



Mathematics Learning Design Using Dynamic Technology Scaffolding to Improve Student Learning Outcomes

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Abstract

This study aims to develop and validate a mathematics learning design using Dynamic Technology Scaffolding (DTS) that meets the criteria of validity, practicality, and effectiveness to overcome learning obstacles for high school students in circle materials. The research uses the Educational Design Research (EDR) approach, with the following stages: Preliminary Research, Prototyping, Evaluation, and Implementation. Preliminary analysis identifies complex learning barriers, namely epistemological (abstraction difficulties) and ontogenic (weakness of prerequisites and affective motivation), which are exacerbated by didactic barriers. The DTS design is integrated into a Problem-Based Learning (PBL) model that focuses on three pillars: Physical Modeling, Exploratory Modeling, and Expressive Modeling using dynamic software (GeoGebra). The results of expert validation showed that the design was in the Very Valid category (average 3.77). Practicality was tested with an average of 1.78 (fully implemented) and very positive responses from teachers/students (79.11% and 92.85%, respectively). A significant increase in learning outcomes evidences effectiveness: the average pretest of 53.11 jumps to 92.65 on the Learning Outcome Test, with classical completeness of 89.92% (exceeding the 80% criterion). The normalized N-Gain score reached 0.86 (High category), confirming that the mathematics learning design using DTS is very effective as an adaptive intervention to bridge the Proximal Development Zone (ZPD) and improve students' mathematical skills.

Keywords: *Dynamic Technology Scaffolding; Educational Design Research; Learning Barriers; Circle; Problem-Based Learning*



INTRODUCTION

National education leads to the development of reasoning skills, forming character, and producing human resources who have faith, noble character, knowledge, capability, creativity, independence, and responsibility (Andi Ika, 2022; Kalla, 2016; Fristadi, 2015). Of course, this achievement aligns with global demands in the 21st century, which emphasize mastering core competencies, especially the 4C skills: creative and innovative, critical and problem-solving, communication, and collaboration (Mardhiyah et al., 2021; Kurniawan, 2020; Rahmadi, 2019). Mastering 21st-century competencies is very important so that students can adapt and compete in the face of global competition (Kusmaryono, 2021; Mardati, 2018).

Mathematics, as a field of science, plays a crucial role in achieving the educational goals pursued. Mathematics functions to organize reasoning, form personality, and contribute to the development of science and technology (IPTEK). The curriculum also stipulates that the purpose of mathematics learning must equip students with reasoning and problem-solving skills, both in the mathematical context and in daily life (Permendikbud No. 58 of 2014).

Although mathematics plays a central role, there is a significant gap in students' achievement in higher-order thinking skills (HOTS) in Indonesia. Data from the 2018 PISA study show that students' thinking skills remain below OECD standards (Andi Ika, 2022; Noor et al., 2022). This situation is exacerbated by teaching methods that are still often traditional or teacher-centered. This less meaningful approach often fails to develop problem-solving skills, leading students to view mathematics as less desirable, even likely to be avoided.

To address this condition, a paradigm shift is needed from traditional teaching (show-and-tell) to a social constructivist approach (responsive guidance and facilitation). One pedagogical approach that supports the construction of thinking and learning autonomy is scaffolding (Aulia et al., 2020; Fitriani et al., 2021). Scaffolding is the process of assisting students in stages by more competent parties (teachers or peers), which is then reduced (faded) as students' ability to act independently increases (Bakker, Smit, & Wegerif, 2015; Kusmaryono & Wijayanti, 2020).

Improving the learning process through model and strategy innovation is crucial to improving the quality of education. One relevant approach is scaffolding, which is the process of providing temporary assistance from more competent individuals to support students' thinking until they can be independent (McCarthy, Sithole, McCarthy, Cho, & Gyan, 2016). The integration of technologies, particularly dynamic geometry (DGS) software such as GeoGebra, is essential to facilitate the visualization and understanding of complex mathematical concepts. Through this integration, a design principle called Dynamic Technology Scaffolding (DTS)

emerged, designed to expand students' mathematical understanding (Ramadhany, Tampa, A., and Upu, H. 2025) while improving their facility with dynamic technology tools. DTS provides access to complex mathematical ideas and supports novice users' technological facilities (Madden, 2008, 2010; Madden & Gonzales, 2017).

However, the process of acquiring mathematical knowledge is often hampered by fundamental problems, known as learning obstacles, which can be classified into ontogenic, didactic, and epistemological (Brousseau, 2002; Suryadi, 2023). Preliminary analysis in this study identified significant learning barriers to circular material, especially in the concept of Common Intersections, which demand high visual-algebraic abstraction (epistemological barriers). In addition, difficulties were found in distinguishing the basic elements of the circle (conceptual ontogenic barriers) and the lack of intrinsic motivation (psychological ontogenic barriers). Passive and static teaching methods are also identified as didactic barriers that fail to bridge the gap between abstract concepts and students' understanding (Sugiarni et al., 2025).

This study adopts the DTS theoretical framework, combined with the Problem-Based Learning (PBL) model, which focuses on problem-solving and improving critical thinking (Awi, Upu, H., et al., 2025), and fosters initiatives, and is developed using the Educational Design Research approach (EDR). The scientific novelty of this research lies in the design of a learning design that explicitly uses DTS as an adaptive and dynamic intervention, formulated through a Hypothetical Learning Trajectory (HLT) based on an in-depth analysis of three specific types of learning barriers in the circular material. This design aims to produce products (Guidebooks, Teaching Modules/RPP, Textbooks, LKPD) that are valid, practical, and effective (Van den Akker, J., Gravemeijer, K, McKenney, S., & Nieveen, N., 2006) in improving the ability to construct the understanding of mathematical concepts and students' learning outcomes.

The purpose of this study is to find out: 1) The learning barriers faced by class XI MAN 2 students in Makassar City regarding circle materials need to be overcome through a mathematics learning design that uses DTS, 2) The process and results of mathematics learning design using DTS for Class XI MAN 2 Makassar City students, 3) The effectiveness of mathematics learning design using DTS is related to learning outcomes, student activities, and student responses.

METHOD

This research uses the Educational Design Research (EDR) approach, specifically the Development Studies type, which aims to formulate research-based solutions to complex problems in educational practice and advance knowledge about the characteristics of

interventions (Putrawangsa, S. 2018).

Research Stages

The EDR procedure in this study includes four main stages (Plomp, 2010):

1. Preliminary Research Stage: Includes the analysis and identification of learning obstacles (ontogenic, didactic, epistemological), the analysis of teacher and student needs, a literature review, and the development of conceptual frameworks for DTS interventions.
2. Prototyping Phase: Designing interventions (Design Manuals, Textbooks, Teaching Modules/RPPs, LKPD) by integrating DTS into the Problem-Based Learning (PBL) syntax. This stage involves a microcycle of testing, formative evaluation, and revision (redesign).
3. Assessment Phase: Summative or semi-summative evaluation to determine whether an intervention meets the criteria of validity, practicality, and effectiveness (Nieveen Criteria). This stage includes expert validation and limited trials (Trial 1 and Trial 2).
4. Systematic Reflection and Analysis: Formulate the design principles or Local Instructional Theory (LIT) of the developed intervention, followed by final Implementation and dissemination.

Trial Location and Subject

The trial locations are MAN 2 Makassar City (Trial 1 and Implementation) and MAN 1 Makassar City (Trial 2). The study's subjects were grade XI (Phase F) students and mathematics teachers, selected through purposive sampling.

Instruments and Data Analysis

Data is collected using:

1. Validity Instruments: Design assessment sheets, validation sheets of devices and instruments by experts (Validators I, II, and III). The analysis uses the average of the total and the Criteria for Degree of Validity (minimum for the Valid category). Reliability between validators is measured by a formula (minimum for reliability). $\geq 2,5R = \frac{dA}{dD+dA} \geq 0,75$
2. Practical Instruments: Observation sheet for the Implementation of learning design (Criteria for Partially Implemented) and teacher response questionnaire (Criteria for Positive). $\geq 0,5 \geq 70\%$
3. Effectiveness Instruments: Student response questionnaire (Criteria for Positive), observation sheet of student activities (Criteria for Good), and Learning Outcome Test (THB) (Criterion: classical completeness with KKM). The improvement in learning outcomes was

measured by $\geq 70\% \geq 60\% \geq 80\% \geq 80$ Normalized Gain (N-Gain) using the formula:

Minimum N-Gain effectiveness category Moderate. $N - Gain = \frac{Skor THB - skor pretes}{skor ideal - skor pretes} \geq 0,3$

RESULTS AND DISCUSSION

a) The Design Process of Mathematics Learning Using DTS

The design process is carried out on a cyclical basis in accordance with EDR, starting with the analysis of learning needs and obstacles.

1. Learning Barriers Analysis

The learning barriers identified became the foundation of DTS design: 1) Epistemological: A dominant difficulty in the Commonwealth Crossroads material, in which learners fail to perform visual-algebraic abstraction (moving the tangent to form a right triangle of the Pythagorean Theorem); 2) Ontogenic: Fundamental difficulty in distinguishing the elements of a circle (radius vs. diameter) and neutral/lack of intrinsic (psychological) motivation; 3) Didactic: Conventional teaching methods and static visual media (PowerPoint/GeoGebra basic) that do not facilitate dynamic abstraction.

2. DTS Prototype Design and Integration

To overcome these obstacles, a mathematics learning design was developed using DTS, which was integrated into the PBL Model. DTS serves as an adaptive aid in three phases of Modeling (Madden, 2018): 1) Physical Modeling: Exploration with concrete objects/measuring instruments (overcoming ontogenic/didactic barriers at the beginning); 2) Exploratory Modeling: The use of *route-type software* for the observation of patterns and relationships that have been built by experts (GeoGebra simulation); 3) Expressive Modeling: Self-construction with software *landscape-type* (GeoGebra construction) to encode conceptual understanding (overcoming epistemological barriers).

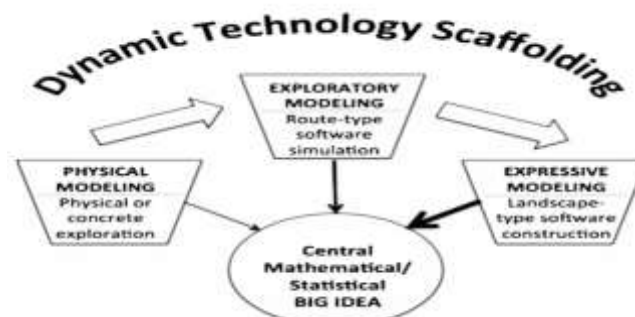


Image 1 Dynamic technology scaffolding model (Madden, 2008, 2013)

HLB is formulated to map the cognitive pathways of learners, determining the crucial points at which DTS is activated (e.g., when proving the relationship between the center angle and the circumference angle)

3. Validation Results

All tools (Guidebooks, Teaching Modules/RPP, Textbooks, LKPD) and research instruments were validated by three experts. **Design Validity:** The overall average score of the research instrument was **3.77** (Very **Valid Category**), supported by a reliability coefficient among experts of **0.86** (Very **High Category**). It confirms the design concept's conformity with the established theory and objectives.

Analysis of Trial and Implementation Results

The final Implementation was carried out after the post-Trial and Trial 2 revisions (to address the lack of tools, time allocation, and student participation in discussions).



Image 1: Recap of the Validity of Research Instruments



Image 2 Results of Practicality Analysis



Image 3: Effectiveness Analysis Results

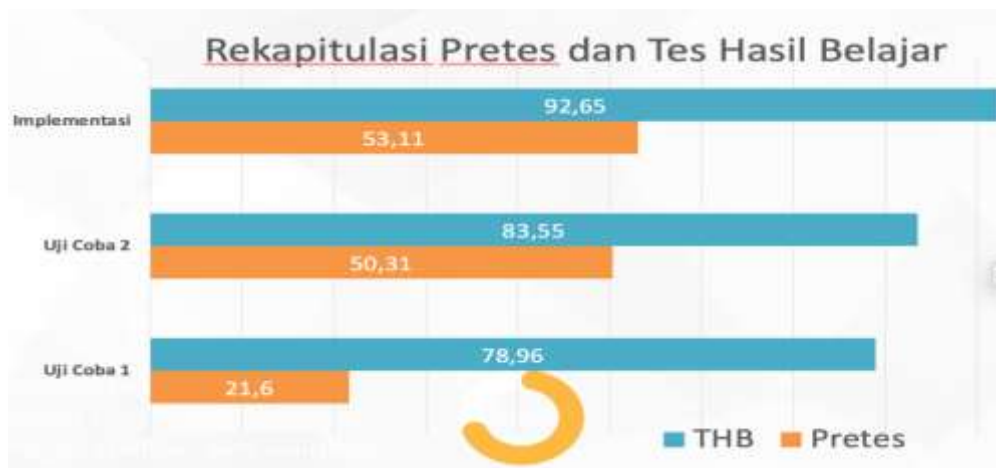


Image 4 Pretest and Posttest Recap

For more details, note the table below:

Quality Indicators	Success Criteria	Trial 1	Trial 2	Implementation	Conclusion
A. Validity	Average Expert Score (Valid) $\geq 2,5$	$3.77 > 2.5$	$3.77 > 2.5$	$3.77 > 2.5$	Stable: The conceptual and theoretical qualities of the design are maintained in the Highly Valid category throughout the process
B. Practicality					
Average Design Implementation	$\geq 0,5$ (partially)	1.80 (Fully Implemente	1.81 (Fully	1.78 (Fully Implemented)	Consistent: Operational design is easy for teachers

Quality Indicators	Success Criteria	Trial 1	Trial 2	Implementation	Conclusion
	implemen ted)	d)	Implem ented)		to implement (average observation score is stable in the highest category
Teacher's Response (Questionnaire)	$\geq 70\%$ (Positive)	84.26% (Positive)	84.65% (Positive)	79.11% (Positive)	Positive: The teacher gave a consistent and positive response, demonstrating acceptance and practicality of using the DTS device
C. Effectiveness					
Student Responses (Questionnaire)	$\geq 70\%$ (Positive)	98.8% (Very Positive)	98.24% (Very Positive)	92.85% (Very Positive)	Very Positive: Learners rated the design as very engaging and helpful with understanding, supporting that DTS successfully overcame didactic barriers
Student Activities (Observation)	$\geq 60\%$ (Good)	94.64% (Excellent)	88.69% (Good)	84.40% (Good)	High: Overall student participation activity was very high, confirming the success of the design in overcoming psychological ontogenic barriers (shyness/lack of confidence)
Classical Completeness (THB)	≥ 80	50% (Not Met)	80.56% (Met)	89.92% (Met)	Targets Met: Classical completeness criteria were achieved since Trial 2 and increased at Implementation, proving the effectiveness of DTS interventions after revision (e.g., focus on

Quality Indicators	Success Criteria	Trial 1	Trial 2	Implementation	Conclusion
					time efficiency)
Average N-Gain Score	$\geq 0,3$ (Medium)	0,73 (High)	0.64 (Medium)	0,86 (High)	Highly Effective: N-Gain again increased dramatically in the Final Implementation, confirming that the revision of <i>scaffolding</i> and PBL flows in <i>Local Instructional Theory (LIT)</i> has been optimal.

The level of effectiveness of mathematical learning design using DTS has proven to be very high, supported by outstanding final implementation data:

- The improvement in learning outcomes was significant: the average *pretest score* of 53.11 increased by 92.65 on the *Learning Outcome Test*.
- The classical completeness of 89.92% in the final Implementation expressly exceeded the minimum success criteria of 80%.
- A normalized N-Gain score of 0.86 (High Category) and an N-Gain percentage of 86.42% (Effective Category) indicate that improved learning outcomes are a substantial direct impact of the DTS intervention.

These results confirm that DTS effectively serves as a cognitive catalyst, facilitating the exploration-construction-application cycle. This success is due to DTS's ability to provide adaptive assistance right in the Proximal Development Zone (ZPD) of learners (Rahmawati, F. A., & Purwaningrum, J. P., 2022; Yohanes, R. S., 2013; Cole et al., 1978), particularly in overcoming epistemological barriers that demand visual abstraction, which traditional methods fail to bridge. This design transforms learners from passive recipients to active constructors of knowledge, aligning with qualitative findings that learning becomes more engaging and triggers independent discovery of concepts.

CONCLUSION

Mathematics learning design using Dynamic Technology Scaffolding (DTS) developed through the Educational Design Research (EDR) approach has been proven to be Valid, Practical, and Highly Effective in improving the ability to construct understanding of mathematical



concepts and learning outcomes for high school/MA students in circle material. Validity and Practicality, the design met the high-quality criteria with an average instrument validity of 3.77 (Very Valid) and a high level of Implementation (1.78/Fully Implemented), supported by very positive responses from teachers (79.11%) and students (92.85%). Effectiveness, the design is highly effective, evidenced by the average score increased from 53.11 to 92.65 on the learning outcome test. The classical completeness rate was 89.92%, exceeding the established success criteria (80%). An N-Gain score of 0.86 (High Category), which confirms that DTS successfully bridges the comprehension gap substantially and is a transformative solution to address the spectrum of learning barriers to circular material. This learning design resulted in a Local Instructional Theory that emphasizes the importance of dynamic, technology-based scaffolding within the Problem-Based Learning framework to encourage learners to engage in active knowledge construction and achieve their ZPD.

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