design. Data collection techniques included tests, observations, interviews, and documentation. Specifically, tests were used to uncover students' epistemological obstacles related to cube nets. Observation sheets were used to monitor the implementation of the initial didactic design. Interview guidelines were used to gather respondents' answers regarding cube nets and to support observational data. Documentation was used to review the material structure in learning resources. Data analysis techniques employed qualitative descriptive analysis based on Miles & Huberman's data triangulation model (Sugiyono, 2016). Data analysis was conducted through stages of data reduction, data presentation, and conclusion drawing or data verification. The results of the analysis were then reviewed in depth and related to various relevant previous studies.

Results and Discussion

The results of this study will be presented according to the stages of DDR, namely prospective analysis, metapedadidactic analysis, and retrospective analysis.

Prospective Analysis

In the prospective analysis stage, the first step is to analyze the mathematics textbook used by fifth-grade elementary students, focusing on the concepts and content of the material.

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The textbook in use is "Senang Belajar Matematika SD/MI Kelas 5." Within this book, the material on cube nets is covered under the topic of three-dimensional shapes, with the subtopic being cube nets. The textbook includes only one indicator for each competency, which is 1) identifying cube nets, and 2) constructing cube nets. To effectively teach the material on cube nets, the learning indicators should include: 1) understanding the concept of cube nets, 2) recognizing various types of cube net patterns, and 3) creating and verifying cube net patterns. The didactic design pattern created is as follows:

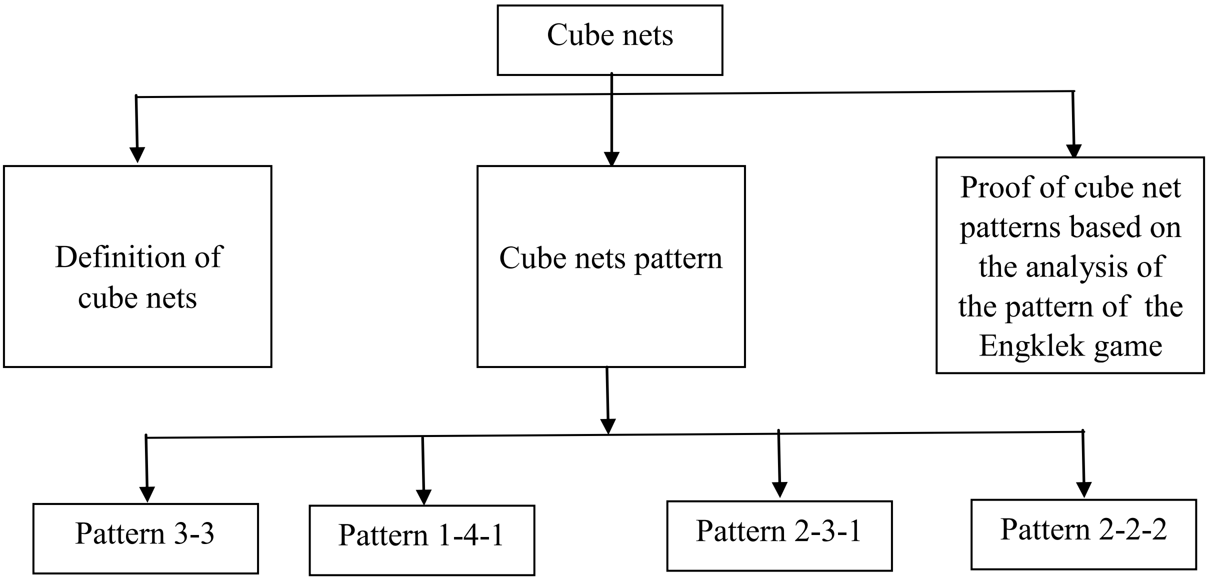

Figure 1. Concept Map of Cube Nets Material Using the Engklek Game

Then, an analysis of students' conceptual understanding of cube nets was conducted through a learning obstacle test. The type of obstacles investigated were related to epistemological constraints or the limited knowledge students have regarding the concept of cube nets. The test results indicated that many students struggled to identify cube net shapes, confusing when solving problems. Additionally, interviews with teachers revealed that while not all students faced the same difficulties with mathematics, each student encountered challenges with specific topics. This suggests that cube nets are considered a particularly difficult topic for students. The difficulty students experience in understanding cube nets represents a limitation in knowledge that falls under epistemological obstacles.

Specifically, the epistemological obstacles encountered by students are categorized into three types: conceptual errors, principle errors, and verbal errors. The issues identified include students' difficulty in identifying cube net shapes, which is a conceptual error.

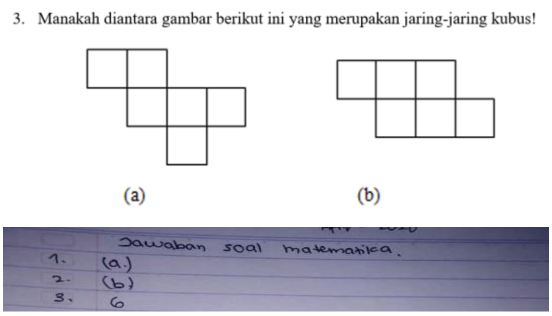

Figure 1. Student Questions and Answers Related to Conceptual Errors

In response to question number 3, some students provided incorrect answers. For example, a student answered with the number 6, whereas the correct answer was not a number but an image indicating that there were two cube nets, A and B, and students were required to identify the correct one. Out of 28 students, 7 faced difficulties with question number 3. Regarding principle errors, students struggled with problems related to the base and top of cube nets.

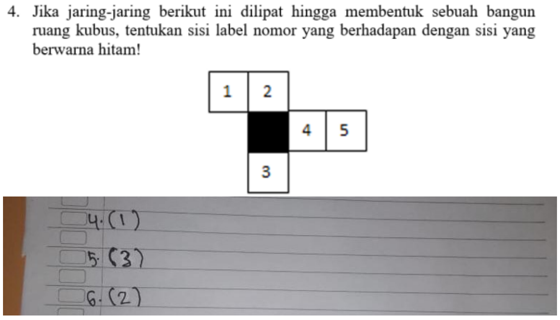

Figure 2. Student Questions and Answers Related to Principle Errors

For question number 4, some students answered incorrectly by labeling the side as number 1, whereas the correct label should have been number 5. Ten out of the 28 students faced difficulties with question number 4. Regarding verbal errors, students struggled with determining the shape of cube nets.

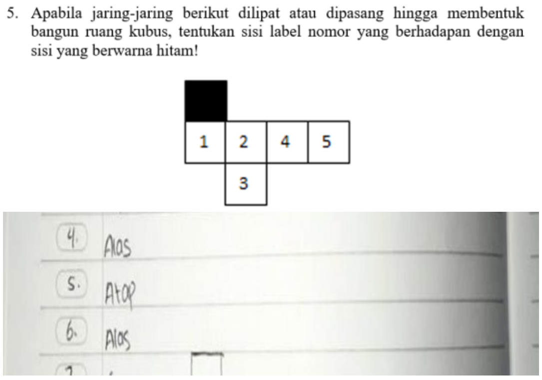

Figure 3. Student Questions and Answers Related to Verbal Errors

For question number 5, some students provided incorrect answers, as shown in the image above. Eleven out of the 28 students faced difficulties with question number 5.

According to the interviews, students found it challenging to complete the test questions, including difficulty in visualizing the cube nets. Additionally, students were not aware that cube nets are related to the game of "Engklek.". The issues identified from the initial test results form the basis for predicting student responses and planning didactical-pedagogical anticipations. Before developing the didactical design, a learning hypothesis was created, consisting of learning objectives, learning activities, and pedagogical design anticipations. The learning objectives for the didactical design are: 1) through the game of Engklek, students should be able to accurately and carefully determine cube nets, 2) through experiments using cardboard media, students should be able to accurately identify cube net shapes, 3) through experiments using cardboard media, students should be able to correctly and carefully solve problems related to cube nets, 4) through observing the Engklek game board, students should be able to correctly analyze cube nets, and 5) through teacher instructions, students should be able to create cube nets accurately and carefully.

The initial didactical design involves starting with stimulating students' knowledge about the definition of cube nets related to everyday life and conducting question-and-answer sessions between students and the teacher. Next, students will learn about different types of cube net patterns and finally create and validate patterns of the Engklek game related to cube nets. Students can discover various cube net patterns by analyzing the Engklek game board, allowing them to create alternative Engklek game patterns with modified rules.

Predicted student responses include: 1) students may not realize that the Engklek game patterns contain geometric elements (cube nets), 2) students may struggle to explain the definition of cube nets, 3) students may have difficulty understanding and identifying cube net shapes, 4) students may find it challenging to solve problems related to cube nets, and 5) students may struggle to create cube nets, and 6) students may easily forget cube net patterns.

The didactical design anticipates various student responses by: 1) illustrating Engklek game patterns as cube net patterns using media, 2) illustrating the definition of cube nets using media, 3) reinforcing the concept of cube nets using media, 4) explaining the concept of cube nets using media, 5) demonstrating how to create cube nets and having students follow along, and 6) instructing students to use the cube nets they create as new patterns for the Engklek game. The didactical design created is as follows.

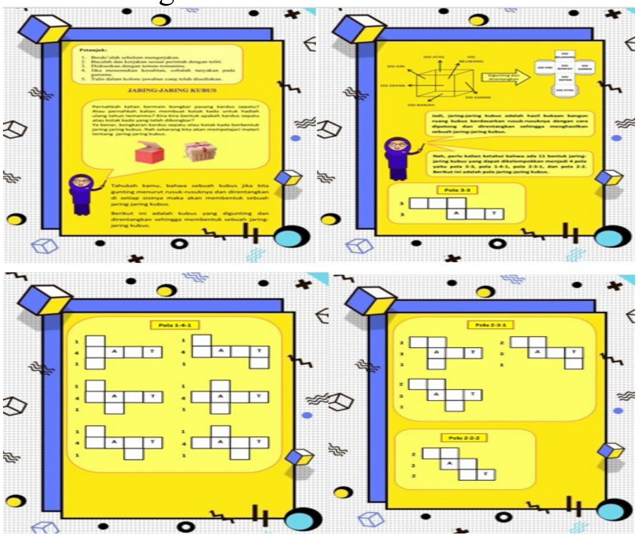

Figure 2. Didactic Design of Cube Nets Using the Engklek Game

The next designed learning activity involves proving that the patterns of the Engklek game are related to the concept of cube nets. Through this activity, students will discover various cube net patterns by analyzing the "Engklek Kapal Terbang" game patterns. This allows the cube nets discovered by students to become an alternative design for new Engklek game patterns and modified rules. Below is the initial didactical design related to the technical aspects of teaching ethnomathematics through the Engklek game or the concept of proving and discovering cube net patterns.

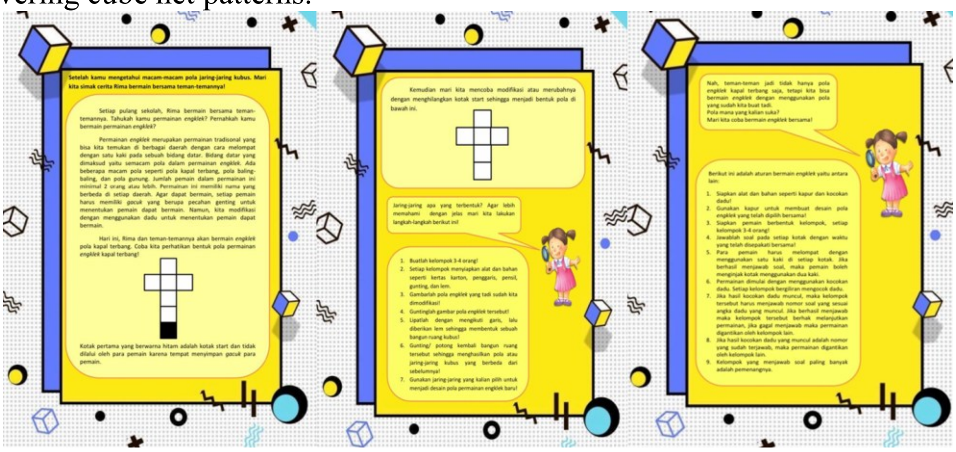

Figure 3. Initial Didactic Design Techniques for Cube Nets

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Metapedadidactic Analysis

The didactical design was then validated by experts in ethnomathematics and education practitioners using assessment components based on the National Education Standards Agency (BSNP). Following this, it was implemented with fifth-grade students in elementary school. During the implementation of the didactical design, students were able to construct the concept of cube nets and prove various patterns of cube nets using the Engklek game. The students' responses during the learning process aligned with the predicted responses, indicating that the didactical anticipations effectively addressed the obstacles encountered by students. After the lesson, students understood that the "Engklek Kapal Terbang" game patterns could form a cube net. When students cut out their cubes again, they could produce different cube net patterns, not just one but many variations. Once students had this knowledge and understanding, they tried playing a new Engklek game pattern with modified rules. The new Engklek pattern used was the 2-2-2 pattern, and there were problems in each square, as follows.

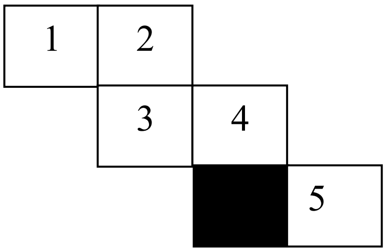

Figure 3. New Engklek Game with 2-2-2 Pattern

Retrospective Analysis

In the retrospective analysis phase, the impact of the didactic design was evaluated by conducting a final test on 6 fifth-grade students who had been exposed to the initial didactic design. The test results were analyzed based on epistemological obstacles, categorized as follows: learning obstacles related to conceptual errors, principle errors, and verbal errors. The number of students related to conceptual errors were 1 student, principle errors were 1 student, and verbal errors were 2 students out of a total of 6 students. Overall, the comparison of epistemological obstacles between students who did not receive and those who did receive the implementation of the didactic design is explained in Table 1 below.

Table 1. Comparison of Epistemological Obstacles Among Students

Type of Epistemological Obstacle	Students who did not Receive the Didactic Design	Students who did receive the Didactic Design
Conceptual errors	7 students	1 students
Principle errors	10 students	1 students
Verbal errors	11 students	2 students

Based on Table 1 above, the didactic design created has proven effective in reducing students' epistemological obstacles related to cube nets in the fifth grade of elementary school. This didactic design can continue to be refined to further reduce learning obstacles, including ontogenic, epistemological, and didactic obstacles, through the process of didactical design research.

Discussion

In learning mathematics, students often encounter difficulties in understanding certain concepts, known as learning obstacles. According to Brousseau (2002), learning obstacles are caused by several factors, including ontogenic obstacles (mental readiness to learn), didactic

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obstacles (due to the education system, teaching methods, and the presentation of textbooks), and epistemological obstacles (due to students' limited knowledge in understanding certain concepts). Epistemological obstacles in mathematics learning, particularly in geometry, are common. Findings from this study indicate that some students still struggle to understand the concept of cube nets, which is attributed to their low conceptual understanding. According to Ningsih (2016), conceptual understanding is a fundamental skill that must be achieved first in the objectives of mathematics learning.

Another obstacle encountered is the difficulty students face in visualizing the parts of cube nets. This falls under the category of problems related to the use of principles in mathematics learning. The use of principles is closely related to how students solve specific problems (Fauzi & Arisetyawan, 2020). The final obstacle observed is related to verbal usage, which arises because students are unable to apply concepts and principles in mathematics learning (Abrar, 2018). Consequently, students struggle significantly to comprehend certain mathematical terms.

These obstacles are caused by various factors, including the presentation of teaching materials and the teacher's instructional methods. According to Turmudi (2008), mathematics has been taught to students in an informative manner, where students merely receive information from the teacher. However, Piaget explained that children aged 7-11 years (elementary school) are still in the concrete operational stage (Ojose, 2008), while the context of mathematics learning often emphasizes operations and symbolism (Conway, 2007). Therefore, the method of teaching mathematics in elementary school should follow Bruner's principle of enactive, iconic, and symbolic stages (Bruner, 1966) or transition from informal, semiformal, to formal stages. In mathematical theory, this is part of the process of mathematization.

According to Gravemeijer (1994), mathematization occurs through two important processes: horizontal mathematization and vertical mathematization. Horizontal mathematization occurs when students explain problems that are close to their lives (contextual) using informal strategies to solve them. If these informal strategies guide students to solve problems using mathematical language or to discover algorithms, this process leads to vertical mathematization. The didactic design utilizing the "Engklek 2-2-2" game is an essential component in the process of mathematization for teaching the concept of cube nets in elementary school. This teaching concept is grounded in several important theories from Piaget (concrete operations, social interaction, cognitive conflict), Vygotsky (scaffolding), Bruner (enactive, iconic, and symbolic processes), and Ausubel (meaningful learning). The effectiveness of this teaching method is further enhanced by incorporating play as a characteristic of children's learning. The use of play contexts is based on an understanding of early childhood development and the perspective that play is crucial in their lives, as detailed by educational psychology experts such as Erikson (1963), Piaget (1962), & Vygotsky (1966)). According to Juhász (2021), play generates enjoyment, which is a positive educational element that makes learning activities more meaningful.

Play integrated into the learning context allows students to explore, solve problems, and ultimately discover various concepts that contribute to their understanding. This is evident from the decrease in epistemological obstacles after students were exposed to the didactic design using the "Engklek 2-2-2" game. It also indicates that the learning process has become meaningful, in line with Ausubel's theory. According to Mayer & Wittrock (1996), through meaningful learning, students can retain concepts for the long term (retention) and apply these concepts to solve new problems (transfer). Retention and transfer are critical components of educational goals.

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The "Engklek" game in the didactic design is seen not only as a means of instilling the concept of cube nets but also as a way to introduce culture to children at an early age. According to Koentjaraningrat (1985), culture is an inseparable part of human daily life, representing the behavior of society. Therefore, ethnomathematics is an important tool for teaching mathematical concepts and introducing culture to children in schools. This research has important implications for the concept and practice of education. Conceptually, this study has implications for 1) strengthening ethnomathematical concepts, 2) creating meaningful mathematics learning, and 3) involving contextual learning. In addition, the practical implications of this study are 1) the development of didactic design in mathematics learning, and 2) the integration of cultural context in mathematics learning

Conclusion

Based on the results of this study, several key points are identified: 1) Identification of Epistemological Obstacles, initial and final epistemological obstacles were classified into three categories: conceptual errors, principled errors, and verbal errors, 2) Development of Didactical Design, the initial didactical design was created by integrating the cultural game of Engklek, based on the analysis of the mathematics textbook and the initial epistemological obstacles related to cube nets. Additionally, the implementation of the initial didactical design resulted in a new Engklek game pattern with the 2-2-2 cube net design, and 3) Effectiveness of Didactical Design, the ethnomathematics-based didactical design using the new 2-2-2 Engklek pattern can be utilized in teaching cube nets to fifth-grade elementary school students. This design effectively reduces the epistemological obstacles encountered by students and fosters an appreciation for local cultural values by preserving and promoting the traditional game of Engklek.

Recommendation

The didactic design developed in this study can be used in mathematics learning, and can also be refined through further research. In addition, the implementation of this didactic design needs to be tested using quantitative research to see its effectiveness on the mathematics learning process of students. This study provides recommendations to teachers in elementary schools to 1) create didactic designs for mathematics learning that are in accordance with children's development, 2) involve cultural elements that are close to students' lives (contextual) as part of teaching materials, and 3) create meaningful and fun mathematics learning for students.

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