

Designing translation learning trajectory using tayub dance context through RME assisted by GeoGebra

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Abstract

The concept of translation plays a crucial role in geometry education, fostering students' spatial understanding, visual thinking, and transformational reasoning. Despite its importance, many students still struggle to abstract the concept of translation, demonstrating a low level of conceptual understanding and a limited ability to apply it in a coordinate context. To address this gap, this study introduces a culturally grounded, context-based learning design that integrates Tayub dancers' movement into translation learning. This study aims to develop a learning trajectory that supports students' conceptual understanding of translation through meaningful and realistic mathematical experiences. This study involved 32 ninth-grade students from a public junior high school in Semarang. It employed a validation study design research methodology that included three phases: preliminary design, teaching experiment, and retrospective analysis. The learning activities were implemented using the Realistic Mathematics Education (RME) approach assisted by GeoGebra. The resulting Learning Trajectory (LT) consisted of three interrelated activities: analyzing a video of Tayub dance movements to identify translation features; deriving formal rules for translation vectors through the "box arc" strategy and GeoGebra exploration; and solving a contextual problem involving the design of dancer formations. The findings indicate that integrating culturally relevant contexts and visual media into RME effectively enhances students' understanding of translation. This research contributes to the field by offering a novel approach that bridges ethnomathematics and the teaching of formal geometric transformations, and by serving as a reference for future studies seeking to incorporate local wisdom and technology into mathematics education.

Keywords: Hypothetical Learning Trajectory; Realistic Mathematics Education; Ethnomathematics; Translation; Tayub Dance

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INTRODUCTION

Transformation geometry is essential for understanding advanced mathematical concepts, including functions, vectors, and symmetry (Handayani & Sulisworo, 2021), as well as for developing spatial reasoning and problem-solving skills (Kemendikbudristek, 2022; Lestariningsih et al., 2017). Among its components, translation serves as a fundamental building block for geometric literacy and acts as a prerequisite for more complex concepts, such as isometry and composition (Evidiasari et al., 2019; Trisna et

al., 2022). Despite its importance, translation remains a challenging topic for students. Difficulties primarily arise from an inability to visualize direction and magnitude, which significantly increases cognitive load (Yurniwati & Hanum, 2017), and a struggle to apply the formal algebraic rule $(x, y) \rightarrow (x + a, y + b)$ to authentic problems (Lestariningsih et al., 2017). Our preliminary study at SMP Negeri 38 Semarang corroborated this gap, revealing that students struggled to link translation to real-world phenomena and relied heavily on rote procedural approaches.

Teacher-centered instruction and minimal use of interactive media often exacerbate these epistemological obstacles (Aulia et al., 2025; Suryaman & Ni'mah, 2022). Such approaches reduce instructional depth and student motivation, reinforcing the perception that geometry is purely abstract (Dewi et al., 2019). Realistic Mathematics Education offers a robust pedagogical solution by utilizing real-world contexts as a starting point (Freudenthal, 1991). Through didactical phenomenology, emergent models, and horizontal-vertical mathematization (Gravemeijer & Doorman, 1999; Treffers, 1987), RME has been proven effective in enhancing conceptual understanding, critical thinking, and student engagement (Nursyahidah et al., 2021).

While various cultural contexts have been utilized to teach transformation geometry, such as *tedhak siten* (Hardiyanto et al., 2024), Sam Poo Kong (Aisyah et al., 2021), and *batik* (Yanto et al., 2024), these contexts are primarily static. A dynamic, kinesthetic context explicitly designed to overcome the persistent misconception between "facing direction" and "shifting direction" remains unexplored. This study addresses this gap by proposing the Tayub Dance. The dancer's shifting movement, while maintaining a fixed facing direction, provides a concrete, kinesthetic representation of a translation vector. To facilitate vertical mathematization, this cultural context is integrated with GeoGebra. The software has been shown to assist students in visually generalizing translation rules (Jelatu et al., 2018), aligning with the proven efficacy of virtual reality-based ethnomathematics media (Rahmawati et al., 2022) and contextual mobile games (Ariyanto et al., 2020). Therefore, this study aims to design a Learning Trajectory for ninth-grade translation based on the Tayub Dance context and RME principles through a validation study approach.

METHODS

This study employed a design research methodology, specifically a validation study approach. This methodology is characterized by iterative cycles of design, development, evaluation, and revision, aimed at producing educational interventions that address complex practical problems (Plomp & Nieveen, 2013). The design research process is distinguished by its interventionist nature, process orientation, reflective inquiry, cyclical structure, and strong theoretical foundation (Gravemeijer & van Eerde, 2009). Specifically, this validation study adopted the three interconnected phases outlined by Gravemeijer and Cobb (2006): (1) preliminary design, (2) teaching experiment, and (3) retrospective analysis.

Preliminary Design

This initial phase involved a comprehensive literature review covering geometric prerequisites, RME principles, and the translation content for Phase D (Indonesian curriculum) to develop the initial Hypothetical Learning Trajectory (HLT). The HLT served as a theoretical framework encompassing learning objectives, instructional sequences, and anticipated student responses. Activities included analyzing students' learning obstacles through literature and interviews with ninth-grade mathematics teachers at SMP Negeri 38 Semarang, as well as exploring the shifts in the Tayub Dance as a tangible representation of translation vectors. The resulting HLT outlined a sequence of RME-based activities, progressing from the situational context of the Tayub Dance (*model-of*) toward the formal mathematical rule $(x, y) \rightarrow (x + a, y + b)$ (*model-for*). Subsequently, student worksheets and assessment instruments were developed. GeoGebra was strategically integrated to facilitate vertical mathematization, enabling continuous refinement of the design in response to emergent empirical insights.

Teaching Experiment

The teaching experiment was conducted in two stages: a pilot experiment and the actual teaching experiment. The pilot stage involved six heterogeneous ninth-grade students (categorized into two low, two medium, and two high achievers) at SMP Negeri 38 Semarang. In this stage, the researcher acted as the instructor to test and refine the initial HLT. Following revisions, the refined instructional design was implemented in the main teaching experiment, conducted from July to August 2025. This stage involved one intact ninth-grade class of 32 students, divided into 8 collaborative groups, across three

80-minute sessions. In-depth tracking was focused on a representative subset of six students. The researcher served as the primary teacher, while the regular subject teachers acted as observers. Data were collected via observation protocols, video recordings, field notes, student worksheets, and clinical interviews to rigorously track the students' learning trajectories, strategies, and difficulties.

Retrospective Analysis

The final phase comprised a retrospective analysis of the empirical data collected during the teaching experiment. This involved a systematic, comparative evaluation between the implemented Actual Learning Trajectory (ALT) and the predictions established in the HLT. Students' problem-solving strategies and conceptual difficulties were analyzed to determine the extent to which the learning objectives were achieved by comparing the hypothesized and actual learning processes, profound insights into the development of students' mathematical thinking were formulated. These insights enabled the refinement of both the underlying local instructional theory and the HLT. The research questions were consequently addressed through an iterative, theory-driven interpretative process, yielding the final, empirically grounded Learning Trajectory.

RESULTS AND DISCUSSION

The findings of this study present a detailed learning trajectory for teaching translation concepts through the cultural context of the Tayub Dance, complemented by animated video media and GeoGebra. The results are structured into the three main phases of design research, as described below.

Preliminary Design Phase

In this initial stage, the researchers conceptualized an instructional design for mathematical translation based on the context of the Tayub Dance. This traditional Javanese dance was selected because its movement patterns possess the potential to represent vector shifts concretely and dynamically. The characteristic Tayub movement, shifting positions while maintaining a fixed facing direction, provides a meaningful, experientially real context for introducing and exploring key translation concepts.

Subsequently, a Hypothetical Learning Trajectory (HLT) was developed to guide the instructional design. The formulation of this HLT was grounded in an extensive literature review, empirical observations from a preliminary study at SMP Negeri 38

Semarang, and alignment with Phase D of the Indonesian Independent Curriculum. This process involved defining appropriate learning objectives, structuring the mathematical content, and outlining anticipated student learning outcomes. The HLT comprises three core learning activities, as summarized in Table 1.

Table 1. HLT of Translation Material in the Context of Tayub Dance

Activity Learning	Learning objectives	Student Allegations
Activity 1: Observing the Tayub Dancers' Movements	To identify, analyze, and interpret the concept of "parallel shifting" as an informal representation of translation.	1. Students can extract the characteristics of the Tayub dancers' movements: displacement of position, fixed facing direction, and constant distance. 2. Students can describe the movement as "shifting without rotating" in their own language. 3. Students can distinguish the concept of "direction of movement" from the "facing direction."
Activity 2: Representing Motion Trajectories and Formulating Vector Rules	To represent displacement on a coordinate plane and deduce the formal translation rule $(x, y) \rightarrow (x + a, y + b)$.	1. Students can illustrate the dancer's trajectory on grid paper using a "box-arc" strategy. 2. Students can calculate horizontal and vertical differences to determine vector components (a, b). 3. Students can generalize that every point shifts a units horizontally and b units vertically. 4. Students can formulate the algebraic translation rule $(x, y) \rightarrow (x + a, y + b)$. 5. Students can define translation as "a shift of a specific distance in a uniform direction."

Activity 3: Solving Contextual Problems and Designing Formations	To solve contextual translation problems and apply the concepts to design dance formations.	1. Students can apply the rule $(x, y) \rightarrow (x + a, y + b)$ to determine the coordinates of an image. 2. Students can solve problems involving the composition of translations. 3. Students can explain how translation functions to create repetitive patterns. 4. Students can design a formation of three dancers by determining three distinct translation vectors, demonstrating mathematical originality.
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Teaching Experiment

The teaching experiment was conducted in two stages: a pilot experiment and the main teaching experiment, aimed at testing and validating the proposed learning trajectory. The pilot experiment involved six ninth-grade students with heterogeneous mathematical abilities (low, medium, and high achievers). The researcher acted as the instructor to identify initial obstacles within the HLT, which was subsequently revised based on student feedback. The main teaching experiment was conducted from July to August 2025, involving 32 students divided into eight collaborative groups over three 80-minute sessions.

Data were collected through student worksheets, video recordings, field notes, and semi-structured clinical interviews. The retrospective analysis focused on students' problem-solving strategies and conceptual difficulties to refine the Actual Learning Trajectory.

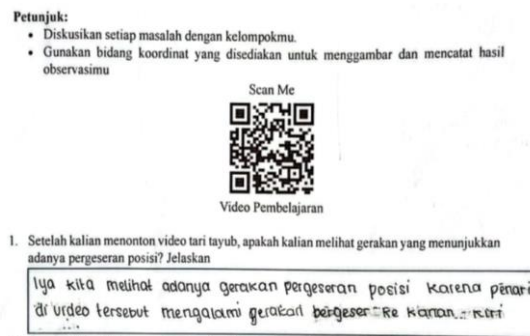
Activity 1: Identifying the Concept of Parallel Shifting via Video Observation

The initial activity commenced with students divided into groups of four. The teacher introduced the lesson by presenting an animated video of Tayub dancers in motion (Figure 1). A preliminary discussion followed, emphasizing the importance of understanding the dancers' movements as physical representations of translation vectors, specifically highlighting the critical distinction between the dancers' "facing direction" and their "direction of movement."



Figure 1. Example of a video observed by students

The teacher then distributed the first worksheet, focusing on identifying translation characteristics. As evidenced in Figure 2, students successfully abstracted the core principles of translation from the visual media. They demonstrated the ability to articulate concepts such as "shifting" and "parallelism" using informal language.



English Version:

Answer: Yes, we see a movement shift position because the dancer in the video experiences movement shift to the left and right

Figure 2. Example response to student task identification characteristics translation

As seen in Figure 2, the students are able to identify characteristics of translation in the videos they observe. In addition, the students demonstrate the ability to describe the concepts of “shifting” and “parallel” using language alone. Animated video plays an important role in catching students' attention, which contributes to their engagement in the learning process. An interview excerpt from one of the students further supports this observation:

Researcher : “How do you know if the dancer’s movement is translational?”

Student : “I saw from the video that the dancer moved, but his body remained facing forward, ma’am. He didn’t turn.”

Researcher : “How do you differentiate the direction of facing from the direction of displacement?”

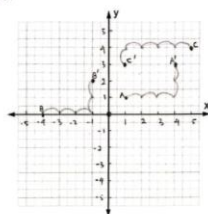
Student : “The direction of facing is still forward, but the direction of displacement is to the right. So it’s different.”

This dialogue confirms that the animated videos effectively functioned as an informal starting point, establishing a robust foundation for subsequent activities and preventing the common misconception of conflating facing direction with movement trajectory.

Activity 2. Representing Trajectories and Discovering Translation Formulas

In the second activity, students utilized grid paper to map motion trajectories and deduce the algebraic rule $(x, y) \rightarrow (x + a, y + b)$. Figure 3 illustrates student responses employing a "box-arc" (grid-based counting) strategy to decompose diagonal movements into horizontal and vertical components.

- a. Gambarkan titik-titik pada bidang kartesius
- Titik A(1,1) Geser titik A sebanyak 3 satuan ke kanan dan 2 satuan ke atas. Tentukan bayangannya A'.
 - Titik B(-4,0) Geser titik B sebanyak 3 satuan ke kanan dan 2 satuan ke atas. Tentukan bayangannya B'.
 - Titik C(5,4) Geser titik C sebanyak 4 satuan ke kiri dan 1 satuan ke bawah. Tentukan bayangannya C'.



- b. Lengkapi tabel di bawah ini (sesuai soal 4a)

Titik awal (x,y)	Titik Bayangan (x',y')
A (1,1)	A' (4,3)
B (-4,0)	B' (-1,2)
C (5,4)	C' (1,3)
O (x,y)	O' (x+a, y+b)

English Version:

- a. Complete the table in the lower This (in accordance with question 4a)

Point initial (x,y)	Point Shadow (x',y')
A (1,1)	A' (4,3)
B (-4,0)	B' (-1,2)
C (5,4)	C' (1,3)
O (x,y)	O' (x+a, y+b)

Figure 3. Student responses regarding the concept of translation vectors and the "box arc" strategy

As shown in Figure 3, students were able to identify the horizontal and vertical components of displacement. They were also able to write translation vectors and generalize formal rules. The following discussion further supports this observation.

Researcher : "How do you determine the values of a and b ?"

Student : "First, let's look at the picture. From P to P' , move 3 to the right, that's a . Then move up 2, that's b . So the vector is $(3,2)$."

Researcher : "If the point is $P(x,y)$, what will the image look like?"

Student : " x is increased by 3, y is increased by 2. So $(x+3, y+2)$."

This interaction demonstrates successful vertical mathematization, where students transitioned from visual geometric representations to algebraic abstraction. To verify these discovered rules, students utilized GeoGebra (Figure 4). The software allowed them to test conjectures interactively. One student noted, "I tested it in GeoGebra. If you shift

any point 3 units right and 2 units up, the coordinate formula always remains $x+3$ and $y+2$." This confirms that technology integration successfully supported students in formalizing their mathematical discoveries.

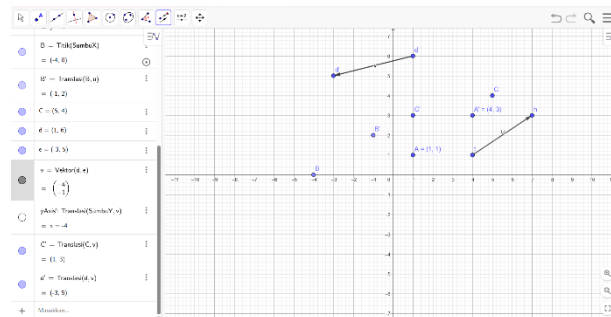


Figure 4. Student responses during exploration with GeoGebra

Figure 4 illustrates that students can discover the general rule of translation. After identifying the vector components, students correctly generalize to any point (x,y) . Furthermore, students demonstrate a clear understanding of translation. The following interview further explains this process.

Researcher : *"How are you sure the rule $(x+a, y+b)$ is always true?"*

Student : *"I tried it in GeoGebra, ma'am. If you shift any point 3 to the right and 2 to the top, the result is $x+3$ and $y+2$. It's always the same."*

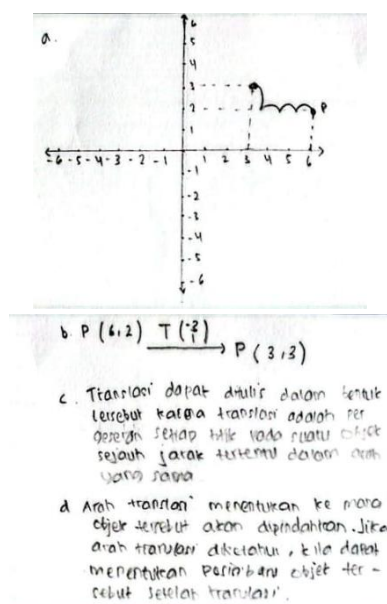
The interviews confirmed that the students successfully discovered the formal rules of translation. These calculations involved visualization, generalization, and verification using GeoGebra, demonstrating their ability to apply theoretical knowledge to formal contexts.

In short, this teacher-facilitated activity, supported by group discussions, allows students to explore the concepts of vectors, translation rules, and translation composition. By working collaboratively and engaging in discussions guided by peers and the teacher, students can apply their theoretical knowledge to practical contexts. A final group presentation provides an opportunity for students to verify and refine their answers, thus strengthening the learning process.

Activity 3. Solving Contextual Problems and Designing Formations

The final activity required students to solve complex, contextual problems based on a scenario in which Tayub dancers navigate a stage. Figure 5 demonstrates students'

proficiency in plotting coordinates, applying vector operations, and analyzing the effects of positive and negative directional shifts.



English Version:

- Illustration image*
- $P(6,2) \rightarrow T\begin{pmatrix} -3 \\ 1 \end{pmatrix} \rightarrow P'(3,3)$
- Translation can be written in this form because translation is the shift of each point on an object by a certain distance in the same direction.*
- The translation direction determines where the object will be moved. If the translation direction is known, we can determine the object's new position after the translation.*

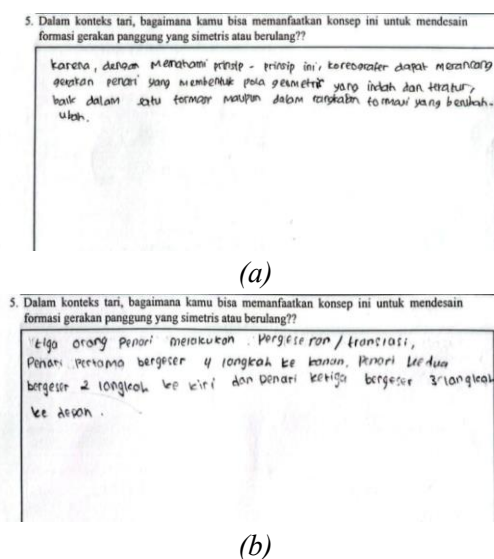
Figure 5. Students' answers regarding solving contextual problems of translating the Tayub dance

Figure 5 shows that students can solve contextual translation problems. The process begins by plotting a point on a coordinate plane, calculating the coordinates of its image using vector operations, and analyzing the effect of direction. The following interview excerpt provides insight into the students' reasoning and problem-solving process:

- Researcher : "How do you determine the coordinates of the end point after two translations?"
- Student : "The first one from P (6,2) shift 3 left so $6-3=3$, 1 front so $2+1=3$. So $P'(3,3)$. Then the second one from $P'(3,3)$ shift 3 right $3+3=6$, 1 back $3-1=2$. So back to $P''(6,2)$, Ma'am."
- Researcher : "How do you write the translation in the form $T = \begin{pmatrix} x \\ y \end{pmatrix}$?"
- Student : "The first translation $T_1 = \begin{pmatrix} -3 \\ 1 \end{pmatrix}$ This is because the left is negative, the front is positive. The second $T_2 = \begin{pmatrix} 3 \\ -1 \end{pmatrix}$ is because the right is positive, the back is negative."

Interview data confirmed that students successfully solved contextual problems involving translation rules and translation composition. The computational processes students performed, such as negative vector addition for the left/backward direction and inverse vector analysis, demonstrated their ability to translate theoretical mathematical knowledge into practical, real-world applications. This was demonstrated by conjecturing

about how these concepts could be used to analyze the dancers' repetitive motion patterns in Figure 6.



English Version:

- (a) *By understanding these principles, choreographers can design dancers' movements that are shaped by beautiful, regular geometry, both in a single formation and in a series of changing formations.*
- (b) *Three dancers perform a shift/translation, the first dancer shifts 4 steps to the right, the second dancer shifts 2 steps to the left, and the third dancer shifts 3 steps down.*

Figure 6. (a) Student answers using the translation principle, (b) Student answers using concrete analysis

This demonstrates not only procedural fluency but also a conceptual understanding of translation in a meaningful context. The effectiveness of this learning outcome is closely related to the implementation of the RME approach. RME fosters the development of mathematical concepts by encouraging students to initially engage in the informal “arc-square” strategy before moving on to the formal method $(x,y) \rightarrow (x+a, y+b)$. Furthermore, this approach encourages connections between geometry and algebraic topics, supports an interactive and collaborative learning environment, and values students’ reasoning and contributions. These pedagogical principles significantly contribute to improving students’ problem-solving abilities and their capacity to contextualize mathematical concepts in everyday situations.

The retrospective analysis of the Learning Trajectory indicates that the RME-based instructional design, contextualized within the Tayub Dance, successfully facilitated progressive mathematization among ninth-grade students. This discussion highlights three primary themes: (1) the role of the Tayub Dance context in horizontal mathematization, (2) the transition *from model-of* to *model-for* assisted by GeoGebra, and (3) the emergence of creative thinking as an impact of LT.

1. The Context of Tayub Dance as a Bridge of Horizontal Mathematization

The findings confirmed that the Tayub dancers' shifting movements served as a meaningful starting point for constructing the concept of translation. This aligns with the RME principle that learning should begin with phenomena that are experientially real to students (Gravemeijer, 1994; Sholihah & Afriansyah, 2017). Students easily recognized that "the dancers shift, but their bodies remain the same," which concretely represents the isometric property of translation. This supports previous studies that local cultural contexts can reduce geometric abstraction (Hardiyanto et al., 2024; Aisyah et al., 2021). The novelty of this Learning Trajectory lies in the use of Tayub Dance, which has not been previously used as translation material. Unlike the static context of *batik* (Yanto et al., 2024), the Tayub movement is dynamic and directly embodies the concept of vector displacement. This addresses the gap in previous research that relied on static contexts for dynamic transformations. Moreover, this context strengthens students' appreciation of local culture, consistent with the goals of ethnomathematics (Simorangkir et al., 2020).

Furthermore, a misconception regarding facing direction and displacement direction emerged during the situational stage, which was unpredicted in the initial HLT. The revision of the trajectory by adding the trigger question "Does the dancer's body rotate when shifting?" proved effective in addressing this misconception, in line with Aulia et al. (2025), who emphasized the need for explicit focus on isometric invariance in translation learning.

2. Transition from *Model-of* to *Model-for* assisted by GeoGebra

The final LT showed that the informal "box arc" strategy served as an effective *model-of bridging the context to the symbol* (a, b). This strategy was not anticipated in the initial HLT but emerged naturally from the students. The recognition of the "box arc" as a visual representation of a "step" in the final LT is in accordance with the *guided reinvention principle* of RME (Gravemeijer & Doorman, 1999), where the models developed by students are valued as a basis for formalization.

The acceleration of the introduction of the symbol (a,b) to the *model-of stage* in the final LT was proven not to hinder, but rather strengthen vertical mathematization. Students who had written $O'(x+a,y+b)$ in the referential stage were able to use GeoGebra in the *model-for stage* to test conjectures and generalize the rule $(x,y) \rightarrow (x+a,y+b)$. This

supports the findings of Jelatu et al. (2018) that GeoGebra visually helps students generalize geometric transformation rules.

The addition of a *worked example* of the procedural error $P(6,2) + T(3, -1) = (9,1)$ to the final LT addresses the LT finding that students tend to focus on addition procedures without understanding the meaning of vectors. Class discussion of this incorrect example facilitates the cognitive conflict necessary for conceptual understanding, in line with Suryaman & Ni'mah (2022).

3. The Emergence of Creative Thinking as an Impact of TL

The division of the final LT into two sub-levels of the formal stage *Formal-Principles* and *Formal-Design* was a response to the LT finding that students demonstrated two levels of achievement. The *Formal-Design level*, in which students designed a formation of 3 dancers with vectors $T(4,0)$, $T(-2,0)$, $T(0,3)$, is an indicator of *originality* in mathematical creative thinking (Silver, 1997). This open-ended design activity was not present in the initial HLT.

The emergence of diverse strategies in Activity 3, namely the analytical method $(x,y) \rightarrow (x+a,y+b)$ and the geometric method of drawing vectors, demonstrates indicators of *flexibility*. The final LT adds didactic notes for teachers to facilitate class discussions comparing the efficiency of various strategies. This is in line with Nursyahidah et al. (2025) that RME-ethnomathematics has the potential to foster creative thinking through open exploration.

The finding of commutative translation composition in the student dialogue: “Dancer 2 translated $(0,3)$ is the same as Dancer 3 translated $(4,0)$ ” shows that students achieved relational understanding, not just instrumental (Skemp, 1976). This goes beyond the initial HLT goal of targeting only single rules.

CONCLUSION

This design research successfully developed a robust Learning Trajectory (LT) for ninth-grade mathematical translation by integrating Realistic Mathematics Education (RME) with the cultural context of the Tayub dance assisted by GeoGebra. The retrospective analysis confirms that the LT effectively scaffolded students' progressive mathematization through situational, referential, general, and formal stages. The dynamic, kinesthetic nature of the Tayub dance provided a highly intuitive starting point

that clarified the isometric physical meaning of displacement, successfully rectifying early student misconceptions regarding "facing direction" versus "displacement direction." Furthermore, the emergent "box-arc" strategy served as a vital *model of* the context. At the same time, GeoGebra effectively facilitated vertical mathematization at the *model-for* stage, allowing students to generalize the formal algebraic rule $(x, y) \rightarrow (x + a, y + b)$. Ultimately, the open-ended activities involving the design of dance formations fostered significant indicators of mathematical creativity, including flexibility and originality.

Despite the positive outcomes, this study has several limitations. First, the teaching experiment was conducted with a relatively small sample size (32 students) within a single school in Semarang, which may limit the broad generalizability of the findings. Second, the heavy reliance on the Tayub dance, a specific Javanese cultural artifact, means the situational context might not be experientially real for students from different cultural or geographical backgrounds. Finally, the intervention was limited to three sessions, focusing solely on translation and not addressing other geometric transformations comprehensively. Based on these findings, future research should aim to implement and validate this Learning Trajectory across a broader range of schools and cultural backgrounds to assess its adaptability. Researchers are encouraged to explore other dynamic local cultural contexts to teach more complex topics in transformation geometry, such as rotation, reflection, and dilation. Additionally, longitudinal studies examining the long-term retention of spatial reasoning skills developed through RME and ethnomathematics, integrated with technology-based interventions, would make valuable contributions to the field of mathematics education.

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