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# Enhancing Students' Understanding of Spatial Nets through Problem-Based Learning Integrated with Two Stay Two Stray

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**Abstract**

This study aims to implement spatial net learning based on Problem-Based Learning (PBL) integrated with the Two Stay Two Stray (TSTS) strategy for ninth-grade junior high school students. The learning was conducted through an open class approach in three Plan–Do–See cycles, focusing sequentially on flat-sided nets, curved-sided nets, and their combinations. Learning implementation was observed using the Basic Teaching Skills (KDM) instrument, while student outcomes were evaluated in terms of attitude, skills, and knowledge. The results show that learning implementation consistently reached an excellent category, with scores ranging from 96.43% to 97.72%. Students' attitudes improved from 94.4% in the first cycle to 100% in the second and third cycles. Skill performance increased significantly in the second cycle (98.3%) and slightly decreased in the third cycle (96.6%) as task complexity increased. Knowledge scores also rose from 90 to 95.5 before slightly declining to 93.3 in the final cycle. These findings indicate that improvement occurred because contextual problem-solving in PBL, combined with structured cross-group idea exchange through TSTS, supported students' visual spatial reasoning and conceptual understanding of spatial nets. Overall, this study demonstrates that integrating PBL and TSTS provides a pedagogically meaningful approach for geometry learning that emphasizes exploration, visualization, and collaborative reasoning.

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## INTRODUCTION

Mathematics education at the junior high school level plays a crucial role in developing students' critical and analytical thinking skills. However, in geometry learning, particularly on nets of solid figures, students often face persistent difficulties. These difficulties are not merely related to a lack of understanding, but stem from students' inability to construct conceptual relationships between two-dimensional net representations and three-dimensional solid forms (Octaviani, Indrawatiningsih, & Afifah, 2021). As a result, students tend to rely on mechanical memorization of net patterns without meaningful spatial reasoning, leading to low

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engagement and limited ability to apply these concepts in real-life contexts (Arhalifi, Witarsa, & Nurmalina, 2023). Initial classroom observations also show that students frequently choose incorrect nets when presented with multiple options, indicating that conventional instruction has not sufficiently supported the development of 2D and 3D conceptual understanding, and therefore requires learning approaches that are more concrete, collaborative, and conceptually meaningful.

Various innovative learning models have been developed to overcome these challenges. One approach that is considered relevant and effective is Problem-Based Learning or PBL. This model focuses on providing authentic problems as the core of the learning process, enabling students to build understanding through active investigation, discussion, and direct experience. According to Afni (2020), PBL allows students to construct knowledge through exploration and discussion, so that conceptual understanding and critical thinking skills can develop simultaneously. In the context of spatial nets, students' difficulties in visualizing and linking two-dimensional representations with three-dimensional forms often lead not only to conceptual misunderstandings but also to low motivation, reduced confidence, and limited participation in group interactions. Therefore, learning solutions need to address the learning process itself by engaging students actively in exploration and collaboration. In this context, PBL is highly relevant because learning spatial nets requires exploration of shapes, manipulation of concrete objects, and visual analysis, all of which can be facilitated through contextual problems close to students' daily experiences. These problems encourage students to reconstruct the relationship between flat and spatial shapes through analytical and experiential processes.

Previous studies have shown that PBL is effective in supporting geometry learning, particularly for topics that require spatial reasoning and higher-order thinking. Oktaviani, Syahrial, & Putri (2023) reported increased student engagement through PBL, while Aprina, Fatmawati, & Suhardi (2024) highlighted its role in fostering critical thinking and collaborative inquiry. Importantly, PBL is especially relevant for learning nets of solid figures because it engages students in exploring, testing, and deciding on appropriate net forms, rather than merely memorizing procedures. Through problem situations that require students to evaluate whether a two-dimensional net can form a three-dimensional object, PBL helps address students' difficulties in constructing conceptual 2D–3D relationships. Therefore, PBL provides a learning approach that not only improves understanding of spatial nets but also prepares a foundation for collaborative interaction and knowledge exchange among students.

However, previous studies consistently show that while PBL is effective for learning materials that require spatial visualization and higher-order reasoning, its implementation often encounters challenges in collaborative learning contexts. Differences in students' communication skills and conceptual confidence frequently lead to unequal participation during group investigations, particularly in tasks that demand intensive visual reasoning, such as exploring and validating nets of solid figures. This imbalance can hinder the construction of shared understanding and reduce the overall effectiveness of PBL. Therefore, instructional strategies that reorganize interaction patterns are needed to ensure more equitable knowledge

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exchange. One such strategy is the Two Stay Two Stray or TSTS method, which facilitates structured intergroup interaction and information sharing. As reported by Maharani, Susilowati, & Ellianawati (2024), TSTS improves information distribution, cross-group communication, and students' mathematical communication skills. In the context of spatial nets, integrating TSTS into PBL enables students to collaboratively examine alternative net configurations, identify construction errors, and refine their spatial reasoning through shared visual exploration.

This learning design is aligned with the Merdeka Curriculum, which emphasizes deep conceptual understanding of geometry and its application in meaningful contexts. At the ninth grade level, students are required not only to construct nets of flat and curved-sided solids but also to integrate these structures into more complex three-dimensional models, demanding analytical and creative reasoning. Therefore, integrating TSTS within PBL is not merely a variation of instructional methods, but a pedagogical strategy to ensure equitable participation and effective knowledge distribution during collaborative problem solving. While PBL facilitates exploration and decision making in spatial tasks, TSTS strengthens interaction by positioning all students as active contributors in constructing and exchanging geometric ideas. This integration directly addresses the practical challenge of uneven participation in learning spatial nets and supports the achievement of the Merdeka Curriculum learning outcomes.

Based on these considerations, this study aims to evaluate the effectiveness of a reflective learning design for spatial nets through the integration of PBL and the TSTS strategy. This research does not merely position the Merdeka Curriculum as a normative framework, but demonstrates its concrete implementation in classroom practice, particularly in supporting deep conceptual understanding, equitable participation, and contextual problem solving in geometry. The learning design was implemented through an open class based microteaching approach conducted in three iterative Plan–Do–See cycles, each addressing increasing levels of conceptual complexity from flat-sided nets to curved and combined spatial structures. By examining both the quality of learning implementation and student outcomes in affective, skill, and cognitive domains, this study contributes empirical evidence on how a reflective PBL TSTS learning design can effectively address practical challenges in spatial geometry learning within the Merdeka Curriculum context.

## THEORETICAL FRAMEWORK

Concept-oriented mathematics learning requires students to actively construct knowledge through exploration and reflection. Therefore, constructivism underpins the spatial net learning design in this study. From a constructivist perspective, knowledge is not directly transmitted but built through experience, interaction, and reflection (Aprina et al., 2024; Azzahra, Ali, & Bakar, 2025; Wardani, 2023). In this research, these principles were realized through student-centered activities, including manipulating flat shapes, assembling various net configurations, testing three-dimensional forms, and discussing results within and across groups. Particularly in spatial net learning, conceptual understanding develops when students transform two-dimensional representations into three-dimensional

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structures and relate them to contextual problems (Rafidah, Annisa, Fadhilah, & Komariah, 2023; Ulandari, Dewi, & Istiningsih, 2022). Accordingly, the learning process was designed to provide structured opportunities for exploration, experimentation, and collaborative problem solving, allowing constructivist theory to be implemented in concrete classroom practice (Muavi, Mustaji, Sumarno, Widodo, & Bidandari, 2024).

Within the constructivist framework applied in this study, PBL functions as a learning mechanism that enables students to actively construct understanding through exploration and reflection. Through engagement with contextual problems, students are required to analyze spatial situations, explore alternative net configurations, predict folding outcomes, and test their constructions through manipulation and visualization. Group discussions serve as a medium for negotiating meaning, comparing solutions, and refining spatial reasoning based on peer feedback. In learning spatial nets, this iterative process of exploration, justification, and revision supports students in developing conceptual understanding and problem-solving skills beyond procedural trial and error (Rafidah et al., 2023; Ulandari et al., 2022). Thus, PBL in this study is positioned as a structured learning process that facilitates active cognitive and social engagement, aligning constructivist principles with concrete classroom activities.

The theoretical foundation of PBL in this study is strengthened by Vygotsky's social interaction theory, which emphasizes that knowledge is constructed through interaction, dialogue, and collaboration within the zone of proximal development (Azzahra et al., 2025; Dheta et al., 2024; Tohari & Rahman, 2024). In learning spatial nets, such interaction is crucial because students develop spatial reasoning more effectively when they exchange perspectives, compare net representations, and discuss possible folding outcomes (Mulyadi, Fatmala, Tsumu, Yulianti, & Islami, 2024; Wardani, 2023). Group discussions enable students to evaluate their constructions, predict three-dimensional forms, and identify errors. However, collaborative learning does not automatically lead to equitable knowledge construction. Without a clear interaction structure, group work often becomes imbalanced, with some students dominating while others remain passive, limiting the effectiveness of peer scaffolding (Lestari, Saleha, Richmasari, & Alfan, 2021). This condition highlights the necessity of structured collaborative strategies to ensure meaningful participation and effective knowledge distribution.

To address the imbalance of participation and knowledge distribution that often occurs in PBL-based group work, the TSTS method is applied in this study as a form of social scaffolding rather than merely a discussion technique. By structuring peer interaction through alternating roles as knowledge providers and receivers, TSTS supports students in articulating ideas, receiving feedback, and refining understanding through guided social exchange (Maharani et al., 2024; Mutiara, 2020). This structured interaction helps less confident students participate more actively while enabling more advanced students to deepen their understanding through explanation and comparison. In the context of spatial net learning, TSTS facilitates the exploration of multiple net configurations and the justification of why certain nets form specific three-dimensional shapes, thereby strengthening students' spatial reasoning through peer-supported learning (Rafidah et al., 2023). Consequently, the integration of PBL and TSTS creates a problem-centered

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learning environment that is also socially structured to ensure equitable participation and meaningful knowledge construction.

In addition to constructivism and social interaction theory, this study also adopts the theory of geometric visualization, which serves as a key cognitive bridge in learning nets of three-dimensional figures. Visualization enables students to connect two-dimensional net representations with three-dimensional mental images through processes such as imagining folding and performing mental rotation (Muavi et al., 2024; Ulandari et al., 2022). Understanding spatial nets, therefore depends on students' ability to identify component shapes, mentally transform them into spatial forms, and anticipate the outcomes of folding. To support this process, the learning activities in this study deliberately incorporated concrete and manipulative media, such as cardboard models and cutting–assembling tasks, which helped students strengthen their visual–spatial abilities. Consistent with previous findings Muavi et al. (2024); Ulandari et al. (2022), these hands-on experiences enabled students to gradually bridge two-dimensional and three-dimensional thinking, particularly when working with curved shapes and combined spatial structures.

This theoretical framework is further strengthened by the Plan, Do, and See cycle–based microteaching approach, which supports reflective improvement in the quality of teacher facilitation when implementing PBL integrated with the TSTS strategy (Deswita, 2019). In this approach, learning is systematically planned, implemented, and reflected upon, with the implementation stage observed using Basic Teaching Skills (KDM) indicators. These indicators, such as questioning, explaining, classroom management, media use, and reinforcement, directly reflect the teacher's capacity to facilitate problem exploration, structured collaboration, and intergroup interaction within PBL and TSTS learning. Through reflective analysis in the See stage, teachers and observers evaluate how effectively these facilitation skills support students' active engagement, equitable participation, and conceptual understanding, and use the findings to refine subsequent cycles (Deswita, 2019; Lengari, Fadiana, & Nisa, 2025). Thus, microteaching provides a coherent framework for ensuring that PBL and TSTS learning is not only well designed but also effectively facilitated from cycle to cycle.

This study is grounded in the Merdeka Curriculum, which emphasizes competency mastery and the application of mathematics in meaningful contexts. At Phase D, students are expected to understand spatial nets, apply them in problem solving, and develop new models from combinations of spatial structures (Kemendikbudristek BSKAP, 2024). The learning design developed in this study operationalizes these curriculum demands through concrete, contextual tasks, such as designing product packaging or a half-tube shaped wall lamp, which require students to apply geometric concepts in real situations. By integrating PBL and TSTS, the design supports flexible, learner-centered, and collaborative learning as promoted by the Merdeka Curriculum (Risandy, Sholikhah, Ferryka, & Putri, 2023; Wardani, 2023). Therefore, this learning design is not only aligned with the curriculum in principle, but is also practically applicable in classroom settings.

Overall, the theoretical framework of this study is based on three main foundations, namely constructivism which emphasizes experience-based learning activities and problem solving, social interaction theory which emphasizes dialogue

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and collaboration, and geometric visualization theory which explains the mental processes of learners in understanding spatial structures. The integration of PBL and TSTS bridges these three theories in the design of spatial structure learning. The PBL and TSTS approaches support all these competencies while strengthening the character of the Pancasila Student Profile, such as independence, critical thinking, and mutual cooperation (Risandy et al., 2023; Wardani, 2023). This theoretical framework is the basis for ensuring the suitability between the research objectives, the learning process, and the analysis of findings. Thus, this research not only contributes to the development of geometry learning methods but also provides a broader understanding of how students actively, collaboratively, and contextually construct mathematical knowledge.

## RESEARCH METHOD

This study employed a qualitative descriptive research design implemented through an open class–based microteaching approach with three iterative cycles following the Plan, Do, and See stages. Given the small number of participants and the microteaching context, this study does not aim to produce broadly generalizable findings, but rather to provide an in-depth analysis of the learning process and the effectiveness of a specific instructional design. This design was chosen to facilitate continuous reflection and improvement of learning, allowing the integration of the PBL model with the TSTS strategy to be examined systematically. The research subjects consisted of nine ninth-grade students who participated in the learning activities, while two observers documented the implementation using the KDM observation sheet. Consistent with the characteristics of microteaching, this approach prioritizes close observation, detailed analysis of instructional quality, and careful monitoring of students' learning processes and outcomes.

The research procedure was conducted through three complete and iterative cycles, each consisting of the Plan, Do, and See stages. In the Plan stage, the researcher systematically developed and refined learning tools, including teaching modules, Student Worksheets (LKPD), assessment instruments, geometric manipulative media, and learning observation sheets. At this stage, the integration of PBL and the TSTS strategy was deliberately designed, particularly within the investigation phase, to ensure that students engaged not only in problem solving within their groups but also in structured intergroup knowledge exchange. In the Do stage, the learning design was implemented in an open classroom setting, where students participated in sequential PBL activities such as problem orientation, group organization, investigation, and presentation of results, with TSTS applied to facilitate information sharing and balanced collaboration. Throughout this stage, observers systematically documented the teacher's facilitation using KDM indicators, including questioning techniques, explanation clarity, classroom management, use of media, reinforcement, and lesson closure. In the See stage, teachers and observers collaboratively reflected on the learning process, focusing on students' engagement, the effectiveness of PBL TSTS implementation, and the alignment between planned and enacted instruction. These reflective discussions served as the primary source for revising learning tools, improving facilitation strategies, and refining the instructional design in subsequent cycles, thereby ensuring continuous improvement throughout the research process.

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The research tools were selected and designed to directly address the objectives of this study, namely to evaluate the effectiveness of the reflective PBL TSTS learning design in terms of learning implementation and student learning outcomes. The LKPD was used to analyze the suitability between the designed learning activities and the instructional process that was implemented. The KDM observation sheet served as the main tool for assessing the quality of teacher facilitation in the implementation of PBL TSTS, including skills in questioning, explaining, managing classroom interactions, using media, providing reinforcement, and closing lessons. Student learning outcomes were measured using three complementary instruments, namely an attitude assessment rubric to capture students' critical, cooperative, and independent learning behaviors during PBL TSTS activities. Then, a spatial network construction skills rubric was used to evaluate students' ability to assemble, modify, and combine spatial networks accurately. And a knowledge test to assess students' conceptual understanding of flat-edged, curved-edged, and combined space nets. Data were collected through classroom observation, analysis of student work, documentation, and learning outcome assessment. Data analysis followed a qualitative descriptive approach involving data reduction, data presentation, and conclusion drawing. Quantitative data from KDM observations and learning outcome scores were analyzed in percentage form to identify trends in development between cycles, while qualitative data from observer notes and reflective discussions were analyzed to explain how and why changes occurred. This integrated analysis enabled a comprehensive evaluation of the learning process and its outcomes in the implementation of PBL TSTS learning design on spatial nets.

## RESULTS AND DISCUSSION

This section of the research presents the main findings covering the implementation of learning and student learning outcomes in terms of attitude, skills, and knowledge during the three learning cycles. The data is presented in narrative paragraphs accompanied by summary tables so that readers can more clearly understand the comparisons between cycles.

1. Learning Implementation

Learning implementation was observed using the KDM instrument completed by two observers, with the results serving as a baseline for evaluating improvements across cycles. In the first cycle, although the implementation score reached 96.43%, several initial problems were identified, particularly students' confusion in visualizing flat-sided spatial nets and uneven interaction during group discussions, which indicated that facilitation strategies had not yet fully supported students' conceptual and collaborative needs. The limited use of reinforcement also reduced opportunities for students to confirm or revise their understanding. In the second cycle, following reflective revisions to the learning design, such as the intensified use of concrete media and more structured facilitation during investigation activities, the implementation score increased to 97.72%. These changes directly contributed to clearer explanations of curved sided nets, improved student engagement, and more balanced interaction among group members. In the third cycle, the implementation score remained stable at 97.72%, demonstrating that the revised facilitation strategies were effective in maintaining learning quality

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despite increased material complexity involving combinations of flat and curved-sided spatial figures. This progression indicates a cause effect relationship between improvements in instructional design and facilitation and students' responsiveness to learning activities across cycles.

Table 1. Recapitulation of Learning Implementation in Each Cycle

| Cycle | Learning Material | Percentage of Implementation | Prominent KDM | Less Prominent KDM |
|---|---|---|---|---|
| 1 | Flat shapes | 96.43% | Explaining | Providing reinforcement |
| 2 | Curved-sided nets | 97.72% | Explaining | Reinforcement, use of media |
| 3 | Combination of spatial figures | 97.72% | Explaining | Reinforcement |

2. Learning Outcomes in Attitude

In terms of attitude, students demonstrated progressive development across the three learning cycles, however the nature of this development differed at each stage. In the first cycle, the average attitude score reached 94.4%, indicating a generally positive response to learning activities. At this initial stage, students' positive attitudes were largely reactive to the group-based learning format and the novelty of collaborative activities, rather than reflecting deep conceptual engagement with the spatial net content. Students tended to participate because of task demands and peer interaction, but their involvement was not yet consistently accompanied by sustained reasoning or critical questioning. In the second cycle, the attitude score increased to 100%, suggesting a qualitative shift in student engagement. Students not only participated actively and cooperatively but also demonstrated greater independence and confidence in expressing ideas during problem-solving and intergroup discussions. This level of positive attitude was maintained in the third cycle despite increased material complexity, indicating that students had internalized collaborative norms and developed a more stable form of engagement that supported meaningful learning. Thus, the progression of attitude scores reflects a transition from reactive participation in the early cycle to more self-regulated and conceptually grounded involvement in subsequent cycles.

Table 2. Recapitulation of Student Attitude Results for Each Cycle

| Cycle | Attitude Indicators Observed | Average |
|---|---|---|
| 1 | Faithful and devout, critical, cooperative, independent | 94.4% |
| 2 | Faithful and devout, critical, cooperative, independent | 100% |
| 3 | Critical, cooperative, independent | 100% |

3. Learning Outcomes in Skills

The students' skill scores showed an upward trend from the first to the second cycle, followed by a slight decline in the third cycle. In the first cycle, the average skill score was 92.7%, which falls into the very good category, however several common skill-related difficulties were still observed. At this stage, some students made errors in mapping corresponding faces when assembling nets, incorrectly orienting adjacent sides, or failing to anticipate how certain faces would align after folding. These mistakes indicate that students' procedural skills had not yet been fully supported by accurate spatial reasoning. In the second cycle, the skill score

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increased significantly to 98.3%, coinciding with students' increased familiarity with concrete media and the use of cross-group discussions through the TSTS method. Exposure to alternative net constructions and peer explanations helped students identify and correct earlier errors, particularly those related to side alignment and folding orientation. In the third cycle, the skill score decreased slightly to 96.6%, which can be attributed to the increased complexity of tasks involving the combination of flat- and curved-sided nets. In this cycle, students commonly struggled to integrate different net structures coherently, especially when determining the correct orientation and connection between flat and curved surfaces, indicating that while overall skills had improved, continued practice and scaffolding were still necessary for more complex spatial constructions.

Table 3. Recapitulation of Student Skill Results for Each Cycle

| Cycle | Skill Focus | Average |
|---|---|---|
| 1 | Assembling flat nets | 92.7 |
| 2 | Assembling curved-sided nets | 98.3 |
| 3 | Combining flat-sided and curved-sided nets | 96.6 |

4. Learning Outcomes in the Knowledge Aspect

Students' knowledge scores demonstrated a generally stable pattern across the three cycles, however these scores reflect underlying conceptual challenges rather than simple mastery of factual content. In the first cycle, the average score was 90, indicating that students had begun to understand the basic properties of flat-sided nets. Nevertheless, several students still experienced difficulty conceptually linking two-dimensional net representations to the corresponding three-dimensional objects, particularly when required to predict folding outcomes or justify why a specific net could form a given solid. In the second cycle, the average score increased to 95.5, suggesting improved conceptual understanding supported by the use of concrete learning media and visual exploration of curved-sided nets. These supports helped students mentally coordinate 2D representations with 3D forms. In the third cycle, the average score decreased slightly to 93.3 as students encountered tasks requiring the integration of flat- and curved-sided nets. This decline was not due to a lack of conceptual recall or memorization, but rather to ongoing difficulties in coordinating multiple two-dimensional representations into a coherent three-dimensional structure, which demands higher levels of spatial reasoning. Despite this challenge, students' scores remained in the excellent category, indicating meaningful conceptual development alongside increasing task complexity.

Table 4. Recapitulation of Student Knowledge Results for Each Cycle

| Cycle | Knowledge Material | Average |
|---|---|---|
| 1 | Flat-sided nets | 90 |
| 2 | Curved-sided nets | 95.5 |
| 3 | Application of net combinations | 93.3 |

The findings indicate that integrating PBL with the TSTS strategy improves the quality of learning and student outcomes in spatial geometry by enhancing the quality of interaction and exchange of ideas, rather than merely refining

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instructional procedures. In line with constructivist principles, students constructed understanding through active exploration and social negotiation of meaning (Aprina et al., 2024; Wardani, 2023). While PBL structured inquiry around authentic problems, TSTS functioned to redistribute participation and facilitate more equitable knowledge sharing across groups, allowing students to articulate, compare, and refine spatial ideas (Maharani et al., 2024; Mutiara, 2020). This interactional learning environment is particularly important for spatial net material, which demands visualization and representational reasoning, thereby supporting deeper conceptual engagement and higher-order thinking.

The improvement in students' attitudes to the excellent category reflects not only the participatory nature of PBL, but also the increasingly effective functioning of the TSTS mechanism across cycles. While PBL positioned students as active problem solvers who were responsible for group decisions, supporting the development of critical, independent, and cooperative attitudes aligned with the Pancasila Student Profile (Risandy et al., 2023; Wardani, 2023) the attitudinal shift became more evident in cycles II and III when TSTS began to operate as a systematic channel for distributing ideas across groups. Through structured role exchanges, students gained more equal opportunities to explain, question, and compare solutions, leading to more balanced participation and greater confidence in expressing ideas. This interaction pattern aligns with Vygotsky's social interaction theory, which emphasizes dialogue and peer support within the zone of proximal development as key drivers of cognitive and affective growth (Azzahra et al., 2025; Tohari & Rahman, 2024). Consequently, the sustained positive attitudes observed in cycles II and III indicate that improved social interaction and equitable idea exchange rather than task structure alone played a central role in shaping students' engagement.

Findings in the skill aspect show that students increasingly developed their ability to construct spatial nets, predict folding outcomes, and combine different patterns into new spatial structures. This improvement was closely related to the use of concrete media such as cardboard, scissors, and spatial models, which supported students' visual exploration and reasoning (Muavi et al., 2024; Ulandari et al., 2022). In cycles II and III, these activities no longer only promoted physical engagement, but also strengthened students' confidence and sense of ownership over their ideas, as reflected in their willingness to justify net constructions and revise designs based on peer feedback. Through the straying phase of TSTS, students were exposed to alternative net configurations from other groups, allowing ideas to be distributed more evenly and visual representations to be refined. This progression indicates that skill improvement across cycles was accompanied by deeper conceptual engagement and self-confidence, in line with the theory of geometric visualization that emphasizes mental rotation, shape prediction, and coordination between two and three-dimensional representations.

Meanwhile, the knowledge aspect showed a generally positive development, despite a slight decline in the final cycle due to increased material complexity involving the integration of flat-sided and curved-sided nets, which required higher spatial reasoning. This variation reflects a shift in the quality of students' thinking rather than a decline in conceptual understanding. As task demands increased, students began to move beyond imitating example nets and demonstrated an

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emerging ability to explain why certain net configurations could or could not form specific three-dimensional shapes. This pattern is consistent with findings by Rahmawati, Baa, & Asma (2021), which indicates that tasks with higher cognitive load may result in fluctuating performance while fostering deeper understanding. Within the PBL framework, conceptual learning is therefore reflected not only in score accuracy but also in students' engagement in investigation, argumentation, and justification processes during group discussions (Lestari et al., 2021).

The consistently excellent implementation scores across the three cycles indicate that the PBL syntax and TSTS procedures were applied in a stable and coherent manner. More importantly, this consistency supported students' conceptual understanding rather than mere memorization, as reflected in their increasing ability to mentally transform three-dimensional objects into two-dimensional net representations. Through iterative problem-solving, concrete manipulation, and structured peer interaction, students began to reason about why certain nets could represent specific solids, instead of simply recalling examples. This development was facilitated by the Plan, Do, and See microteaching mechanism, which enabled continuous reflection and refinement of instructional strategies from one cycle to the next (Deswita, 2019; Lengari et al., 2025). However, the relatively weak use of formative reinforcement suggests that improving the quality of teacher feedback remains essential to further strengthen students' conceptual consolidation and spatial reasoning.

Conceptually, the integration of PBL and the TSTS strategy can be explained through the synergy of constructivism, social interaction theory, and geometric visualization theory. These perspectives jointly account for how students construct knowledge through experience, receive social scaffolding through cross-group interaction, and develop the ability to mentally transform two- and three-dimensional representations. Within this framework, the stabilization or slight decline in students' skill performance in later cycles should be interpreted as a result of increased task complexity rather than a limitation of the learning model. As students were required to integrate flat- and curved-sided net structures, cognitive demands increased, revealing the boundaries of emerging competencies while still indicating ongoing conceptual growth. Thus, the observed dynamics across attitudes, skills, and knowledge reflect progressive learning within increasingly complex tasks, rather than uniform or superficial improvement.

Despite its limitations, including the small number of participants, the microteaching context, and the absence of a control group that limits generalization, this study provides a specific empirical contribution to geometry learning research. The findings show that integrating PBL with the TSTS strategy is particularly effective for visual geometry content, such as spatial nets, because it facilitates systematic exploration and exchange of spatial representations. Through problem-based tasks, concrete manipulation, and structured intergroup interaction, students were supported in comparing, articulating, and refining two and three-dimensional representations. Thus, this study extends existing theoretical claims by demonstrating how the PBL TSTS integration functions as an effective pedagogical approach for visual and representational reasoning in geometry within the Merdeka Curriculum context.

Overall, the findings show that PBL-based spatial geometry learning

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integrated with the TSTS strategy supports students' understanding through a gradual, cycle-based process rather than instant conceptual change. Across cycles, students progressively refined their understanding of spatial nets by engaging in authentic problem solving, manipulating concrete materials, exchanging ideas through structured intergroup discussions, and reflecting on their reasoning. Each cycle served as a stage of conceptual consolidation, enabling students to address earlier misconceptions and strengthen connections between two and three-dimensional representations. With continued feedback and scaffolding for increasingly complex tasks, this learning model demonstrates strong potential for sustainable application in mathematics classrooms.

## CONCLUSION

Based on the results obtained across the three learning cycles, it can be concluded that the integration of PBL with the TSTS strategy effectively improved the quality of the learning process and students' learning outcomes in spatial net instruction. The improvement observed in this study specifically reflects the development of students' visual–spatial understanding, particularly their ability to connect two-dimensional net representations with corresponding three-dimensional forms and to explain why certain net configurations are valid. This understanding emerged gradually across cycles, as students engaged in problem exploration, concrete manipulation, and structured intergroup interaction. The consistently excellent learning implementation scores, increasing from 96.43% in the first cycle to 97.72% in the subsequent cycles, indicate that teachers successfully facilitated these processes, while TSTS supported more balanced interaction and distribution of ideas among students.

Student learning outcomes in attitude, skills, and knowledge developed in a mutually reinforcing manner rather than as separate components. Improvements in learning attitudes particularly confidence, active participation, and collaboration supported students' engagement in constructing and testing spatial nets. As students became more confident in expressing ideas and participating in discussions, their manipulative and visual–spatial skills also improved, enabling them to assemble nets more accurately and revise errors. In turn, these skill developments contributed to deeper conceptual understanding, especially in connecting two-dimensional net representations with three-dimensional forms. Although performance slightly declined in more complex integrative tasks, this reflected increased cognitive demands rather than a breakdown in learning. Overall, these findings indicate that the implemented learning design facilitated holistic development, in which affective, procedural, and conceptual aspects evolved coherently across cycles.

Thus, the effectiveness of the integrated PBL TSTS learning model can be attributed to the complementary roles of each approach in supporting students' visual–spatial learning. PBL presents contextual problems that require students to explore, test, and reason about spatial net configurations, while the TSTS strategy facilitates systematic exchange of visual ideas across groups, enabling students to compare representations and refine spatial reasoning through peer explanation. Through this combination, learning becomes active, collaborative, and conceptually meaningful, supporting the achievement of Merdeka Curriculum competencies. To sustain these outcomes, teachers are encouraged to continue

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using this model while strengthening scaffolding and feedback, particularly for more complex spatial tasks.

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