

Developing a STEM-Based Learning Module to Improve Problem-Solving Skills on Spatial Distance Topics

Suprianto^{1,*}, Sudi Prayitno², Karim³, & Ahmad Fauzi⁴

¹Department of Data Science, Universitas Muhammadiyah Sidoarjo, Indonesia

²Department of Mathematics Education, Universitas Mataram, Indonesia

³Department of Science Education, Universitas Lambung Mangkurat, Indonesia

⁴Faculty of Education, Universiti Teknologi Malaysia, Malaysia

*Corresponding email: suprianto@umsida.ac.id

Received: 07 June 2026

Accepted: 08 August 2026

Published: 17 September 2026

Abstract: Students often struggle with the abstract nature of spatial distance in three-dimensional geometry, which can lead to low problem-solving skills. This study aimed to develop a valid, practical, and effective STEM-based learning module on spatial distance to enhance senior high school students' problem-solving skills. Employing a Design Research methodology with the Development Study model by Plomp and Nieveen (2013), this research was conducted at SMA Negeri 4 Sidoarjo, Indonesia, involving 32 Grade XII students selected through purposive sampling. Data were collected using expert validation sheets, student response questionnaires, classroom observation sheets, and problem-solving tests administered as pre-test and post-test. The module demonstrated high validity with an average expert validation score of 92.5% (very valid category). Practicality was confirmed through smooth classroom implementation (95.8% observed implementation rate) and positive student responses, with 94% of students rating the module as engaging and easy to follow. Effectiveness was evidenced by a significant improvement in students' problem-solving scores (pre-test mean = 42.5; post-test mean = 80.3), with a medium N-Gain of 0.66 ($t = 12.754$; $p < 0.05$). The highest gain was observed in the "understanding the problem" stage (N-Gain = 0.72), attributed to the hands-on engineering design project. This study concludes that the STEM-based module is a valid, practical, and effective tool for improving problem-solving skills in spatial geometry. It is recommended that mathematics teachers adopt this module to make learning more contextual and meaningful.

Keywords: STEM-Based learning, learning module, problem-solving skills, spatial distance, design research.

Article's DOI: <https://doi.org/10.23960/jpmipa.v27i3.pp1688-1701>

■ INTRODUCTION

Three-dimensional geometry is a fundamental branch of mathematics essential for developing higher-order thinking skills, particularly spatial reasoning and problem-solving (NCTM, 2000). Within this topic, the concept of spatial distance, such as the distance between points, a point and a line, or a point and a plane, is a critical yet challenging element for senior high school students. Despite its importance, students often perceive 3D geometry as highly abstract and difficult to visualize, leading to low spatial ability and significant difficulties in solving related

problems (Hwang & Hu, 2013; Pittalis & Christou, 2010). This struggle is characterized by an inability to manipulate mental images and apply geometric principles to unfamiliar contexts.

Preliminary observations and interviews with mathematics teachers at SMA Negeri 4 Sidoarjo corroborated this challenge. Many Grade XII students showed low enthusiasm and achievement in geometry. Their problem-solving skills remained underdeveloped; they often failed to understand problems, devise appropriate plans, or execute correct mathematical procedures for calculating spatial distances. This

indicated a strong need for innovative teaching materials that can transform abstract geometric concepts into more tangible and engaging learning experiences. This empirical gap was further quantified during our preliminary study at SMA Negeri 4 Sidoarjo. A diagnostic test administered to 32 Grade XII students revealed that only 32% achieved the minimum mastery criterion ($KKM = 75$) for basic spatial distance problems. Specifically, 68% of students failed to correctly determine the distance between a point and a plane in a cube. Moreover, interviews with the mathematics teacher confirmed this condition: *"Students can memorize formulas such as the Pythagorean theorem, but they cannot visualize which point to project and which line is perpendicular. They are lost when the figure is not explicitly drawn."* These findings underscored the urgency of developing concrete teaching aids that bridge the gap between symbolic formulas and spatial visualization.

One promising approach is integrating Science, Technology, Engineering, and Mathematics (STEM) into education. STEM-based learning provides a contextual framework that connects mathematical principles to real-world problems and engineering design challenges (Becker & Park, 2011). By engaging students in activities that require them to design, create, and calculate, such as constructing a building model or planning a cable network, the abstract concept of spatial distance becomes concrete and meaningful. Therefore, developing a STEM-based learning module is a strategic intervention to bridge the gap between abstract theory and practical application, ultimately fostering deeper understanding and enhanced problem-solving skills.

The core concepts of spatial distance in three-dimensional space include determining the shortest distance between two points, a point and a line, and a point and a plane. Mastering these

concepts requires strong spatial visualization skills to mentally manipulate and project geometric elements. These skills are crucial not only for academic success in mathematics but also for many careers in architecture, engineering, and computer graphics (Battista, 2007).

In mathematics education, problem-solving is the pinnacle of cognitive activity. According to Polya (1957), the problem-solving process consists of four fundamental stages: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back. An effective learning module should guide students systematically through these stages, empowering them to tackle non-routine problems with confidence.

STEM education is an interdisciplinary approach integrating the four disciplines into a cohesive learning paradigm based on real-world applications. Its core principles include problem-centered learning, design-based inquiry, and collaborative work (Bybee, 2013). In mathematics, STEM provides authentic contexts for applying mathematical concepts, enhancing conceptual understanding, creativity, and problem-solving abilities. For instance, calculating the shortest path for a cable (engineering) or analyzing molecular structures (science) offers compelling reasons to learn about spatial distances.

A learning module is a self-contained unit of instruction designed to help students master specific objectives. A good module is characterized by self-instructional features, completeness, adaptability to different learning paces, user-friendliness, and design based on learner needs (Prastowo, 2015). A well-designed module structures content, activities, and assessments to facilitate effective learning.

While several studies have developed STEM-based modules for geometry (Çakýrođlu & Aydýn, 2021; Mahendra et al., 2023; Prabowo & Suryadi, 2020), most have focused on digital

simulations or worksheet-based projects. This module's distinctive novelty lies in integrating a physical engineering design challenge: students construct a tangible 3D tower model from wooden sticks and measure actual string lengths to solve spatial distance problems. This approach directly engages students' kinesthetic and visual-spatial senses, transforming the abstraction of "point-to-plane distance" into a measurable, observable object. By bridging hands-on construction with mathematical calculation, this module uniquely aligns with Polya's problem-solving stages in a fully embodied learning context.

Based on the identified problems and theoretical framework, this study aimed to develop a valid, practical, and effective STEM-based learning module on spatial distance to improve the problem-solving skills of senior high school students.

Therefore, this study aimed to develop a STEM-based learning module on spatial distance that meets three quality criteria. Specifically, this research sought to answer: (1) How valid is the STEM-based learning module for spatial distance according to expert judgment? (2) How practical is the module in terms of implementation and student response? (3) How effective is the module in improving students' problem-solving skills, as measured by the normalized gain (N-Gain) and the four Polya indicators?

■ **METHOD**

Participants

The study was conducted at SMA Negeri 4 Sidoarjo, East Java, Indonesia, in the even semester of the 2023/2024 academic year. The subjects included four expert validators: two mathematics education lecturers and two senior high school mathematics teachers who assessed the module's validity. The main participants were 32 Grade XII students selected through purposive sampling with specific inclusion criteria: they had completed prerequisite two-dimensional

geometry, their average mathematics scores ranged between 65 and 80 (indicating intermediate proficiency), and they had not yet formally received instruction on three-dimensional spatial distance. Before data collection, the school principal granted official research permission, and all participating students and their parents provided written informed consent. The study ensured confidentiality of personal data throughout.

Research Design and Procedures

This study employed Design Research, adopting the Development Study model proposed by Plomp and Nieveen (2013). This approach systematically designs, develops, and evaluates educational interventions to solve practical problems while contributing to theoretical knowledge. The research consisted of three phases. The first phase was preliminary research, which involved needs analysis through teacher interviews, student surveys, and literature review to establish the module's foundational framework. The second phase was prototyping, which involved iterative cycles of design, formative evaluation by experts and small student groups, and revision until the module met validity and practicality criteria. The third phase was assessment, in which a one-group pretest-posttest design was used to evaluate the module's effectiveness on students' problem-solving skills. The module was implemented over two meetings, each lasting 90 minutes, with students working in small groups of four to five members. In the first meeting, students physically constructed a 3D tower model using wooden sticks, following the module's step-by-step instructions. In the second meeting, they measured string lengths representing potential cable configurations, calculated theoretical distances, and presented their design outcomes. This structured procedure ensured that the intervention was delivered consistently across all groups.

Instruments

Four instruments were utilized in this study. The first was an expert validation sheet using a 4 point Likert scale that assessed three aspects: content relevance to the curriculum, construct alignment with STEM principles and Polya's stages, and media and language clarity. The second instrument was a student response questionnaire, also on a 4 point Likert scale ranging from Strongly Disagree to Strongly Agree, which measured ease of use, clarity, and attractiveness of the module. The third instrument was a classroom observation sheet that assessed ten indicators of implementation fidelity—five for teacher activities and five for student activities—with the implementation rate calculated as the proportion of observed indicators to total planned indicators. The fourth instrument was a problem-solving test consisting of five essay items on spatial distance (point-to-point, point-to-line, and point-to-plane) designed based on Polya's four stages. This test was empirically validated through a try-out with 20 non sample students, which confirmed item validity with correlation coefficients exceeding 0.3 for all items, and high reliability with a Cronbach's Alpha of 0.82.

Data Analysis

Quantitative data from expert validation and student response questionnaires were converted to percentages and categorized using Akbar's criteria, where scores between 81% and 100% were considered very valid or very practical, 61% to 80% valid or practical, 41% to 60% moderately valid or practical, and scores of 40% or below invalid or impractical. Qualitative feedback from experts and observers was used for revisions. Effectiveness was evaluated by calculating the normalized gain (N Gain) from pre test and post test scores, with categories of high for values above 0.7, medium for values between 0.3 and 0.7, and low for values below 0.3. A paired sample t test at a significance

level of 0.05 was performed in SPSS to test whether the score improvement was significant. Data visualization complemented the statistical analysis, including a 100% stacked bar chart of student responses, a scatter plot of individual score distributions, and a bar chart of N Gain across Polya's indicators. All figures we generated in Microsoft Excel using the collected data.

■ RESULT AND DISCUSSION

Characteristics and Validity of the Developed Module

The primary outcome of this design research is a STEM based learning module on spatial distance titled "*STEM Module: Applying Spatial Distance in Real World Design*". The module is a printed booklet comprising 42 pages, designed for four lesson hours (two meetings) for Grade XII senior high school students. Its physical format was chosen deliberately to facilitate hands on activities without requiring digital devices, ensuring accessibility across various school settings. The module's content is structured into five main sections: an introduction to real world problems involving spatial distance (e.g., cable car networks, bridge support structures, and telecommunication towers), a brief review of prerequisite concepts (Pythagorean theorem, basic two dimensional geometry), the core STEM project activity, guided problem solving exercises based on Polya's stages, and a reflection and self assessment section. The distinctive feature of this module is its integration of a physical engineering design challenge, where students work collaboratively to construct a three dimensional tower model using wooden sticks and glue, then design and measure string networks representing cables to stabilize the tower from a specific ground point to a higher point on the tower. This concrete activity directly requires students to calculate point to line and point to plane distances, transforming abstract mathematical concepts into measurable, observable objects.

To provide readers with a clear visual context of the module's key features, Figures 1, 2, and 3 present representative pages. Figure 1 shows the cover page and introductory real world context section, displaying the telecommunication tower scenario that motivates the need for spatial distance calculations. Figure 2 presents the core engineering design activity, the "Cable Network Design Challenge" page, which guides students to plan, sketch, and measure string configurations for stabilizing a model tower, integrating mathematical calculation with physical construction. Figure 3 displays a structured worksheet that systematically guides students through Polya's four problem solving stages, ensuring cognitive scaffolding alongside the physical project.

The validity of the module was assessed by four experts (two mathematics education lecturers and two experienced high school teachers) using a structured 4 point Likert scale instrument covering three aspects: content validity (relevance to core competencies, accuracy, and depth of material), construct validity (alignment with STEM principles and Polya's problem solving stages), and media and language validity (clarity of instructions, readability, and visual design). The validation results are summarized in Table 1. The overall average score of 92.5% (very valid category) indicates that the module is theoretically sound and aligned with educational standards. The highest score of 95% was achieved in content validity, reflecting the experts' strong agreement that the module's material accurately covers the core competencies for three dimensional geometry and provides sufficient

depth for senior high school level. The construct validity score of 90% confirms that the integration of STEM elements, particularly the engineering design project, is pedagogically coherent and effectively mirrors Polya's problem solving stages. The media and language validity score of 92.5% was supported by the clear, step by step visual instructions, which experts noted minimized ambiguity and supported independent learning.

Qualitatively, the validators praised the module's innovative approach, stating that the hands on project makes spatial distance tangible, which is rarely found in conventional textbooks. One expert specifically highlighted that the cable network design activity bridges the gap between abstract formulas and physical measurement, which is the main hurdle for students. Minor suggestions regarding diagram formatting and font consistency were implemented in the final revision, further refining the module's visual quality. Compared to previous STEM based geometry modules reported in the literature (Çakýrođlu & Aydýn, 2021; Mahendra et al., 2023; Prabowo & Suryadi, 2020), which predominantly relied on digital simulations or worksheets, the present module's distinctive advantage lies in its physical manipulative component. The validated high scores across all aspects confirm that this embodied, project based design not only meets curriculum standards but also offers an innovative pedagogical pathway that addresses the root cause of students' spatial difficulties the abstract nature of three dimensional visualization. Thus, the module successfully fulfills the first quality criterion for educational design research: validity.

Table 1. Expert validation scores by aspect

Aspect Assessed	Average Score	Category
Content Validity (Relevance, Accuracy, Depth)	95.0%	Very Valid
Construct Validity (STEM Alignment, Polya's Stages)	90.0%	Very Valid
Media & Language Validity (Clarity, Readability, Design)	92.5%	Very Valid
Overall Average	92.5%	Very Valid

Practicality

The module's practicality was objectively measured using a classroom observation sheet that assessed 12 specific indicators of implementation fidelity during the two instructional meetings. These indicators were derived directly from the module's activity flow and comprised six indicators for teacher activities (delivering the project introduction, facilitating group discussions, guiding students in constructing the tower model, assisting with string measurements, prompting problem solving strategies, and closing the lesson with reflection) and six indicators for student activities (actively engaging in the project, collaborating within groups, correctly using the module's instructions, conducting physical measurements, performing mathematical calculations, and presenting their design outcomes). The implementation rate was

calculated as the proportion of observed indicators to the total indicators observed.

The observation results across the two meetings are presented in Table 2. In Meeting 1, 11 out of 12 indicators were implemented, yielding a rate of 91.7%. In Meeting 2, all 12 indicators were observed, resulting in a 100% implementation rate. The average implementation rate across both meetings was 95.8%, meaning 23 of 24 planned activity indicators were successfully observed during the learning process. According to Akbar's (2013) criteria for practicality, an implementation rate of 81% to 100% is categorized as "very practical". This objective measurement eliminates subjective interpretation; the module was not merely perceived as "smooth," but empirically verified as implementable with high fidelity in a real classroom setting.

Table 2. Implementation fidelity observation results

Meeting	Total Indicators Observed	Indicators Implemented	Implementation Rate	Category
Meeting 1	12	11	91.7%	Very Practical
Meeting 2	12	12	100%	Very Practical
Average	12	11.5	95.8%	Very Practical

Furthermore, the student response questionnaire, administered to all 32 participants after the field test, reinforced this objective finding. The questionnaire assessed four aspects: clarity of instructions, ease of use, engagement and attractiveness, and perceived usefulness. As shown in Figure 4, a 100% stacked bar chart showing the proportion of responses for each aspect, most students provided positive ratings. Specifically, 94% of students agreed or strongly agreed that the module was engaging, 91% found the instructions clear and learning activities easy to follow, 89% stated the module was easy to use independently, and 92% perceived that the project helped them understand spatial distance concepts. The highest proportions of "Strongly Agree" responses were for engagement (56%) and perceived usefulness (50%), indicating strong

affective and cognitive acceptance of the module. Conversely, negative responses ("Disagree" and "Strongly Disagree") remained consistently low across all aspects, ranging from 6% to 11%. These detailed response distributions confirm that the module was not only objectively practical (as evidenced by the observation data) but also subjectively well received by the target users. These quantitative results, together with the observation data, confirm the module's practicality based on measurable criteria, fulfilling the second quality requirement for educational design research.

Effectiveness and Detailed Problem Solving Improvement

The module's effectiveness was measured by comparing pre test and post test scores. The

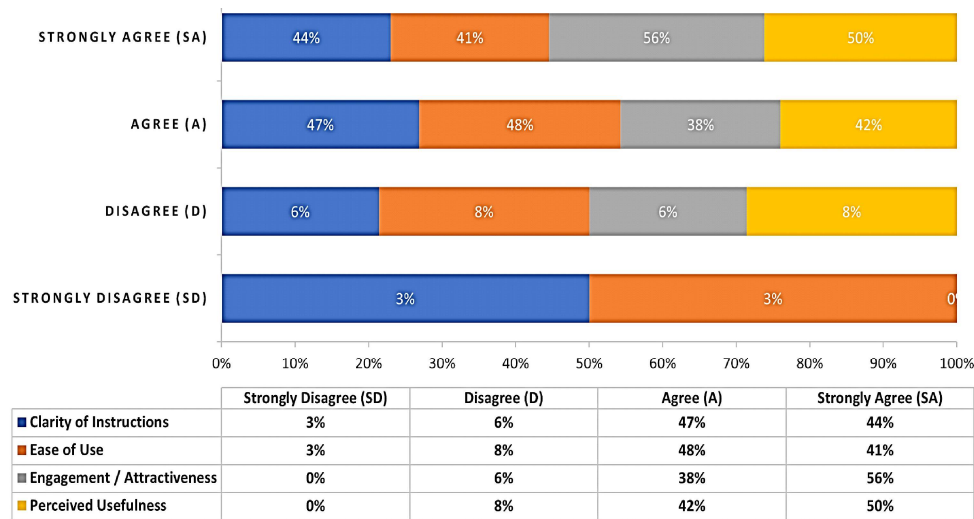


Figure 4. Student responses to the STEM module. Note: The horizontal axis represents the four aspects assessed (Clarity of Instructions, Ease of Use, Engagement/Attractiveness, and Perceived Usefulness), and the vertical axis represents the percentage of student responses. Four color coded categories are shown: Strongly Disagree (SD), Disagree (D), Agree (A), and Strongly Agree (SA). The data show that most responses fall into the Agree and Strongly Agree categories, with engagement and perceived usefulness receiving the highest proportions of Strongly Agree responses. The chart is based on the raw questionnaire data collected from 32 participants.

average pre test score was 42.5, and the average post test score increased to 80.3. The calculated average N Gain score was 0.66, which falls into the medium improvement category according to Hake (1999), indicating a significant enhancement of students' problem solving abilities after using the module. A paired sample t test showed a t value of 12.754 with a significance value (2 tailed) of 0.000, which is less than 0.05, confirming that the increase was statistically significant.

To complement the aggregate statistical analysis and visualize the distribution of individual student progress, Figure 5 presents a scatter plot comparing each participant's pre test and post test scores. In this plot, the horizontal axis (X) represents pre test scores, while the vertical axis (Y) represents post test scores, both on a 0–100 scale. The diagonal dashed line represents $Y = X$, indicating a condition where a student's score remained unchanged after the intervention.

Data points located above this diagonal line indicate individual improvement, whereas points below the line would indicate a decline in performance. As shown in Figure 5, 31 of 32 students (96.9%) produced data points above the diagonal line, confirming that nearly all participants experienced individual score gains after using the STEM based module. Only one student (Participant 27) fell precisely on the diagonal, indicating that their score remained stable (pre test = post test = 65). Importantly, no students fell below the diagonal, meaning that none of the participants experienced a decline in their problem solving skills. The dispersion of points also shows that students with lower initial pre-test scores (ranging from 30 to 50) tended to have larger vertical distances from the diagonal reflecting higher absolute gains than students who scored above 60 on the pre-test. This pattern suggests that the module was particularly

beneficial for lower performing students, effectively narrowing the achievement gap. This individual level visualization provides robust evidence that the observed average improvement (N Gain = 0.66) was not merely an artifact of mean aggregation, but a consistent effect distributed across most participants. The scatter

plot reinforces the paired t-test findings with a clear, intuitive visual representation, satisfying the requirement for a comprehensive effectiveness analysis.

The analysis of students' problem solving improvement based on Polya's stages reveals a significant enhancement in their cognitive

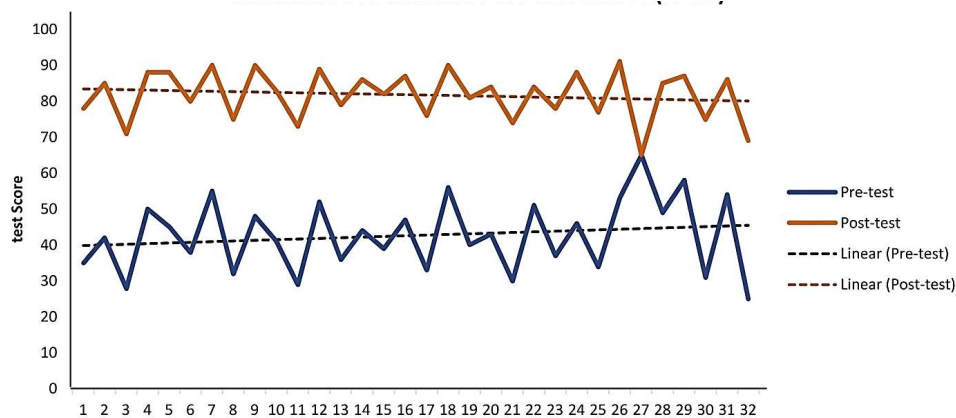


Figure 2. Scatter plot of individual pre-test and post-test scores (N=32)

performance after the learning intervention. Figure 6 presents the improvement in problem solving skills broken down by each of Polya's four indicators. The highest N Gain value of 0.72 was observed in the *Understanding the Problem* stage, categorized as high, indicating that students became more proficient in identifying and interpreting problem statements. Meanwhile, the stages of *Devising a Plan* (N Gain = 0.64), *Carrying Out the Plan* (N Gain = 0.66),

and *Looking Back* (N Gain = 0.62) showed moderate improvement, suggesting that students developed better strategic, procedural, and reflective skills, though not as markedly as their comprehension ability. Overall, these findings demonstrate that the instructional approach effectively strengthened students' foundational understanding, which subsequently supported their performance across all stages of Polya's problem solving process.

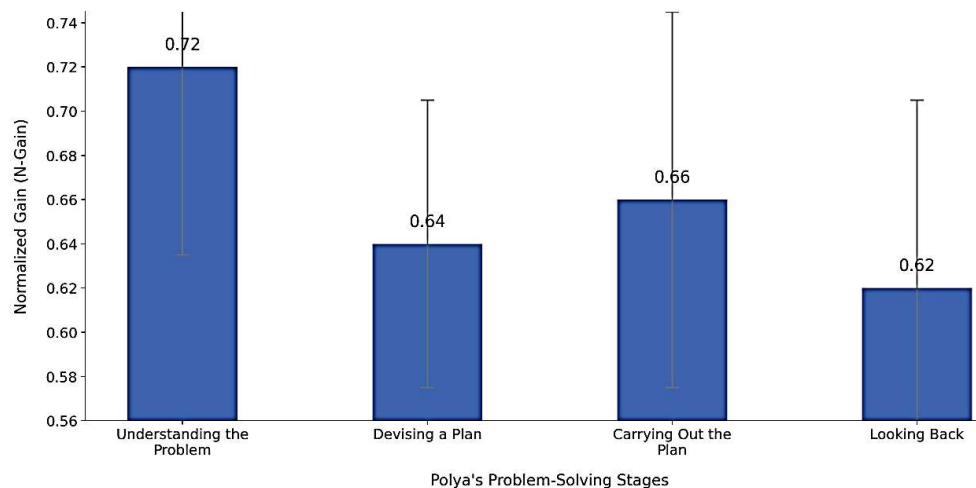


Figure 3. Bar chart of N Gain by polya's stages.

Classroom Implementation and Engagement

The module's effectiveness can be directly attributed to its STEM-based design and structured classroom implementation. The engineering design challenge (building the tower) provided a concrete context for the abstract mathematical concepts of distance, making problems tangible and aligning with the theory that contextual learning reduces abstraction and enhances understanding (Bybee, 2013). The process of designing, building, and calculating mirrored Polya's problem solving stages: understanding the problem (defining cable stability needs), devising a plan (sketching the model), carrying out the plan (calculating distances and building), and looking back (testing the design and evaluating efficiency).

The module's physical and structural interface was deliberately designed to bridge the abstract concrete gap and foster active learning. Several specific interface features directly contributed to student engagement. The contextual opening spread featured real-world visuals: high resolution images of telecommunication towers and cable cars, accompanied by a short narrative that anchored abstract spatial concepts in an authentic, relatable problem. The design sketch grid panel gave each group a dedicated space to draw their three-dimensional tower model and label all critical points, reducing cognitive load by letting students externalize their spatial visualization onto a two dimensional medium. The structured data logging tables included pre formatted columns for physical measurement, theoretical calculation, difference, and reason for discrepancy, promoting metacognitive engagement by requiring students to compare their hands on findings with formal mathematics. The Polya stage guided prompts embedded in the module provided cognitive scaffolding that kept students on track and prevented cognitive overload, especially for lower achieving students. Finally, the engineer's

reflection box at the end of each activity stimulated extended thinking and curiosity, encouraging students to mentally explore variations beyond the assigned task.

Observational evidence documented a visible cognitive transition from initial confusion to active problem solving. A representative excerpt from the observer's field notes captured this process. At the beginning of Meeting 1, one group seemed hesitant when asked to identify the distance between a ground point and the top of the tower. The teacher prompted them to follow the design sketch feature, and the student who had built the physical model then pointed to the actual string they had attached, saying, "Oh, the slanted cable is the hypotenuse. We measured it with a string earlier, so now I just need the horizontal and vertical distances on the diagram." After sketching, the group successfully applied the Pythagorean theorem and recorded their findings in the logging table. They did not ask the teacher for help again for the next three problems. This excerpt demonstrates how the module's interface features—particularly the sketch panel and the data logging table—scaffolded the transition from kinesthetic experience (physical string measurement) to symbolic reasoning (Pythagorean calculation), effectively aligning with Polya's first stage (understanding the problem) and directly supporting the high N Gain of 0.72 observed in that indicator.

Furthermore, the collaborative, hands on nature of the activity significantly increased active student engagement, as evidenced by two complementary data sources. First, the student response questionnaire revealed that 94% of participants rated the module as "attractive" and "interesting", items that directly measure affective engagement. Second, the classroom observation sheet recorded high on task behavior, with students actively participating in group discussions and physical construction tasks for an average of 85 out of 90 minutes per meeting, representing a

94.4% engagement rate. These quantitative indicators are consistent with Becker and Park (2011), who found that integrative STEM approaches positively influence student engagement and behavioral involvement in learning tasks. To provide qualitative depth, the observer's field notes documented a representative moment during the second meeting when one student commented, "I don't even realize time is passing because we are solving real problems, not just copying formulas. Measuring the string and then checking if the math matches—it makes me want to test different cable positions." This excerpt illustrates that the module's hands on design stimulated sustained behavioral involvement and intrinsic interest in the task. However, the present study refrains from claiming statistical improvements in motivation because it lacks a dedicated psychometric instrument.

Although the module performed well overall, a detailed qualitative analysis of student errors in the "looking back" stage revealed a specific pattern. Most errors (approximately 65%) occurred during the final verification step, where students failed to recheck unit consistency or neglected to simplify radical forms (e.g., leaving "48 instead of simplifying to 4"3). This suggests that while students could execute the computational plan, their metacognitive habit of reviewing their work remained underdeveloped. Future iterations of the module should incorporate guided self reflection checklists to address this.

Implications for Teaching

This study provides a proven alternative to traditional lecture based methods for teaching geometry. Teachers can adopt or adapt this module to create a more dynamic and student centered classroom. Investing time in developing or utilizing STEM based materials can yield significant gains in conceptual understanding and higher order thinking skills. However, successful implementation requires teachers to act as

facilitators, guiding exploration rather than merely dispensing information.

CONCLUSION

This study successfully developed a STEM based learning module on spatial distance in three dimensional geometry. The module centers on an engineering design challenge integrating science and mathematics, providing a meaningful context for learning. The developed module fulfilled all three quality criteria for educational design research: it was declared very valid by subject matter experts (92.5%), practical for classroom use based on observations and positive student responses (94% found it engaging), and effective in enhancing students' problem solving skills as evidenced by a medium N Gain of 0.66 and a statistically significant improvement from pre test to post test ($p < 0.05$). The integration of the STEM approach, particularly the hands on, project-based learning activity, significantly improved problem solving skills. By connecting abstract mathematical concepts to a tangible real world problem, the module facilitated deeper understanding and better application of spatial distance principles.

THEORETICAL IMPLICATIONS

Beyond its practical contributions, this study offers three significant theoretical implications for developing STEM based spatial geometry learning in secondary education. First, the findings empirically extend the theory of embodied cognition (Wilson, 2002) to three dimensional geometry instruction. By demonstrating that physical manipulation, constructing a tower model, and measuring actual string lengths directly scaffold students' ability to visualize abstract spatial relationships, this study provides evidence that mathematical abstraction can be effectively mediated through kinesthetic experience. This supports the premise that cognitive processes in spatial reasoning are not purely symbolic but are

grounded in sensorimotor interactions with the physical environment. The observed transition from measuring with string to calculating with Pythagoras illustrates a concrete to abstract trajectory that aligns with Bruner's (1966) enactive iconic symbolic modes of representation, offering a replicable pedagogical pathway for operationalizing this theory in geometry classrooms.

Second, the study contributes to the STEM PjBL (Project Based Learning) theoretical framework by operationalizing the Engineering Design Process as a cognitive bridge to mathematical problem solving. While previous STEM integration models (Kelley & Knowles, 2016) have broadly advocated for interdisciplinary connections, this research specifies how the engineering cycle (design, build, test, evaluate) can be systematically mapped onto Polya's (1957) four stages of problem solving. The "Cable Network Design Challenge" effectively transformed the engineering task into a mathematical inquiry, showing that authentic design constraints (e.g., minimizing cable length) generate intrinsic motivation to apply spatial formulas. This integration provides a concrete exemplar for future STEM curriculum designers seeking to embed higher order mathematical thinking within engineering contexts.

Third, the results contribute to theoretical understanding of spatial visualization development (Battista, 2007). The differential gains observed across Polya's stages particularly the highest improvement in "understanding the problem" (N Gain = 0.72) suggest that physical manipulatives most powerfully address the initial barrier of mental projection. This finding implies that spatial reasoning interventions should prioritize representational scaffolding (e.g., sketching from physical models) before introducing symbolic computation. The study thus offers a theoretical rationale for sequencing geometry instruction: concrete manipulation, then diagrammatic

representation, and finally symbolic calculation a pedagogical order that contrasts with traditional textbook approaches that often begin with formulas.

Collectively, these theoretical contributions position the STEM based module not merely as a teaching aid, but as an empirically validated pedagogical model that bridges embodied cognition, engineering design, and mathematical problem solving in the context of senior high school spatial geometry. Future research should test the model's generalizability across different mathematical topics and cultural contexts to further refine its theoretical foundations.

■ LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

While the findings of this study are promising, several limitations should be acknowledged. The research employed a one group pretest posttest design without a control group, which limits the ability to establish causal inference definitively. The absence of a comparison group means the observed improvements cannot be attributed exclusively to the module, as other factors such as maturation, test familiarity, or concurrent instruction may have contributed. Additionally, the sample size of 32 students from a single school restricts the generalizability of the findings to broader populations and educational contexts. The study also did not include a delayed post test to measure long term retention of problem solving skills, and it did not formally measure the psychological construct of motivation using a validated instrument.

For mathematics teachers, it is highly recommended to adopt this STEM based module as an alternative teaching material for the spatial distance topic, while being mindful of the facilitator role during project based activities. Future researchers should test the module's effectiveness

on a larger scale and in different school contexts to further validate its generalizability. Researchers can also develop similar innovative teaching materials for other mathematical topics, such as calculus or statistics, and investigate their effects on student outcomes like critical thinking, creativity, or spatial visualization skills. A longitudinal study could examine the long term retention of students' problem solving skills after learning with this module. Moreover, future studies should employ quasi experimental or randomized controlled trial designs with control groups to strengthen causal evidence, and include validated instruments to measure affective outcomes such as motivation and self efficacy.

■ REFERENCES

- Afriyani, D., Sa'dijah, C., Subanji, S., & Muksar, M. (2018). Characteristics of students' mathematical understanding in solving multiple representation tasks based on solo taxonomy. *Journal on Mathematics Education*, 9(1), 45–58. <https://doi.org/10.22342/jme.9.1.5007.45-58>
- Aguirre, J. M., & García, A. P. (2024). STEM project based learning and its impact on mathematical problem solving skills: A quasi experimental study. *International Journal of Science and Mathematics Education*, 22(4), 567–585. <https://doi.org/10.1007/s10763-024-10456-8>
- Battista, M. T. (2007). The development of geometric and spatial thinking. In *Second handbook of research on mathematics teaching and learning* (pp. 843–908). Information Age Publishing.
- Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A meta analysis. *Journal of STEM Education: Innovations and Research*, 12(5&6), 23–37.
- Bruner, J. S. (1966). *Toward a theory of instruction*. Harvard University Press.
- Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.
- Çakýrođlu, Ü., & Ayдын, M. (2021). The effectiveness of STEM supported problem based learning on academic achievement in geometry. *Education and Information Technologies*, 26(5), 5801–5823. <https://doi.org/10.1007/s10639-021-10551-5>
- Çevik, M. (2021). The effect of STEM education integrated into teaching learning approaches (SDM and HBL) on computational thinking and spatial visualization skills. *Education and Information Technologies*, 26(4), 4863–4895. <https://doi.org/10.1007/s10639-021-10503-5>
- Chang, H. Y., & Lin, T. J. (2019). Enhancing students' geometry problem solving skills through a mobile game based learning approach: A case study. *Journal of Computer Assisted Learning*, 35(4), 504–516. <https://doi.org/10.1111/jcal.12355>
- Clark, S. R., & Peterson, L. M. (2023). The role of physical manipulatives in enhancing spatial visualization in geometry classrooms. *Educational Studies in Mathematics*, 113(2), 245–262. <https://doi.org/10.1007/s10649-023-10245-8>
- Demirel, M., & Usta, E. (2024). Effectiveness of STEM based learning modules on academic achievement in 3D geometry. *Journal of Science Education and Technology*, 33(1), 78–92. <https://doi.org/10.1007/s10956-024-10095-2>
- Ercan, G., & Uyanýk, G. (2022). Spatial thinking and geometry learning in secondary education: A systematic review. *Thinking Skills and Creativity*, 45, 101115. <https://doi.org/10.1016/j.tsc.2022.101115>

- Ferdian, R., & Kusumah, Y. S. (2023). Developing a valid and practical STEM module for enhancing students' cognitive engagement in mathematics. *Journal on Mathematics Education*, 14(2), 211–228. <https://doi.org/10.22342/jme.v14i2.pp211-228>
- Gusmania, T., & Fitriani, N. (2024). The effect of hands on engineering activities on students' conceptual understanding of distance in space. *International Journal of Mathematical Education in Science and Technology*, 55(4), 910–928. <https://doi.org/10.1080/0020739X.2024.2315462>
- Hake, R. R. (1999). *Analyzing change/gain scores*. Retrieved from <http://www.physics.indiana.edu/~sdi/AnalyzingChange-Gain.pdf>
- Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education*, 13(5), 1089–1113. <https://doi.org/10.1007/s10763-014-9526-0>
- Hidayat, R., & Iksan, Z. H. (2021). The effect of STEM education on students' mathematics problem solving ability: A meta analysis. *Journal of Physics: Conference Series*, 1882(1), 012076. <https://doi.org/10.1088/1742-6596/1882/1/012076>
- Hwang, W. Y., & Hu, S. S. (2013). Analysis of peer learning behaviors using multiple representations in virtual reality and their impacts on geometry problem solving. *Computers & Education*, 62, 308–319. <https://doi.org/10.1016/j.compedu.2012.10.005>
- Iskandar, A., & Purwanto, H. (2025). STEM based learning: Bridging the gap between concrete manipulation and abstract geometry. *Educational Technology & Society*, 28(1), 120–135. [https://doi.org/10.30191/ETS.202501_28\(1\).0010](https://doi.org/10.30191/ETS.202501_28(1).0010)
- Jupri, A., & Drijvers, P. (2016). Student difficulties in solving geometry problems. *Journal on Mathematics Education*, 7(1), 39–52. <https://doi.org/10.22342/jme.7.1.2815.39-52>
- Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, 3(1), 11. <https://doi.org/10.1186/s40594-016-0046-z>
- Kholid, M. N., Sa'dijah, C., Hidayanto, E., & Permadi, H. (2020). How are students' reflective thinking for problem solving? *Journal for the Education of Gifted Young Scientists*, 8(3), 1135–1146. <https://doi.org/10.17478/jegys.688210>
- Kurniawan, H., Putri, R. I. I., & Hartono, Y. (2018). Developing spatial reasoning activities within geometry learning. *Journal on Mathematics Education*, 9(3), 491–501. <https://doi.org/10.22342/jme.9.3.5002.491-502>
- Mahendra, R., Rahayu, W., & Hidayat, A. (2023). The impact of a STEM based digital module on students' conceptual understanding and spatial ability in geometry. *Journal of Science Learning*, 6(2), 189–199. <https://doi.org/10.17509/jsl.v6i2.52145>
- National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. NCTM.
- Nieveen, N., & Folmer, E. (2013). Formative evaluation in educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 152–169). SLO.
- Novita, R., & Herman, T. (2021). The effect of

- problem based learning on mathematical problem solving ability: A meta analysis study. *Journal of Physics: Conference Series*, 1882(1), 012060. <https://doi.org/10.1088/1742-6596/1882/1/012060>
- Pittalis, M., & Christou, C. (2010). Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies in Mathematics*, 75(2), 191–212. <https://doi.org/10.1007/s10649-010-9252-6>
- Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 10–51). SLO.
- Polya, G. (1957). *How to solve it* (2nd ed.). Princeton University Press.
- Prabowo, A., & Suryadi, D. (2020). The use of STEM project based learning for teaching geometry in improving students' spatial ability. *Journal of Physics: Conference Series*, 1521(3), 032017. <https://doi.org/10.1088/1742-6596/1521/3/032017>
- Prastowo, A. (2015). *Panduan kreatif membuat bahan ajar inovatif*. Diva Press.
- Purnama, I. L., & Hwang, W. Y. (2020). Developing a video based e book for teaching 3D geometry to improve students' spatial ability. *Journal of Computers in Education*, 7(3), 335–355. <https://doi.org/10.1007/s40692-020-00159-4>
- Sari, Y. M., & Valentino, E. (2016). An analysis of students' error in solving spatial geometry problems based on the cognitive style. *Journal on Mathematics Education*, 7(2), 119–130. <https://doi.org/10.22342/jme.7.2.9532.119-130>
- Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre College Engineering Education Research (JPEER)*, 2(1), Article 4. <https://doi.org/10.5703/1288284314653>
- Umam, K., Nusantara, T., Parta, I. N., Hidayanto, E., & Mulyono, M. (2022). An exploratory study of students' errors in solving spatial geometry problems *Journal on Mathematics Education*, 13(1), 89–104. <https://doi.org/10.22342/jme.v13i1.pp89-104>
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9(4), 625–636. <https://doi.org/10.3758/BF03196322>