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Analysis of Learning Obstacles in Mathematical Connection Ability on Circle and Arc Material

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Abstract

Mathematical connection skills are essential in mathematics. Ideally, students connect concepts, relate mathematics to other fields, and apply them in daily life. However, these skills remain low, especially in circle material, such as the relationship between central and inscribed angles. This study describes learning obstacles related to mathematical connection skills in circles and arcs. The approach is descriptive qualitative. The research subjects consisted of 17 grade XI students and one mathematics teacher. Data collection instruments included a written test of 4 essay question with item validity coefficients ranging from 0.515to 0.796, where all items exceeded the r_{tabel} threshold of 0.482, a learning experience questionnaire, and semi-structured interviews with teachers. The research findings identified three types of obstacles. Epistemological obstacles are evident in students' errors in understanding the relationship between central angles and inscribed angles (reversed), and erroneous arguments regarding the distance of a point to the center. Didactic obstacles stem from procedural and mechanistic learning, a lack of real-world application examples, and limited interactive learning resources. Ontogenic obstacles are reflected in difficulties visualizing word problems and errors in basic algebraic procedures. These three barriers collectively weaken mathematical connection skills, particularly in indicators of connections between mathematical concepts and the connection of mathematics to everyday life. This research contributes to mapping learning barriers, which can serve as an empirical basis for teachers and researchers in developing anticipatory didactic designs and interactive learning media to enhance students' mathematical connection skills in a more meaningful and sustainable manner.

Keywords: circles, inscribed angles, central angles, learning obstacle, mathematical connections

Introduction

Mathematical connection ability is one of the fundamental competencies that students must master in learning mathematics (NCTM, 2000). The National Council of Teachers of Mathematics (NCTM, 2000) states that the process standards in mathematics learning include mathematical connection ability, which enables students to understand the interrelationships among mathematical topics, between mathematics and other disciplines, and between mathematics and everyday life. This ability is crucial because mathematics, in essence, is not a collection of separate branches or standards but rather an integrated field of study (NCTM, 2000). Based on the Decree of the Head of the Curriculum and Educational Assessment Standards Agency of the Ministry of Education, Culture, Research, and Technology Number 008/H/KR/2022 concerning learning outcomes for early childhood, primary, and secondary education within the Merdeka Curriculum, mathematical connection ability is affirmed as one of the objectives of mathematics learning outcomes. This decree emphasizes that mathematical connection ability should develop students' competence in three areas: linking concepts within mathematics, applying mathematical concepts to other disciplines, and applying mathematical concepts in everyday life (Kemendikbudristek, 2022). Mathematical connection ability serves as the foundation for students to understand and meaningfully link mathematical concepts, so that learning is not fragmentary but rather comprehensively integrated (Widodo et al., 2024). Students with strong mathematical connection ability are able to use varied representations to solve complex mathematical problems, including linking geometric concepts to real-life contexts (Naziah & Setyaningsih, 2024). From a broader perspective, learning approaches that successfully develop students' mathematical connections have been shown to significantly improve conceptual understanding and build sustainable mathematical power (Rahmadhani & Wiratomo, 2024). Based on these three theoretical foundations, it can be concluded that mathematical connection ability is an essential prerequisite for designing effective, relevant, and meaningful mathematics instruction.

However, various previous studies on mathematical connection ability show that students' achievement of mathematical connection indicators across various topics remains low and below standard (Hidayati & Jahring, 2021; Rustam et al., 2021). This is reflected in students' inability to identify relationships between topics, difficulty transferring concepts to new contexts, and weak ability to integrate various mathematical representations (Rohendi & Dulpaja, 2013). Many obstacles are found in the indicator of connections between mathematical concepts (Fatimah, 2021). Students with low mathematics ability generally are only able to satisfy one mathematical connection indicator well, making it difficult for them to solve problems that require relational understanding between concepts (Afriani & Machromah, 2025). In addition, mathematics education students also still struggle to connect mathematical concepts with one another (Septian, 2022). Another study classified students with low mathematical connection ability as tending to use patterns or variables only in a limited way, without being able to construct a complete argument (Kholid & Dewi, 2024).

Other evidence also shows that mathematical connection ability is relatively low in circle material, particularly on the indicator of connecting mathematics to everyday life (Leunufna et al., 2025). This condition is reinforced by the findings of Sari, Mardiyana, & Pramudya (2020), who stated that weaknesses in mathematical connection often occur in material that is abstract and requires visualization, such as the relationship between central angles and inscribed angles in circles (Sari et al., 2020). Similarly, a study at SMP Islam Al Falah Jambi found that students were unable to write down what was known and asked in a problem using symbols or notation, and were not accustomed to drawing conclusions at the end of solving circle-related problems (Putriani, 2021). Another study confirmed that students' low mathematical connection ability in circle material was caused by insufficient use of technology in mathematics learning activities (Hanum R, 2024). These various findings indicate the presence of learning obstacles epistemological, didactic, and ontogenic in nature, related to mathematical connection ability in circle material.

Although a number of studies have identified low mathematical connection ability, gaps remain that require deeper examination, particularly regarding the systematic analysis of learning obstacles. First, most studies have focused on identifying general levels of mathematical connection ability or on error analysis, with few specifically exploring the types of learning obstacles that cause weak mathematical connections in circle material. (Evayanti & Munir, 2023; Ningsih et al., 2020; Saksena et al., 2026; Septiana & Subarinah…, 2023). Second, research on circle material, particularly the topic of the relationship between central and inscribed angles, remains limited to profiling students' abilities or errors, without a deeper analysis of the factors behind learning obstacles from the perspective of instructional design (Salamanya & Citra, 2019). Not many studies have examined learning obstacles based on mathematical connection ability in an integrated way, in which the analysis considers not only final test results but also students' thought processes when connecting concepts within circles. To bridge this gap, this study is built upon a conceptual framework that systematically maps the root causes of learning obstacles through to the formulation of alternative solutions in the form of adaptive instructional recommendations. The comprehensive line of reasoning underlying the urgency of this study is presented visually in Figure 1.

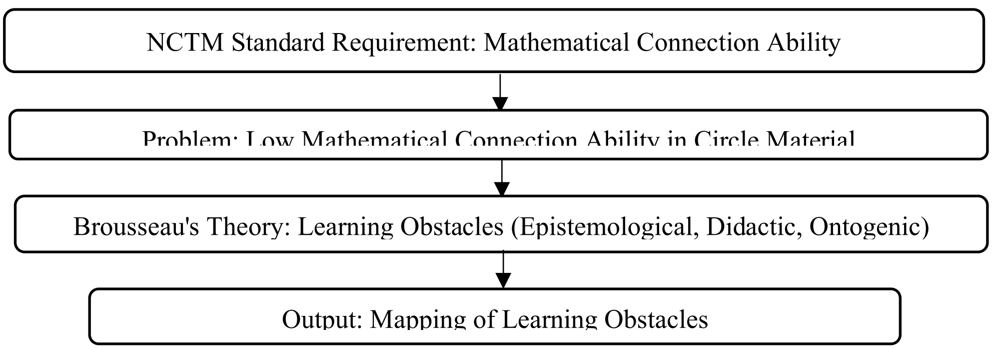

Figure 1. Conceptual Framework for the Analysis of Learning Obstacles in Mathematical Connection

Based on these gaps, an analysis of learning obstacles focusing on mathematical connection ability in circle material is highly urgent to conduct. A comprehensive understanding of learning obstacles (encompassing ontogenic, didactic, and epistemological obstacles) will provide an empirical foundation for teachers and researchers in designing more adaptive and anticipatory instruction. As stated by Suryadi (2013), identifying learning obstacles is a crucial first step before developing an appropriate didactic design. Based on the problem scope and urgency described above, the research questions of this study are: (1) What forms of learning obstacles (epistemological, didactic, and ontogenic) do grade XI students experience in mathematical connection ability on circle and arc material? and (2) What factors underlie the emergence of each type of learning obstacle? Therefore, this study aims to analyze students' learning obstacles based on mathematical connection ability in circle and arc material. This study needs to be carried out promptly to provide a theoretical contribution in the form of a mapping of learning obstacles as well as practical implications for mathematics learning, particularly on the topic of circles and arcs.

Method

This study uses a qualitative approach with a descriptive method. This approach was chosen because the study aims to provide an in-depth description of students' learning obstacles in circle material based on mathematical connection ability. The research focuses on uncovering the forms of learning obstacles experienced by students and the underlying factors, through analysis of test results, questionnaires, and interviews.

This study was conducted during the even semester of the 2025/2026 academic year. The research site was selected because preliminary observations and teacher reports at the school indicated significant learning obstacles among grade XI students in circle material, particularly in establishing mathematical connections between central angles and inscribed angles. Circle material requires an integrated understanding of geometric properties, making it an ideal object of study to uncover epistemological, didactic, and ontogenic barriers. The research subjects consisted of one grade XI mathematics teacher and 17 grade XI-1 who had studied circle material. The research procedure was carried out in three stages: (1) instrument development, (2) data collection, and (3) data analysis to identify learning obstacles.

Based on its source, the data in this study are primary data. The research instruments consisted of a learning-obstacle indication test comprising four essay questions based on NCTM's (2000) mathematical connection indicators, a student learning-experience questionnaire, and a semi-structured interview guide for the teacher. Although this study adopts a qualitative-descriptive approach, quantitative analysis was briefly employed during the instrument validation stage to ensure the technical quality and empirical validity of the test items prior to qualitative data collection. Instrument validity was tested using the product-moment correlation formula as follows:

$$r_{xy} = \frac{N \sum XY - \sum X \sum Y}{\sqrt{\{N \sum X^2 - (\sum X)^2\}\{N \sum Y^2 - (\sum Y)^2\}}}$$

Where:

$X =$ the score obtained by a student for the item being analyzed

$Y =$ the score obtained by a student for all items combined

$r_{xy} =$ the correlation coefficient between variables X and Y

$\sum XY$ = the sum of the products of X and Y

$X^2 =$ the square of X

Y^2 = the square of X

$N =$ the number of data points

$(\sum X)^2 =$ the square of the sum of X

$(\sum Y)^2 =$ the square of the sum of Y

The criteria for the correlation coefficient of the test- validity instrument, as proposed by Arikunto (2010), are as follows:

Table 1. Validity Coefficient Criteria (Arikunto, 2010)

Product Moment r_{xy} Value Range	**Interpretation**
$0,80 < r_{xy} \leq 1,00$	Very high
$0,60 < r_{xy} \leq 0,80$	High
$0,40 < r_{xy} \leq 0,60$	Sufficient
$0,20 < r_{xy} \leq 0,40$	Low
$0,00 < r_{xy} \leq 0,20$	Very low

The correlation-coefficient table used is based on $\alpha = 5\% = 0,05$ and degrees of freedom (df) = 17-2 = 15 as follows.

Table 2. Correlation Coefficients

df (N−2)	**α=0.05**
10	0.576
11	0.553
12	0.532
13	0.514
14	0.497
15	**0.482**
16	0.468
17	0.456
18	0.444
19	0.433
20	0.423

To determine whether an item is valid, the calculated r_{xy} value must be compared with the product-moment r_{table} value at $\alpha = 0{,}05$. The validity testing criteria are as follows:

1. If $r_{xy} \geq r_{table}$ the item is valid (significant)
2. If $r_{xy} < r_{table}$ the item is not valid (not significant)

Instrument-quality testing in this study was directed at measuring internal validity directly within the research subject group. Based on the analysis of response data from 17 students using the product-moment correlation formula above, a summary of the empirical validity test results is presented in Table 3.

Table 3. Item Validity Test Results for Mathematical Connection Ability

Item	**r_{xy} (calculated)**	**r_{table}(N=17)**	**Criteria**	**Conclusion**
Item 1	0,796	0,482	$r_{xy} > r_{table}$	Valid
Item 2	0,650	0,482	$r_{xy} > r_{table}$	Valid
Item 3	0,705	0,482	$r_{xy} > r_{table}$	Valid
Item 4	0,515	0,482	$r_{xy} > r_{table}$	Valid

Data collection techniques included administering the test, distributing questionnaires to several students who had completed the test, interviewing the mathematics teacher, and documenting the research process. Documentation served as supporting data in the form of photographs of the test and interview sessions to strengthen the validity of the research data. Data validity was established through technique triangulation and source triangulation. Technique triangulation was carried out through the written test and the student questionnaire, while source triangulation was carried out by comparing data from students and from the mathematics teacher.

Data analysis in this study follows the qualitative data-analysis stages proposed by Creswell (2014), consisting of six stages: (1) organizing and preparing the data for analysis, (2) reading and reviewing all the data, (3) coding all the data, (4) using the codes to generate descriptions, (5) connecting themes, and (6) interpreting and making meaning of the themes (Creswell, 2014). The details of this qualitative data-analysis procedure, following Creswell (2014), are presented in Table 4.

Table 4. Details of Data Analysis According to Creswell (2014)

Creswell (2014) Stage	Procedure Applied in This Study
Organizing Data	Collecting all students' written test answer sheets, transcribing the teacher interview results, and organizing the questionnaire results.
Reading All the Data	Rereading all student answers and interview transcripts in general to capture dominant error patterns.
Coding	Marking student errors with specific codes, e.g., K1a (first error on item 1), K2a (first error on item 2), K3a (first error on item 3), K4a (first error on item 4).
Describing Themes	Compiling descriptive categories from the codes that emerged, such as "procedural algebraic errors" or "reversed formula understanding."
Connecting Themes	Linking the identified learning obstacles to the three NCTM mathematical-connection indicators through data triangulation.
Interpretation	Drawing philosophical and pedagogical meaning as to why these obstacles occurred and their implications for teachers' future didactic design.

The research findings were used to describe students' learning obstacles based on mathematical connection ability in circle material, which will subsequently serve as the basis for developing a didactic design based on mathematical connection ability in mathematics learning, particularly on the topic of circles.

Result and Discussion

Analysis of Written Test Result

The data presented in this section come from three main sources: (1) the results of the written learning-obstacle test based on mathematical connection indicators in circle material,

(2) the results of the questionnaire administered to students after completing the test, and (3) the results of the interview with the grade XI mathematics teacher. These three data sources were collected to identify the types of learning obstacles that emerge in students' mathematical connection ability, based on the three NCTM (National Council of Teachers of Mathematics) connection indicators, namely: (1) connections between mathematical concepts, (2) connections between mathematics and other disciplines, and (3) connections between mathematics and everyday life (NCTM, 2000). The learning-obstacle indication test was administered to 17 grade XI-1, with the criterion that students had previously studied the relationship between central angles and inscribed angles in circles. Based on the analysis of responses from the 17 students on the mathematical-connection test, a frequency distribution of the number of students who made errors on each item was found. The detailed pattern of student errors, along with example answers, is presented in Table 5.

Based on the data presented in Table 5, the identification results show a consistent and interrelated pattern of errors among grade XI-1 in solving mathematical-connection problems related to circle material. This error pattern indicates the presence of three main types of learning obstacles (epistemological, didactic, and ontogenic) that limit students' relational thinking ability.

Table 5. Identification of Student Errors in Working on the Mathematical Connection Test

Item	Code	Error Description	Example Answer	Number of Students
1	K1a	Reversed the relationship between central and inscribed angle (assuming central angle = ½ inscribed angle)	Central angle = $\frac{1}{2}$ inscribed angle, resulting in $x = 3$	1
	K1b	Used an incorrect operation (adding instead of the correct operation)	$(6x - 10)(2x + 10) = 90$	1
	K1c	Procedural algebraic error despite a correct underlying concept (sign error, distribution, or simplification)	$(6x + 10) = (2x + 10)$ should be $6x - 10$	1
	K1d	Did not state the relationship at all, or wrote only the formula without applying it	$-60 + 20 = 80$ (without an equation)	1
	K1e	Correct answer without explanation	Directly wrote $x = 15$ with no working shown	1
2	K2a	Gave no opinion or reasoning	Only wrote $\angle APB, \angle AQB$; only drew an incorrect visualization	2
	K2b	Reasoning was inaccurate	"Because points P and Q are equally close to the center"; "Because every circle has a radius"; "The value of both inscribed angles is equal"	6
3	K3a	Did not state the correct reasoning or change	Only wrote 90°	1
	K3b	Reasoning was inaccurate	"Because it forms a triangle"; "Because it cuts the diameter in half of the circle"	5
4	K4a	Did not write the relationship between S_1 and S_2	Answered only with algebraic computation	6
	K4b	Did not provide an answer	Blank answer	5

Questionnaire Analysis

The results of the questionnaire given to grade XI-1 students who had completed the mathematical-connection test on circle material were used to explore their subjective perceptions of the difficulties they experienced, their conceptual understanding, visualization strategies, and classroom learning experiences. The analysis results were linked to the three types of learning obstacles (epistemological, didactic, and ontogenic) as well as the mathematical-connection indicators. The main findings based on several questionnaire items are presented below.

1. Identification of the most difficult item

   Based on the questionnaire results, item 4 concerning satellite position was considered the most difficult item because students found the concept complex and could not visualize the situation. Item 3 concerning the architecture of a mosque dome was also considered difficult because it required dynamic visualization. This indicates a strong didactic obstacle, in which students are not accustomed to connecting circle theorems with real-world contexts (satellites, domes). In addition, a lack of visualization ability (part of the ontogenic obstacle) exacerbated the difficulty.
2. Understanding of central and inscribed angles

   Most students claimed to have memorized the property relating central and inscribed angles. However, the written test results showed that many still applied this relationship incorrectly (reversed, or not stated at all). This indicates an ontogenic obstacle (procedural difficulty) despite having memorized the formula. Their knowledge is mechanically memorized without deep rational understanding. This relates to the still-low indicator of connections between mathematical concepts, since students were unable to link memorized formulas to the appropriate algebraic representation.
3. Visualization and difficulty with problems connecting mathematics to real life

   More than half of the students experienced difficulty with visualization. This constitutes a serious ontogenic obstacle, as spatial-representation ability (imagining a semicircular shape and the movement of points) was underdeveloped. Thales' theorem (an inscribed angle subtending a diameter equals 90°) was recalled only by students who did not experience difficulty. This shows that the indicator of connecting mathematics to everyday life remains weak. Students were unable to transfer the abstract theorem to a real-life situation.
4. Perception of the difficulty level of connection-type items

   Most students acknowledged that items requiring conceptual explanation were more difficult than routine computational items. This shows that classroom mathematics instruction tends to focus on computational procedures, so students are not trained to provide concept-based argumentation. Connections between concepts become weak, and this is caused by a didactic obstacle.
5. Learning resources

Limited access to textbooks constitutes a structural didactic obstacle. Students rely on YouTube to understand concepts. They suggested that textbooks include more contextual problems, explanatory illustrations, and clearly sequenced solution steps.

6. Teacher's classroom explanations

   Although the teacher explained abstract concepts fairly clearly, the lack of real-world application examples caused students difficulty in working on items 3 and 4. This is a significant didactic obstacle. Students need repetition, an appropriate pace of delivery, and more explicit connections both between concepts and with the real world. They also wanted a greater variety of learning resources.

Interview Analysis

To strengthen the findings from the written test and the questionnaire, an interview was conducted with the grade XI mathematics teacher. This interview aimed to explore the teacher's perspective on students' mathematical connection ability, the learning obstacles that commonly arise, and the instructional practices applied. The results of the interview analysis, organized into several key findings, are presented below.

Table 6. Summary of Interview Results with the Teacher

Main Question	Answer/Finding
Students' Mathematical Connection Ability	The teacher stated that most students' mathematical connection ability is still fairly weak, particularly on the indicators of connections between mathematical concepts and connections between mathematics and other disciplines. On the indicator of connection to real life, students actually find it easier to understand when the material is linked to everyday contexts. The factors behind the low connection ability include students' weak understanding of prerequisite concepts and insufficient readiness in building conceptual understanding before formulas are introduced.
Learning Obstacles According to the Teacher	The most common obstacle is epistemological: students frequently reverse their understanding of the relationship between central and inscribed angles (e.g., assuming the central angle equals ½ the inscribed angle). In addition, students quickly forget formulas because they only memorize properties without understanding the underlying concept of how the formula or property arises. The teacher acknowledged that her practice of directly giving formulas contributes to this obstacle.
Ways of Addressing the Obstacles	The teacher conducts evaluations at the end of lessons and discusses issues with other teachers (cross-subject sharing) to find solutions to students' difficulties. However, for deeper conceptual obstacles, the teacher has not yet applied specific strategies such as concept-building through visualization or interactive media.
Teacher's Reference Sources	The learning resources used are still limited to the student textbook, teacher's guide, and teaching modules (published by the Ministry of Education, Culture, Research, and Technology). The teacher acknowledged that these resources are not very interactive and suggested using videos, games, or other interactive media to foster mathematical connection ability.

Main Question	Answer/Finding
Teacher's Learning Flow	The learning model used is Problem-Based Learning (PBL) combined with contextual learning. Lessons begin with presenting the learning outcomes, explaining the material and examples (going straight to formulas), followed by group discussion. However, the teacher acknowledged that this model is less effective because students are not conceptually ready beforehand, and in group discussions only some students are actively engaged. Students also tend to be afraid to ask questions when prompted.

Data Triangulation Analysis

Based on the triangulation of data from the written test, the questionnaire, and the teacher interview, the researcher identified three types of learning obstacles, each linked to a mathematical-connection indicator. A summary of these obstacles is presented in the separate tables below.

Table 7. Summary of Epistemological Obstacles

Type of Obstacle	Characteristics	Mathematical Connection Indicator
Epistimological	Students incorrectly understand the relationship between central and inscribed angles (reversed, e.g., central angle = ½ inscribed angle).	Connections between mathematical concepts
	Students do not understand that inscribed angles subtending the same arc are equal, and instead argue based on "distance of a point to the center."	
	Students do not state the conceptual relationship at all (only arithmetic operations without a formula).	
	The teacher acknowledged that students quickly forget formulas because they merely memorize them without understanding the underlying concept.	

Table 8. Summary of Didactic Obstacles

Type of Obstacle	Characteristics	Mathematical Connection Indicator
Didactical	The teacher directly gives formulas without explaining the derivation process or the reasoning behind them, so students lose their conceptual foundation.	Connections between mathematics and everyday life
	The PBL and contextual models are less effective because students are not ready with prior conceptual understanding; group discussions are followed by only some students.	
	Learning resources are limited to the student textbook, teacher's guide, and teaching modules (not very interactive).	

Type of Obstacle	Characteristics	Mathematical Connection Indicator
	The teacher rarely provides real-world application examples such as domes or satellites, making students unfamiliar with contextual problems.	
	Students consider problems requiring conceptual explanation more difficult than routine computational problems because they are used to computational procedures.	Connections between mathematical concepts
	Students are afraid to ask questions when prompted, so obstacles go undetected.	

Table 9. Summary of Ontogenic Obstacles

Type of Obstacle	Characteristics	Mathematical Connection Indicator
Ontogenic	Students have difficulty visualizing the position of a light on a semicircular dome and connecting it with Thales' theorem.	Connections between mathematics and everyday life
	Students are unable to translate information about a satellite's orbit and position into a mathematical model (inscribed angles subtending the same arc).	
	Students make procedural algebraic errors even when the underlying conceptual relationship is correct (e.g., sign errors or distribution errors).	Connections between mathematical concepts
	Students do not create supporting sketches or drawings because they feel unable to draw, making it difficult to understand the geometric configuration.	
	Students struggle to compose a coherent written explanation (writing only numbers or meaningless sentences).	

Integration of Findings and Learning Implications

The finding of a dominant epistemological obstacle in the form of a reversed understanding between central and inscribed angles is consistent with the study by Sari, Mardiyana, & Pramudya (2020), who asserted that weaknesses in mathematical connection often occur in material that is abstract and requires a high degree of visualization. The didactic obstacle stemming from the limited availability of interactive learning resources also reinforces the study by Hanum R (2024), in which students' low mathematical connection ability in circle material was closely correlated with insufficient use of technology and interactive geometry media in the classroom. Furthermore, the basic algebraic procedural errors (ontogenic obstacle) found in this study confirm the findings of

Afriani & Machromah (2025), that students' weaknesses in solving mathematical problems are often triggered by a lack of conceptual readiness in prerequisite algebra material, thereby hindering their overall relational thinking ability. Through confirmation with this body of literature, the triangulation results show that the three learning obstacles are interrelated and not independent of one another. The epistemological obstacle causes students to misunderstand relationships between concepts; the didactic obstacle originates from an instructional design that is insufficiently contextual; and the ontogenic obstacle arises from students' cognitive unreadiness, particularly in visualization and basic algebra. Therefore, efforts to address learning obstacles in circle material must be holistic, encompassing improvements to didactic design, strengthening of prerequisite material, and training in visual representation through interactive media such as animated videos and geometry simulations.

Based on these findings, future research could develop a didactic design based on mathematical connection ability that accommodates all three types of obstacles, so that learning about circles becomes more meaningful and results in enduring understanding for students.

Conclusion and Suggestion

Based on the analysis, it was found that students experienced three main types of obstacles: epistemological obstacles (misunderstanding of the relationship between central and inscribed angles), didactic obstacles (procedural instruction and a lack of real contextual examples), and ontogenic obstacles (difficulty with spatial visualization and basic algebra). These three obstacles simultaneously weaken all three of NCTM's mathematical-connection indicators, namely connections between mathematical concepts, connections between mathematics and other disciplines, and connections between mathematics and students' everyday lives. Theoretically, this study makes a scholarly contribution in the form of a conceptual map of learning obstacles that integrates Brousseau's Theory of Didactical Situations with the NCTM mathematical-connection standards, specifically for the topic of circle-angle relationships, filling a gap in the literature that has thus far focused only on general error profiles without analysis of instructional design. Practically, and in terms of curriculum policy, the results of this study have implications for the importance of reconstructing the Learning Objective Flow (ATP) within the Merdeka Curriculum for geometry material, in which the strengthening of spatial visualization and the use of no-code/interactive application platforms must be explicitly integrated to mitigate learning obstacles before mechanical formulas are introduced.

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