p-ISSN: 2086-4280
e-ISSN: 2527-8827

Didactical Design with Motion Graphics for Enhancing Conceptual Understanding of Geometric Translation

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Article received: 19-08-2025, revision: 11-09-2025, published: 30-10-2025

Abstrak

Pembelajaran transformasi di sekolah menengah menghadapi rendahnya pemahaman konseptual siswa. Desain didaktis berbasis visual dinamis belum terintegrasi sistematis dengan analisis hambatan belajar. Penelitian ini bertujuan menganalisis penguatan pemahaman konseptual translasi melalui desain didaktis berbantuan motion graphic. Penelitian ini menggunakan pendekatan kualitatif dengan tiga fase DDR, yaitu analisis didaktis dan pedagogis, analisis metapedadidaktik, serta analisis retrospektif. Subjek penelitian terdiri dari 10 siswa yang dipilih secara purposif untuk memungkinkan pengamatan mendalam terhadap proses belajar, respons didaktis, dan regulasi hambatan belajar. Data dikumpulkan melalui observasi, wawancara, dan tugas tertulis. Hasil menunjukkan seluruh siswa memahami translasi sebagai pergeseran. Sebanyak 30% siswa mengalami hambatan epistemologis pada interpretasi vektor translasi negatif. Umpan balik visual motion graphic memungkinkan koreksi mandiri selama pembelajaran. Hambatan belajar bergeser dari epistemologis menuju didaktis pada aspek komunikasi matematis formal. Desain didaktis berbantuan motion graphic efektif meregulasi hambatan belajar translasi. Penelitian lanjutan perlu memperluas pada transformasi geometri lain.
***Kata kunci**: Didactical Design Research; translasi geometri; motion graphic; hambatan belajar; pemahaman konseptual.*

Abstract

Learning transformations in secondary schools faces persistently low students' conceptual understanding. Didactical designs based on dynamic visualization have not been systematically integrated with learning obstacle analysis. This study aims to analyze the strengthening of students' conceptual understanding of translation through motion graphic–assisted didactical design. This study employed a qualitative approach with three phases of Didactical Design Research (DDR), namely didactical and pedagogical analysis, metapedadidactical analysis, and retrospective analysis. The participants consisted of ten purposively selected students to allow in-depth observation of learning processes, didactical responses, and the regulation of learning obstacles. Data were collected through observations, interviews, and written tasks. Retrospective analysis compared actual student responses with predicted didactical responses. Source triangulation ensured the credibility of research findings. Results show that all students understood translation as a rigid displacement. Thirty percent experienced epistemological obstacles in interpreting negative translation vectors. Visual feedback provided by motion graphics enabled self-correction during learning. Learning obstacles shifted from epistemological to didactical, particularly in formal mathematical communication. Motion graphic–assisted didactical design effectively regulates learning obstacles in translation. Future studies should extend to other geometric transformations.
Keywords: Didactical Design Research; Geometric Translation; Motion Graphics; Learning Obstacles; Conceptual Understanding.

I. INTRODUCTION

Global data indicate that students' conceptual understanding of geometry remains a persistent challenge across educational systems worldwide. Results from the PISA 2022 reveal that geometry-related tasks, particularly those involving spatial reasoning and transformations, are among the lowest-performing domains in mathematics across OECD countries (OECD, 2023). International statistics further show that more than 40% of secondary students struggle to interpret geometric representations involving motion, symmetry, and coordinate transformations (Mullis et al., 2023). Recent worldwide trends in digital education emphasize the integration of visual and dynamic representations to support abstract mathematical reasoning, especially after the accelerated adoption of technology-enhanced learning following the COVID-19 pandemic (UNESCO, 2022). Across mathematics education research, there is growing evidence that static instructional materials are insufficient for supporting students' understanding of dynamic geometric concepts, such as translation, rotation, reflection, and dilation (Sinclair et al., 2021; Afriansyah, 2022; Octaria et al., 2025). This global context highlights an urgent need for innovative instructional approaches that can bridge the gap between abstract geometric theory and students' cognitive visualization processes.

The limited understanding of geometric transformations constitutes a critical challenge with significant consequences at multiple levels. At the individual level, students with weak conceptual understanding of geometry tend to exhibit persistent misconceptions, reduced problem-solving ability, and lower mathematical confidence (Booth et al., 2020; Firdausi & Suparni, 2022). At the instructional level, teachers often report difficulties in explaining dynamic geometric processes using traditional representations, resulting in teacher-centered instruction and superficial learning outcomes (Leung et al., 2021; Marianti, 2023). At a broader level, insufficient spatial and geometric reasoning has been linked to reduced preparedness for STEM-related careers such as engineering, architecture, and data visualization (Uttal & Cohen, 2019; Hoffmeester, Ratumanan, & Laaamena, 2025). If these challenges remain unaddressed, the gap between curricular expectations and students' actual understanding is likely to widen, particularly for learners with fragile mathematical foundations.

Preliminary classroom observations and analysis of students' written work revealed specific learning obstacles related to geometric translation. Many students were able to describe translation as "movement" or "shifting," yet experienced difficulty coordinating this intuition with formal vector representations and Cartesian structures. Epistemological obstacles were especially evident when students were asked to interpret negative translation vectors, determine horizontal and vertical components, or relate displacement to coordinate notation. These findings indicate that students' existing knowledge structures were insufficient to support formal reasoning about translation, thus justifying the need for a didactical design explicitly grounded in learning obstacle analysis.

Motion graphics were selected as instructional media because they allow continuous and controllable visualization of geometric movement, direction, and magnitude, which are central to the concept of translation. Unlike static images, motion graphics can dynamically represent the process of transformation and make underlying mathematical structures—such as vector orientation and component displacement—explicit and observable. Within a Didactical Design Research (DDR) framework, motion graphics were not positioned merely as illustrative tools, but as integral components of the didactical milieu intended to provoke students' mathematical activity, surface learning obstacles, and support the regulation of learning through feedback.

Previous research has demonstrated that dynamic representations and multimedia environments can enhance students' engagement and spatial reasoning in geometry (Nizar et al., 2025; Aini & Suryowati, 2022; Sinclair et al., 2021; Zengin, 2022; Mayer, 2020; Hegarty, 2019). Studies grounded in design research and DDR have further shown the potential of systematically designed learning situations to identify and address learning obstacles through iterative instructional refinement (Prediger et al., 2020; Winsløw et al., 2018). However, existing literature often treats digital media integration and didactical analysis as separate strands. Moreover, limited attention has been given to motion graphics as a distinct medium capable of representing continuous geometric change within a DDR framework, particularly in the context of geometric transformations.

In response to these gaps, this study aims to develop, implement, and analyze a motion graphic–assisted didactical design for geometric translation grounded in learning obstacle analysis. Specifically, this research seeks to investigate how didactical situations supported by motion graphics can regulate students' learning obstacles and strengthen their conceptual understanding of translation. Theoretically, this study extends the application of DDR to technology-enhanced geometry learning by examining how dynamic representations interact with students' conceptual development. Practically, the findings are expected to inform teachers' instructional design by aligning learning trajectories with students' epistemological needs and by supporting more meaningful and sustainable geometry learning.

II. Method

This study employed a qualitative approach using the Didactical Design Research (DDR) framework to develop and refine an instructional design for geometry transformation based on students' actual learning responses. DDR was selected because it allows systematic examination of didactical interactions among students, teachers, and mathematical content, while supporting iterative refinement of instructional designs grounded in empirical classroom evidence. The study was theoretically situated within a didactical constructivist paradigm, which views learning as emerging from interactions between learners and the instructional milieu. The research focused on the metapedadidactical and retrospective analysis phases, with initial didactical assumptions (Rahadi et al., 2024) informed by findings from prior studies on students' learning obstacles. The design followed a longitudinal single-cycle structure comprising implementation, analysis, and revision, aiming to improve instructional design quality rather than to test causal effectiveness.

Ten students were selected using purposive sampling to ensure rich and relevant qualitative data. Inclusion criteria required students to have received prior instruction in geometry transformation and to participate in all instructional sessions, while students who were absent or declined interviews were excluded. Sample size determination was guided by qualitative sufficiency rather than statistical power, and no randomization or allocation concealment was applied due to the non-experimental nature of the study.

This study operationalized key qualitative constructs aligned with the DDR framework. The primary conceptual independent construct was the didactical design for geometry transformation supported by motion graphic media, defined as a structured sequence of instructional activities incorporating predicted student responses and pedagogical anticipations. The primary dependent construct was students' didactical responses, reflected in their conceptual understanding, mathematical representations, and problem-solving strategies during instruction. Contextual factors such as prior knowledge and classroom interactions were treated as influencing conditions and addressed through repeated observations and data triangulation.

The intervention consisted of implementing the designed geometry transformation instruction supported by motion graphic media within regular face-to-face classroom sessions. The researcher acted as the instructional designer and observer, while the classroom teacher facilitated the implementation. Implementation consistency was maintained by adhering to the prepared instructional design and systematically documenting any instructional adaptations. No control group was employed; instead, analytical comparisons were conducted between the predicted responses embedded in the hypothetical didactical design and the actual student responses observed during implementation, which informed the development of a revised didactical design.

The primary instrument in this study was the didactical design itself, which functioned as both an instructional intervention and an analytical tool. Supporting instruments included unstructured interview guides, classroom observations, and documentation of students' written work. Instrument validity was ensured through theoretical alignment with DDR principles and relevant literature on geometry transformation learning. Data credibility was strengthened through methodological and source triangulation, and data collection procedures were applied consistently across instructional sessions.

The research procedure began with participant selection based on prior studies identifying learning obstacles in geometry transformation. A hypothetical didactical design and supporting instruments were then prepared and implemented in classroom instruction. During implementation, systematic observations of student responses and classroom interactions were conducted and documented. Following the instructional sessions, unstructured interviews were carried out to explore students' cognitive processes and learning experiences. Data analysis was conducted concurrently using the Miles and Huberman interactive model, which involves data reduction, data display, and conclusion drawing. Retrospective analysis linked predicted student responses with those observed in practice, forming the basis for revising the didactical design.

Qualitative data analysis commenced during data collection and continued after fieldwork completion using the Miles and Huberman interactive framework. Relevant data were reduced, organized into analytical narratives, and interpreted through iterative verification. Analytical rigor was enhanced through triangulation of data sources and methods. Qualitative data analysis software was not used due to the manageable volume of data and the manual analytical approach adopted.

Ethical principles of educational research were observed throughout the study. Student participation was voluntary, and permission was obtained from the school and participating students prior to data collection. Participant confidentiality was maintained through anonymization of identifying information in all research records and reports. All research activities were integrated into regular classroom instruction and posed no physical or psychological risk to participants. Students were informed of their right to withdraw from the study at any time without academic consequences.

III. Result and Discussion

A. Result

Within the framework of Didactical Design Research (DDR), the implementation of the initial didactical design for translation aimed to address previously identified epistemological learning obstacles related to students' understanding of geometric transformation. The learning sequence consisted of three didactical situations, which were examined through metapedadidactical analysis focusing on the alignment between predicted student responses and actual students' actual learning trajectories. A comparison between the predicted student responses (PSR) and the actual student responses (ASR) is summarized in Table 1.

Table 1.
A comparison between PSR and ASR

Didactical Situation	Predicted Student Response	Actual Student Response
Situation 1: Introducing translation as geometric transformation	Students identify translation as displacement	All students described translation as shifting
Situation 2: Determining translation vectors from given images	Students determine vector correctly	30% confused x/y and negative direction
Situation 3: Constructing the image of an object given a translation vector	Students apply coordinate rules	20% relied on visual estimation

Table 1 presents the alignment and divergence between PSR dan ASR. The table illustrates that while students' initial conceptualization of translation aligned closely with predicted responses, epistemological obstacles emerged when tasks required coordination between spatial and algebraic representations, particularly in interpreting negative translation vectors. The integration of motion graphics enabled students to confront and regulate these obstacles through visual feedback, resulting in progressive shifts from epistemological to didactical obstacles.

In the first didactical situation, students were introduced to the concept of translation as a rigid geometric transformation through a motion graphic contextualized by a chess game. As shown in Figure 1, chess pieces functioned as objects that undergo displacement with a specific direction and distance on a chessboard. The chessboard was modeled as a Cartesian plane, enabling students to associate the movement of pieces with the measurement of distance and direction in a mathematical context. This representation served to bridge students' visual intuition with the formal concept of geometric translation.

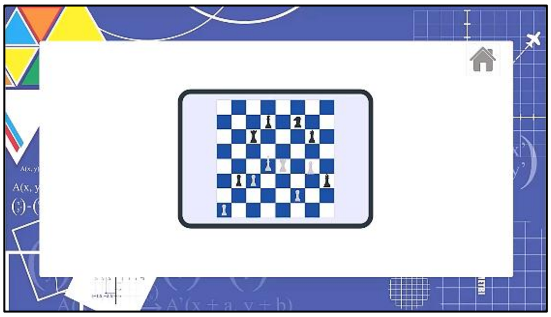

Figure 1. Motion graphic introducing translation.

The hypothetical didactical design predicted that students would recognize translation as a displacement characterized by direction and magnitude without changing the shape or size of the object. The classroom implementation confirmed this prediction: all students (10 out of 10) correctly identified translation as a form of shifting or movement. Analysis of classroom discourse showed that students were able to articulate the concept in their own words and to distinguish translation from other transformations such as rotation and reflection. After observing the motion graphic video, students were guided to express the meanings and ideas they captured from the visualization. The initial discussion indicated that students had developed an intuitive understanding of translation as a geometric transformation. These findings suggest that the first didactical situation effectively supported conceptual construction at the visualization and analysis levels of geometric thinking.

In the second didactical situation, students were presented with tasks requiring them to determine the translation values or translation vectors that map a point onto its image. As shown in Figure 2, students were asked to identify the correct translation that moves point $A$to point A'on the Cartesian plane. The motion graphic video provided several selectable translation options. When students chose the correct answer, the animation dynamically displayed the movement of point Atoward A'according to the selected translation. This visual feedback enabled students not only to identify an answer, but also to understand why it was correct through direct visualization of the displacement process.

The hypothetical learning trajectory predicted that students would correctly identify horizontal and vertical components and interpret positive and negative directions. However, metapedadidactical analysis revealed that some students still experienced difficulties. Three students (30%) incorrectly assigned the values of $a$and b, reversing the roles of the x- and y-components. Some students assumed that $a$referred to the vertical direction and $b$to the horizontal, indicating an incomplete integration of Cartesian coordinate concepts. This error reflects an epistemological obstacle in coordinating spatial displacement with algebraic representation of translation vectors.

The didactical milieu constructed through the motion graphic played a crucial regulatory role in this situation. When an incorrect translation was selected, the animation showed that point Afailed to reach A', prompting students to reconsider their reasoning. Through repeated interaction with the media and guided discussion, students who initially demonstrated misconceptions were able to revise their answers. This finding indicates that motion graphics functioned not merely as illustrative media, but as a didactical environment facilitating self-correction and conceptual regulation.

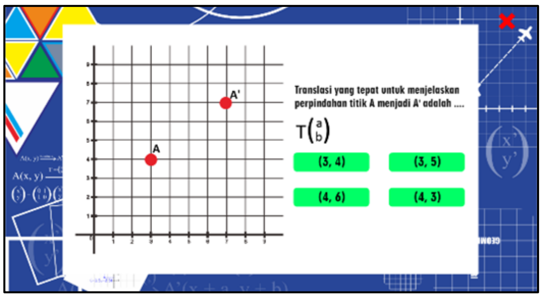

Figure 2. Motion graphic task for determining translation values from point A to point A'.

In the third didactical situation, students were asked to construct the image of an object after a given translation. As shown in Figure 3, students were required to determine the location of point A'after point A was translated by $a = 4$ and $b = -3$. At this stage, students first performed the necessary calculations using coordinate procedures and then moved the red point on the screen to verify their solutions through visual confirmation.

Figure 3. Motion graphic task requiring students to construct the image of a point after translation.

The results indicated that students demonstrated a stronger understanding of object displacement. Most students were able to solve the problem correctly and applied formal coordinate procedures. Eight students (80%) used systematic calculations, while two students (20%) obtained correct answers primarily through visual estimation without explicitly articulating formal procedures, citing forgetfulness in writing solution steps. Although these responses show the development of operational understanding, they also indicate a didactical obstacle related to procedural articulation and formalization of mathematical reasoning.

In addition to cognitive outcomes, classroom observations revealed positive affective changes. In this didactical situation, students appeared more enthusiastic, actively engaged in discussion, and demonstrated increased motivation during learning activities. Direct interaction with the motion graphic environment provided exploratory opportunities that encouraged participation and strengthened students' confidence in solving translation tasks.

Evidence from the retrospective analysis further strengthens these findings. In the written assessment, all students (100%) correctly solved the reverse translation problem requiring them to determine the original point from a given image and translation vector. Seven students (70%) presented complete and formally structured solutions, while three students (30%) provided correct but minimally articulated answers. Interview data confirmed that students perceived translation as the most accessible topic among the geometric transformations studied, indicating a reduction of learning obstacles initially identified in the preliminary analysis phase of DDR.

Overall, the results demonstrate that the initial didactical design for translation effectively reduced major epistemological learning obstacles related to spatial displacement and vector interpretation. Minor persistent difficulties were mainly associated with procedural formalization and symbolic representation rather than conceptual misunderstanding. In line with DDR principles, these findings informed targeted revisions of the didactical design, particularly the inclusion of explicit scaffolding for the formal use of translation matrices and structured written procedures, to further strengthen students' mathematical communication and conceptual consolidation.

B. Discussion

The findings of this study indicate that the motion graphic–assisted didactical design effectively supported students' conceptual understanding of geometric translation and facilitated the regulation of learning obstacles. Across the three didactical situations, students demonstrated progressive conceptual development, marked by a shift from intuitive recognition of translation as movement toward more structured coordination between spatial displacement and formal mathematical representation. This progression reflects the central principle of Didactical Design Research (DDR), which emphasizes the dynamic interaction between epistemological structures, didactical situations, and learning trajectories (Suryadi, 2019; Winsløw, Artigue, & Trouche, 2014).

In the first didactical situation, the chess-based motion graphic successfully functioned as an entry milieu that enabled students to construct an initial meaning of translation as a rigid displacement characterized by direction and distance. This result aligns with Suryadi's conception of DDR, which positions didactical situations as designed environments intended to provoke students' mathematical activity and reveal learning obstacles rather than merely transmit content. Similarly, Gravemeijer and Cobb (2006) argue that design research should begin with experientially meaningful contexts that allow students to develop situated mathematical meanings before formalization. The effectiveness of the initial motion graphic context in this study corroborates previous findings that dynamic visual representations support early stages of conceptualization in geometry learning (Sinclair et al., 2021; Zengin, 2022).

The findings of this study are consistent with those of Noto et al. (2025), who reported that motion graphic–assisted DDR designs supported students' conceptual understanding of dilation. Similarly, this study demonstrates that dynamic motion graphics can function as a didactical milieu that facilitates the regulation of learning obstacles in geometric translation.

However, the emergence of epistemological obstacles in the second didactical situation reveals the limitations of intuitive visualization. The difficulties experienced by 30% of students in interpreting negative translation vectors and coordinating x- and y- components indicate that formal understanding of translation requires a deeper integration of algebraic and spatial knowledge structures. From a DDR perspective, these obstacles are not viewed as individual errors but as indicators of epistemological discontinuities between students' prior knowledge and institutional mathematics (Suryadi, 2019). Comparable findings have been reported by Leung et al. (2021) and Prediger et al. (2020), who found that students often struggle to coordinate representations in geometry and that such difficulties persist even in technology-rich environments.

Within Brousseau's Theory of Didactical Situations, the motion graphic environment in the second situation can be interpreted as a regulatory milieu. Rather than providing direct corrective instruction, the animation externalized the consequences of students' choices: incorrect vectors resulted in visible misalignment between the object and its image. This design minimized the Topaze effect, in which the teacher implicitly leads students toward the correct answer. Instead, students were required to interpret feedback, test conjectures, and revise strategies. Such conditions reflect what Brousseau conceptualizes as adidactical situations, in which responsibility for validation shifts from the teacher to the learner. Similar regulatory roles of digital environments have been documented by Artigue (2012) and Trouche et al. (2019), who emphasize that well-designed technological milieus can support students' epistemic autonomy.

The third didactical situation revealed a transition from predominantly epistemological obstacles toward didactical obstacles. While most students successfully applied coordinate procedures, some relied on visual estimation despite producing correct answers. This phenomenon indicates that although conceptual understanding of translation as displacement had largely been achieved, the institutionalization and formal articulation of mathematical knowledge remained incomplete. In DDR terms, this stage highlights the critical role of retrospective analysis in identifying mismatches between the hypothetical learning trajectory and the actual learning trajectory (Suryadi, 2019). Similar patterns have been reported in design-based studies by Gravemeijer and van Eerde (2009), who observed that dynamic representations often facilitate conceptual access but must be accompanied by explicit institutionalization to consolidate formal mathematical practices.

The affective engagement observed in the third didactical situation further supports existing research showing that dynamic media can enhance students' motivation and participation in geometry learning (Hsu & Hsu, 2025; Sinclair et al., 2021; Mayer, 2020). However, DDR emphasizes that affective engagement must be didactically oriented toward epistemic responsibility. From this perspective, the increased enthusiasm documented in this study is pedagogically meaningful only insofar as it contributes to students' willingness to engage in validation, justification, and formalization processes.

Overall, the findings of this study are consistent with the theoretical foundations of DDR, which conceptualize learning as the evolution of learning trajectories through carefully designed didactical situations (Suryadi, 2019; Winsløw et al., 2014). Compared with previous studies on dynamic geometry and multimedia learning, this research contributes by demonstrating how motion graphics can be embedded not merely as instructional media, but as constitutive elements of the didactical milieu. The results reinforce claims by Gravemeijer and Cobb (2006) that educational design research must integrate theoretical analysis with iterative instructional refinement. At the same time, the persistence of didactical obstacles underscores the necessity of multiple DDR cycles to further align dynamic visualization with symbolic institutionalization. Consequently, this study extends existing literature by showing how motion graphic–assisted environments can both reveal and regulate learning obstacles in geometric translation within a coherent didactical framework.

IV. Conclusion

This study demonstrates that a motion graphic–assisted didactical design developed within the framework of Didactical Design Research (DDR) effectively supports students' conceptual understanding of geometric translation and facilitates the regulation of learning obstacles. The alignment between the hypothetical learning trajectory and the actual learning trajectory indicates that dynamic visual environments, when embedded in carefully structured didactical situations, can guide students from intuitive recognition of translation as movement toward more coordinated conceptual and procedural understanding.

The results show that the initial didactical situation successfully established students' intuitive grasp of translation as a rigid displacement. Subsequent situations revealed epistemological obstacles, particularly in interpreting negative translation vectors and coordinating algebraic and spatial representations. Through interaction with the motion graphic milieu, these obstacles were progressively regulated, leading to improved conceptual coherence. Remaining difficulties were predominantly didactical in nature, related to formalization and mathematical articulation rather than to conceptual access.

Beyond cognitive outcomes, the study also highlights the role of motion graphics in fostering positive learning engagement. Students demonstrated increased participation and motivation, particularly in later didactical situations, suggesting that dynamic representations may contribute to affective conditions that support epistemic responsibility and sustained mathematical activity.

From a theoretical perspective, this research contributes to DDR literature by illustrating how motion graphics can function not merely as instructional media, but as constitutive elements of the didactical milieu that reveal and regulate learning obstacles. Practically, the findings suggest that teachers and instructional designers should integrate dynamic visualization with explicit institutionalization strategies to ensure that conceptual understanding is consolidated through formal mathematical communication.

Several limitations should be acknowledged. The study involved a small number of participants and focused on a single topic of geometric transformation, which limits the generalizability of the findings. In addition, the implementation was conducted within a single design cycle. Future research is therefore recommended to involve larger samples, multiple iterative DDR cycles, and different transformation topics to examine the robustness and transferability of the didactical design.

Overall, the study affirms the potential of DDR-based, motion graphic–assisted learning environments to support meaningful geometry learning and to provide a methodological lens for refining didactical designs grounded in students' actual learning trajectories.

Acknowledgement

The authors would like to express their sincere gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia (Kemendikbudristek) for providing financial support for this research.

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