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Designing a Learning Trajectory for the Concept of Division Based on the Traditional Game of Congklak: A Design Research Study on Third Grade Students at Madrasah Ibtidaiyah

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Abstract. *This study aims to design and analyze learning trajectories for division concepts using the traditional game congklak through a design research approach. The participants were 20 third-grade students of an Islamic elementary school. The study was conducted through three phases: preliminary design, teaching experiment, and retrospective analysis. Data were collected through classroom observations, students' learning artifacts, and pretest–posttest results to support design reflection. The findings indicate that the congklak game supported students' initial understanding of division as a fair distribution process through concrete experience. However, a retrospective analysis revealed conceptual difficulties in transitioning from concrete activities to symbolic representations, particularly with regard to the concept of remainders. The study contributes design principles for culturally based division instruction that can inform the refinement of learning designs in subsequent cycles.*

Keywords: *design research, division, congklak*

INTRODUCTION

Mathematics learning in primary schools requires a design that supports the gradual, continuous development of students' conceptual understanding. From a design research perspective, learning is viewed as a systematic process that emphasizes not only the result, but also how the learning design mediates the formation of mathematical meaning through activities that are consciously and reflectively designed. (Cobb et al., 2003; Plomp et al., 2013). Many studies confirm that learning that focuses too much on symbolic procedures, without attention to students' learning trajectories, can result in a mechanistic, meaningless understanding. (Clements & Sarama, 2025). Therefore, the design of mathematics instruction should consider how students construct concepts through concrete experiences before moving to formal representations.

In recent years, game-based learning approaches have shown positive effects on student engagement, motivation, and the exploration of learning strategies in mathematics. (Alt, 2023; Pan et al., 2022). Games provide students with space to actively engage with concepts through activities that require decision-making, meaning negotiation, and reflection on the strategies used. In the context of basic mathematics education, games serve not only as a means of entertainment but also as a pedagogical medium that enables contextual and social construction of meaning.

In addition to game-based approaches, integrating local cultural contexts into mathematics learning has also received widespread attention in ethnomathematics research. Rosa and Orey (2024) and Prahmana et al. (2023) emphasize that cultural practices can serve as conceptual bridges that help students connect their everyday experiences with formal mathematical ideas. Several studies have integrated traditional Indonesian games, such as bola bekel, to support the learning of multiplication and factors (Digdayana et al., 2024; Setyowati et al., 2025). These findings indicate that cultural contexts can enrich meaningful mathematics learning experiences.

The traditional game of congklak, as part of Indonesia's cultural heritage, has characteristics of distribution and grouping that are conceptually related to the idea of division. Several studies report that the activity of distributing seeds in the game of congklak can help students understand division as a process of dividing evenly (Qirom & Juandi, 2023; Zuhri et al., 2023). However, most previous studies still emphasize the effectiveness of media use or quantitative improvements in learning outcomes. In-depth analysis of students' learning trajectories and the conceptual obstacles that arise during the transition from concrete activities to symbolic representations of division remains relatively limited.

In fact, in mathematics education literature, the transition from concrete manipulation to symbolic notation is a crucial phase that does not always occur automatically (Edelsbrunner et al., 2023). Many students can perform concrete activities but experience difficulties when they have to represent results symbolically, especially in understanding the concept of division remainders (Wang et al., 2022). This gap underscores the need for research that not only tests the effectiveness of media but also systematically analyses how students' learning trajectories develop and the obstacles that arise in the process.

From a Design Research perspective, attention is not solely on learning outcomes but rather on how learning design can be developed iteratively through the analysis of students' actual learning trajectories (Cobb et al., 2003). Therefore, studies are needed that design, implement, and reflect on the learning design of the traditional congklak game-based division to produce theoretical contributions in the form of Local Instruction Theory (LIT).

Based on this background, this study aims to design and analyze the learning trajectory of the concept of division through the traditional game of congklak using a Design Research approach. Specifically, this study focuses on formulating a Hypothetical Learning Trajectory (HLT), analyzing students' actual learning trajectories during implementation, identifying conceptual obstacles, especially in the transition to symbolic representation and the concept of division remainders, and compiling learning design principles as a theoretical contribution.

This study was limited to teaching the concept of dividing positive integers to third-grade students at Madrasah Ibtidaiyah, with an emphasis on the meaning of division as equal distribution and on understanding remainders. The study was conducted in a single Design Research cycle, so the resulting design revisions remained conceptual and had not been retested in the subsequent implementation cycle.

RESEARCH METHOD

This study applied a methodological approach, a Research Design, that focused on the development, implementation, and reflection on learning design through an iterative cycle. This approach was chosen to examine the quality of learning design and the students' learning process in depth, rather than simply measuring the effectiveness of learning outcomes (Digdayana et al., 2024).

The research was conducted with 20 third-grade students from Madrasah Ibtidaiyah, focusing on learning positive integer division. The traditional game of congklak was used as the context and manipulative medium to facilitate understanding of division as a process of equal distribution. This context was chosen based on considerations of primary school students' cognitive development, who still need concrete experiences before moving on to symbolic representations.

Research Procedure

The research was conducted in three main phases of Design Research: preliminary design, teaching experiment, and retrospective analysis. In the preliminary design phase, the researcher developed a hypothetical learning trajectory (HLT) based on a literature review of learning trajectories and division learning (Clements & Sarama, 2025), as well as research on the use of traditional games in mathematics education. The HLT contained learning objectives, the sequence of activities for distributing congklak seeds, predictions of student responses and strategies, and anticipations of conceptual obstacles that might arise. The teaching experiment phase was carried out by implementing the learning design in the classroom. At this stage, the researchers observed students' behaviour while playing congklak, the methods they used to distribute the seeds, and the forms of representation in their work. Student work artefacts were collected as empirical data for analysis in the next stage.

The retrospective analysis phase involved comparing students' actual learning trajectories with the designed HLT. This analysis aimed to identify the design's success and the conceptual obstacles that could serve as a basis for developing learning design principles.

The retrospective analysis phase involved comparing students' actual learning trajectories with the designed HLT. This analysis aimed to assess the alignment between the design predictions and student responses and to identify conceptual obstacles that arose during learning. Based on the analysis results, design revisions were formulated as a Revised Hypothetical Learning Trajectory as part of the iterative Design Research process.

Data collection was conducted through classroom observation, documentation of student artefacts, brief interviews to clarify students' strategies, and pre- and posttests as supporting data for design reflection. Data analysis was conducted qualitatively to identify patterns in learning trajectories and conceptual barriers, and descriptively-quantitatively to observe trends in changes in student

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scores. Quantitative data were used to complement qualitative interpretations in understanding the dynamics of student learning trajectories.

This research was conducted in a single cycle of Design Research to produce an initial Local Instruction Theory for the learning division based on the traditional game of congklak. The resulting design revisions were conceptual and recommended for retesting in a follow-up research cycle.

RESULTS AND DISCUSSION

The results of this study are presented based on an analysis of students' learning trajectories during the implementation of a learning design based on the traditional game of congklak. The presentation of the results begins with a descriptive overview of changes in students' understanding, followed by an analysis of concrete distribution activities, identification of conceptual obstacles in the transition to symbolic representation, and reflection on the design in the form of a revised Hypothetical Learning Trajectory that contributes to the formulation of Local Instruction Theory.

To support reflection on the learning design, a descriptive analysis of students' pretest and posttest scores was conducted. These descriptive statistics are presented in Table 1 below.

Table 1. Descriptive Statistics of Student Score Data

Statistics

		pretest	posttest
N	Valid	20	11
	Missing	0	9
Mean		3,75	4,7273
Std. Deviation		2,653	2,86674
Minimum		1	1,00
Maximum		9	9,00

Based on descriptive analysis, the average pretest score of 3.75 increased to 4.65 on the posttest across 20 students. This increase in the average indicates that students' understanding tends to improve after participating in congklak-based

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learning. However, the wide range of scores (minimum = 1, maximum = 9) and the relatively large standard deviation (pretest = 2.653; posttest = 2.870) indicate variation in students' understanding development.

From a Design Research perspective, these variations are not merely differences in outcomes, but indicators of differences in learning trajectories. Therefore, this quantitative data is used as a starting point to guide qualitative analysis of student artefacts and activities during learning.

In the early stages of learning, students engage in distributing congklak seeds to represent division as an even-division process. This activity serves as a conceptual foundation before students are introduced to formal symbolic notation.

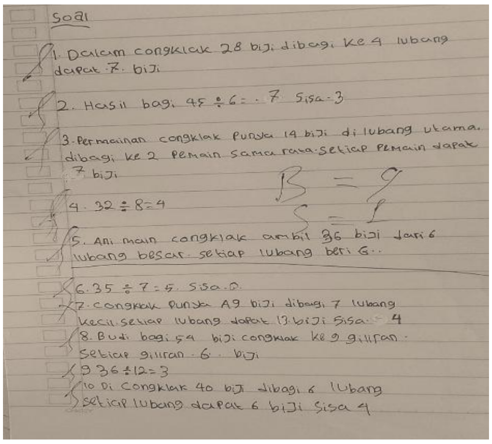

Figure 1. Students' answers representing the division process as an even distribution through the congklak game.

Figure 1 shows that pupils are beginning to understand division as a process of equal distribution between holes. Most pupils can evenly distribute the seeds and record the number in each hole. This representation shows that pupils have developed an initial understanding of division through concrete experience.

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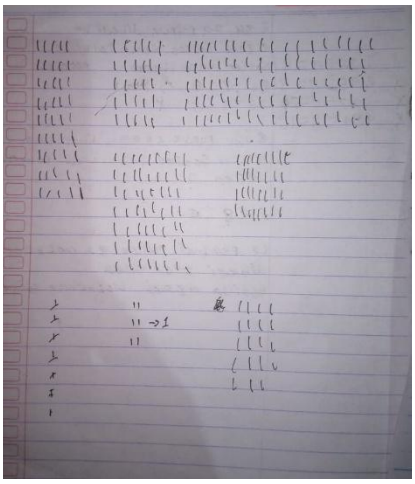

Figure 2. Schematic diagram of the distribution of congklak seeds created by students

Figure 2 shows how students create distribution schemes as an intermediate representation. The scheme shows that students begin to organize the distribution process visually before writing it down in formal notation. This finding shows that the congklak game serves as a bridge between concrete experience and symbolic form (Lin & Cheng, 2022).

Figure 3. Students are trying division using congklak

Although pupils were able to perform concrete distribution quite well, analysis of artefacts showed that the transition to symbolic representation did not always go smoothly.

Analysis of student artefacts shows that the transition from real experiences to symbolic representations requires clear representation mediation. Artefacts serve as an important source of data for understanding how students express and negotiate mathematical meaning (Baccaglini-Frank et al., 2025). Analysis of student artefacts reveals conceptual barriers. Figure 4 shows a student's artefact response that demonstrates a conceptual error in solving a division problem based on the congklak context. The error is evident in the section marked with a circle, where the student writes down the result of the division without accounting for the remaining seeds that cannot be evenly distributed. In this answer, the student records only the result of the division as a whole number and ignores the remaining seeds, so the division notation does not reflect the distribution process carried out. This error shows that the student does not yet fully understand the relationship between concrete activities and the formal meaning of division.

Figure 5 shows the difficulties students encounter in transitioning to the symbolic representation of division. The section marked with an arrow shows that students write down the result of the division without including the remainder, even though there are still undivided seeds in the distribution process. In this answer, students interpret division as a process that must produce an exact division, so that the remainder is considered irrelevant or ignored. This conceptual error shows that students do not yet understand the remainder as a valid part of the division result. This finding reinforces previous research showing that the transition from concrete experience to formal mathematical symbols does not always occur automatically (Wang et al., 2022).

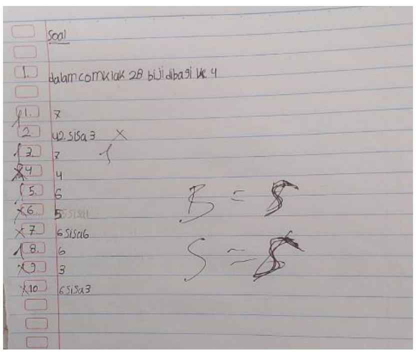

Figure 4. Student response artefacts showing conceptual errors.

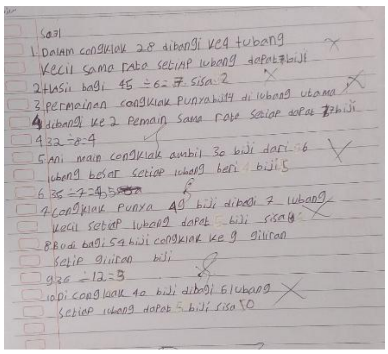

Figure 5. Error in representing the concept of division remainders.

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The researcher's analysis of student artefacts revealed recurring conceptual errors, particularly in relating concrete distribution results to formal division notation (see Figure 6). Within the Design Research framework, these obstacles are viewed as a source of reflection for revising and refining the learning design (Pan et al., 2022).

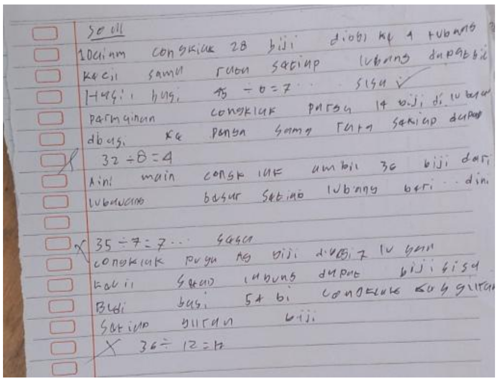

Figure 6. Patterns of conceptual errors made by students in division

Analysis of the student artefacts shown in Figure 7 indicates a pattern of repeated errors in connecting the concrete distribution process with the symbolic notation of division. In addition, variations in distribution strategies were also identified during classroom observations. Some students were seen to distribute the congklak seeds gradually, then repeat the division when the results were not even. Indications of the use of this trial-and-error strategy were reinforced by the results of a brief interview with one of the students, as follows:

Researcher: "Why did you distribute the seeds like that?"

Student: "I tried distributing them one by one first. If there were still many left over, I repeated the process until they were all distributed equally."

The interview excerpts show that students consciously use a trial-and-error approach to achieve what they consider an even distribution. This strategy reflects that students are building understanding through concrete exploration, even though it is not yet fully structured as a formal symbolic representation. This variation in strategy aligns with the characteristics of a dynamic, non-linear learning trajectory. (Pujiastuti et al., 2025).

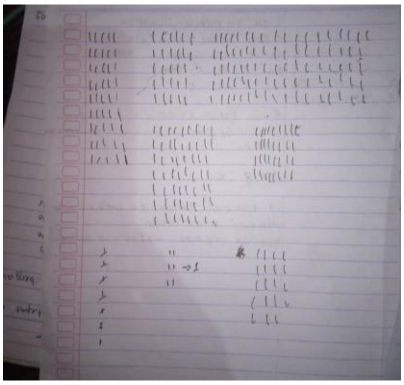

Figure 7. Diagram of the distribution of congklak seeds made by students through trial and error before achieving an even distribution.

Findings on conceptual obstacles and variations in student strategies served as the basis for design reflection during the retrospective analysis stage. A comparison between the initial Hypothetical Learning Trajectory and its revision is presented in Table 2 below.

Table 2. Comparison of Initial and Revised Hypothetical Learning Trajectories

Level of learning	Early HLT	Obstacles Encountered	Design Revision (Revised HLT)	Predicting Student Responses
Initial seed distribution activities	The students evenly distribute the congklak seeds.	Some students focus on results without reflecting on the process	Added reflective questions about the number of seeds per hole	Students begin to associate distribution with the meaning of sharing.
Transition to symbolic representation	Students immediately write down the division notation.	Errors in determining the result and remainder of the division	Added visual scaffolding and discussion of representation between	Students understand the relationship between concrete distributions and symbolic notation.
Understanding the concept of remainder	The remainder is introduced through written questions.	Students ignore or misinterpret the remainder	The remainder is revealed through manipulation of the remaining seeds.	Students understand remainders as part of the division process.

The design revision focused on adding reflective questions after distribution activities, providing visual scaffolding in the transition to symbolic representation, and concrete mediation of the concept of division remainders. Within the framework of Design Research, this revision was part of an iterative process to refine the learning design based on actual student responses (Cobb et al., 2003).

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Classification of Conceptual Barriers

Analysis of student artefacts not only reveals challenges in understanding the concept of division remainders, but also uncovers various conceptual obstacles. From a didactic theory perspective, student learning obstacles can be classified into epistemic, didactic, and ontogenic. This classification provides researchers with an understanding that student difficulties are not only caused by personal abilities, but are also related to the characteristics of mathematical concepts and established teaching strategies.

Epistemic obstacles arise when learners view division as a process that always yields a result, leaving nothing behind. Evidence from students shows that some learners do not pay attention to the remaining seeds after division is carried out evenly, or continue dividing until all the seeds are considered used up. This obstacle indicates a lack of conceptual understanding among students of the nature of division, particularly in recognizing that the remainder is a valid part of the division result.

Furthermore, a didactic obstacle was identified in the initial learning design. In the initial design, the congklak game did not specifically encourage students to reflect on the remaining seeds after division. As a result, students did not gain sufficient learning experience to connect concrete activities with the formal concept of remainder in division. This obstacle indicates that the difficulties students faced did not stem solely from their understanding but also from the limitations of the learning design in supporting targeted mathematical reflection.

Meanwhile, ontogenic obstacles were observed in students' limitations in expressing division results using symbols. Although students were able to divide seeds physically, they had difficulty writing the division results and remainders in mathematical notation. These obstacles relate to students' cognitive development and symbolic abilities at the primary school level.

The classification of these types of conceptual barriers is a key element in retrospective analysis and design decision-making. By recognizing the types of barriers that arise, revisions to the learning design can be made more focusedly, whether through the addition of reflective activities, scaffolding of representations, or increased mathematical discussion. In this way, students' conceptual obstacles in understanding the transition to symbolic representation are not seen as a failure in learning, but as a valuable source of reflection in the development of learning design and local theory (Howell et al., 2021).

Design Principles for Congklak-Based Learning (Local Instruction Theory)

This Design Research study not only presents an overview of the use of congklak games in teaching division concepts, but also produces a theoretical contribution in the form of Local Instruction Theory (LIT), which focuses on context-based learning of division. LIT was formulated through a study of students' learning trajectories, the identification of conceptual obstacles that arose, and reflection on the learning design implemented. Within the framework of mathematics learning theory, this localized theoretical contribution plays an important role in explaining the process of representation transformation, from concrete experiences to symbolic forms, which ultimately supports the development of students' conceptual understanding (Quane, 2025; Edelsbrunner et al., 2023).

Principle 1: Concrete distribution needs to be followed by reflective activities based on the representation between

The study's results show that distributing congklak seeds can help students develop an initial understanding of division as a process of fair sharing. However, without structured reflection activities, some students still find it difficult to connect these concrete experiences with symbolic representations. Therefore, concrete distribution activities need to be followed by reflective activities using tables, diagrams, or visual schemes as intermediate representations before students are introduced to formal division notation. These findings align with research emphasizing that the use of manipulative tools must be accompanied by an explicit representation transformation design to enable students to build meaningful conceptual connections (Ahmad & Siller, 2024).

Principle 2: The concept of division remainders needs to be mediated through concrete manipulation before being formalized symbolically.

Analysis of student artefacts reveals that the concept of division remainders is a significant conceptual obstacle. Students often ignore or misunderstand remainders when the concept is presented directly in symbolic form. The results of this study show that understanding of division remainders develops more easily when the concept is mediated through manipulating the remaining conklak seeds after the division process is completed. This finding reinforces the view that the transition from concrete to symbolic representation should be through an intermediate representational stage, so that students have the opportunity to reflect on the mathematical meaning of the manipulative activities they perform (Khatin-Zadeh et al., 2024).

Prinsip 3: Variasi strategi distribusi siswa perlu diakomodasi melalui diskusi kelas terstruktur

The study's results reveal the diversity of strategies students use to distribute congklak seeds, including trial-and-error approaches. This diversity of strategies reflects the differences in students' learning trajectories, which are dynamic and not always linear. Thus, learning designs need to accommodate these variations in strategy through structured class discussions, so that students have the opportunity to compare and reflect on the strategies they use. This approach aligns with research showing that mathematical discussions grounded in representations can help students consolidate their conceptual understanding and strengthen connections between representations (Edelsbrunner et al., 2023).

Contribution to Previous Research

Based on the results of learning trajectory analysis and the obstacles students encountered, this study developed a Local Instruction Theory (LIT) that explains the role of the traditional game of congklak as a medium for transitioning from concrete experience to symbolic understanding in division operations. This LIT not only presents the empirical results of the study but also contributes to the development of a contextual mathematics learning theory grounded in Design Research. Unlike previous studies that focused more on the effectiveness of media or on quantitative learning outcomes, this study presents a new perspective on the importance of the transition phase towards symbolic representation, mediated by cultural artefacts, in students' learning trajectories. Thus, this research enriches the theory of mathematical learning trajectories by providing a more in-depth explanation of how the process of transformation from concrete to symbolic representations can be systematically facilitated in learning within a cultural context (Khatin-Zadeh et al., 2024).

CONCLUSION

The findings of this study indicate that using the traditional game of congklak as a learning context can facilitate students' understanding of division as a concrete distribution process. However, the analysis of students' learning trajectories shows that the transition to symbolic representation, especially in understanding the concept of division remainders, remains a challenge for some students. This study provides a theoretical contribution by offering a deeper understanding of students' learning trajectories in division learning through traditional games, as well as formulating learning design principles that can serve as a reference for the development of mathematics learning grounded in cultural contexts.

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