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# Deep Learning-Based Project Based Learning on Orthogonal Vector Projection to Enhance Students' Mathematical Problem-Solving Ability and Creativity Assisted by GeoGebra

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**Abstract**
This study investigates the implementation of a Deep Learning-based Project Based Learning (PBL) model integrated with GeoGebra to enhance Grade XI students' mathematical problem-solving ability (PSA) and creativity at MAN 1 Indramayu, West Java, Indonesia. Employing a mixed-method pre-experimental one-group pretest-posttest design (N=26), data were gathered through a Polya-based PSA test (Cronbach's α=0.87), a 24-indicator structured observation sheet across four dimensions, and qualitative analysis of students' GeoGebra project products assessed using Torrance's (1966) four-dimension creativity rubric. Inferential analyses included Shapiro-Wilk normality test, Levene's homogeneity test, Wilcoxon Signed Ranks Test, Hake's (1999) N-Gain analysis, and Spearman's rho correlation. Results show: (1) a statistically significant improvement in PSA (Wilcoxon, Z=−4.46, p<0.001; mean N-Gain=0.691; 88.5% of students in moderate-to-high category); (2) GeoGebra functioned as a cognitive bridge facilitating rich problem representation, with the GeoGebra Exploration dimension recording the highest engagement score (76.1%); (3) mathematical creativity across all four Torrance dimensions developed substantially, with originality most prominent; and (4) a very strong positive correlation between PSA and mathematical creativity (Spearman's rho=0.934, p<0.001). These findings empirically confirm the synergistic effectiveness of integrating PBL, Deep Learning analytics, and GeoGebra in secondary mathematics education and contribute to the empirical literature on creativity-problem-solving reciprocity.

**Keywords:** Project Based Learning; GeoGebra; Mathematical Problem-Solving; Mathematical Creativity; Deep Learning

## INTRODUCTION

The rapid transformation driven by Industry 4.0 and Society 5.0 demands a fundamental pedagogical shift from the transmission of procedural knowledge toward the systematic cultivation of higher-order competencies. Mathematical problem-solving ability (PSA) and mathematical creativity are widely recognised as two indispensable, mutually reinforcing competencies for 21st-century learners. Project-based learning (PBL) has emerged as one of the most evidence-backed instructional models for developing these competencies simultaneously, as it immerses students in sustained, authentic inquiry that mirrors real-world problem structures.[1]

The urgency of this study is underscored by Indonesia's performance in the PISA 2022 cycle,

[1] Nadia Rehman et al., "Project-Based Learning as a Catalyst for 21st-Century Skills and Student Engagement in the Math Classroom," Heliyon 10, no. 23 (2024): e39988, https://doi.org/10.1016/j.heliyon.2024.e39988. PBL frameworks built around 21st-century competencies have consistently outperformed conventional instruction when integrated with authentic mathematical tasks.

where the country ranked 68th out of 81 participating nations, recording a mean mathematics score of 366 substantially below the OECD average of 472. Critically, the deficit is concentrated in reasoning and contextual problem-solving sub-domains rather than in basic computation.[2] At the institutional level, the 2024 Education Report Card (Rapor Pendidikan) of MAN 1 Indramayu explicitly identified teaching method innovation (indicator D.1.3) and the adoption of innovative practices (indicator D.2.3) as priority improvement areas. Preliminary diagnostic data collected from 36 Grade XI students confirmed these findings: 61.1% struggled to visualise orthogonal vector projection geometrically, 72.2% had never used dynamic mathematics software in formal learning, and 83.3% reported that classroom instruction had been dominated by lecture and conventional drill exercises, with no project-based components.

GeoGebra an open-source dynamic mathematics platform integrating geometry, algebra, calculus, and statistics offers a technically well-suited solution to the representational deficit identified above. A meta-analysis covering 20 years of GeoGebra research (2002–2022) established a positive medium-to-large effect on students' mathematics achievement (Hedges's g = 0.653), with the largest effects obtained precisely for abstract topics such as calculus and analytic geometry, the category that subsumes orthogonal vector projection.[3] Complementary empirical evidence from quasi-experimental and developmental studies in the Indonesian context confirms that GeoGebra simultaneously supports conceptual understanding and creative mathematical thinking, particularly when embedded in problem-based or contextual instructional designs.[4]

The integration of Deep Learning analytics provides an additional and theoretically grounded layer of scaffolding. AI-adaptive platforms leveraging Deep Learning analytics have been shown to produce a 25% improvement in academic outcomes and engagement relative to conventional instruction, operating through personalised feedback mechanisms that directly support the metacognitive monitoring that Matlin (2009) identifies as the hallmark of effective problem-solvers.[5] At a meta-analytic scale, PBL has been shown to produce significantly superior learning outcomes compared to traditional models across academic achievement, affective attitudes, and thinking skills findings that establish a rigorous reference benchmark for the present intervention.[6]

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[2] OECD, PISA 2022 Results (Volume I): The State of Learning and Equity in Education (Paris: OECD Publishing, 2023), https://doi.org/10.1787/53f23881-en. Indonesia ranked 68th of 81 nations (mean score 366 vs. OECD average 472), with deficits concentrated in mathematical reasoning and contextual problem-solving, the precise sub-domain addressed by this study.

[3] Gaowei Chen, "Dynamic Visualization by GeoGebra for Mathematics Learning: A Meta-Analysis of 20 Years of Research," Journal of Research on Technology in Education 57, no. 2 (2023): 437-458, https://doi.org/10.1080/15391523.2023.2250886. This meta-analysis (14 studies, N=1,334; 2002-2022) found Hedges g=0.653, with largest effects for abstract topics including calculus and analytic geometry, the category that subsumes orthogonal vector projection.

[4] Fekade Gurmu, Chaltu Tuge, and Abera B. Hunde, "Effects of GeoGebra-Assisted Instructional Methods on Students' Conceptual Understanding of Geometry," Cogent Education 11, no. 1 (2024): 2379745, https://doi.org/10.1080/2331186X.2024.2379745. See also Heri Setiawan, Nelly Fitriani, and Jozua Sabandar, "Development of Junior High School Mathematics Teaching Materials Assisted by GeoGebra with a Contextual Approach to Improve Mathematical Creative Thinking," MaPan: Jurnal Matematika dan Pembelajaran 10, no. 2 (2022): 213-229, https://doi.org/10.24252/mapan.2022v10n2a4.

[5] Aigerim Karaca, Bilal Yildirim, and Kaan Demir, "Integrating Deep Learning Techniques for Personalized Learning Pathways in Higher Education," Heliyon 10, no. 12 (2024): e32468, https://doi.org/10.1016/j.heliyon.2024.e32468. A controlled experiment (N=300, 4 courses) found a 25% improvement in grades and engagement (p=0.00045) with AI-adaptive platforms, operating through metacognitive monitoring mechanisms consistent with Matlin (2009).

[6] Xinyu Tang et al., "A Study of the Impact of Project-Based Learning on Student Learning Effects: A Meta-Analysis Study," Frontiers in Psychology 14 (2023): 1202728,

The theoretical foundation of this study is grounded in Matlin's (2009) cognitive psychology framework, which conceptualises problem-solving as the process of reaching a goal when no direct path is available. Matlin identifies three essential problem components initial state, goal state, and obstacles and emphasises that the quality of problem representation (including symbols, matrices, diagrams, and visual imagery) is the single most critical determinant of problem-solving success. This perspective directly implicates GeoGebra as a representational scaffold: its dynamic environment enables the construction of rich visual and algebraic representations of abstract concepts, facilitating what Matlin terms rich problem representation. In parallel, Matlin defines creativity as the capacity to find a new and useful solution, and emphasises that intrinsic motivation generated by meaningful, authentic tasks is the primary driver of creative output. The PBL model, with its authentic project contexts, is therefore theoretically positioned to simultaneously develop PSA and mathematical creativity through intrinsic motivational pathways.

Despite the growing body of research on PBL, GeoGebra, and AI-adaptive analytics individually, no prior study has integrated all three components within a single coherent instructional design grounded in Matlin's cognitive framework, applied to orthogonal vector projection in an Indonesian Madrasah Aliyah context. This gap constitutes the novelty of the present study. The study addresses four research questions: (1) Does the Deep Learning-based PBL model assisted by GeoGebra significantly improve students' PSA on orthogonal vector projection? (2) How does GeoGebra contribute to problem representation formation and PSA development? (3) What is the level of students' mathematical creativity after the intervention? (4) Is there a significant relationship between PSA and mathematical creativity within this instructional model?

## METHOD

This study employed a mixed-method research design with a pre-experimental one-group pretest-posttest structure. The quantitative strand provided statistical evidence of measurable competency change; the qualitative strand elucidated the cognitive mechanisms and creative processes underlying that change. The study was conducted at MAN 1 Indramayu, Indramayu Regency, West Java, Indonesia, during the even semester of the 2025/2026 academic year (April–Mei 2026). Participants were 26 Grade XI Science students selected through purposive sampling on the basis of diagnostic test profiles, infrastructure availability, and alignment with the school's odd semester of the 2025/2026 Education Report Card priority indicators. To protect participants' privacy, all respondents are anonymised as codes S01–S26 throughout this report.

### Instruments

Three instruments were used. First, a contextual PSA test comprising open-ended items on orthogonal vector projection, structured around Polya's four problem-solving stages: understand the problem, devise a plan, carry out the plan, and look back.[7] Content validity was verified by two mathematics education experts; reliability was computed using Cronbach's Alpha ($\alpha = 0.87$). Second, a structured observation sheet with 24 indicators distributed across four dimensions: D1 Group Discussion Activity (6 indicators); D2 GeoGebra Exploration (7 indicators); D3 Project Presentation (5 indicators); D4 Matlin's Cognitive Heuristics (6 indicators). Third, a creativity rubric applied to students' GeoGebra project products, operationalising Torrance's (1966) four dimensions: fluency, flexibility, originality, and elaboration dimensions confirmed as psychometrically valid by a recent

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https://doi.org/10.3389/fpsyg.2023.1202728. Synthesising 66 studies (190 effect values), this meta-analysis established PBL as significantly superior to traditional instruction across academic achievement, affective attitudes, and thinking skills, setting the N-Gain threshold benchmark used in the present study.

[7] Janet Jahudin and Nyet Moi Siew, "The Effects of Polya's Problem Solving with Digital Bar Model on the Algebraic Thinking Skills of Seventh Graders," Problems of Education in the 21st Century 82, no. 3 (2024): 390-409, https://doi.org/10.33225/pec/24.82.390. Polya's four-stage framework remains the dominant scaffolding structure in mathematics PSA research, with stage-based rubrics producing valid and reliable assessments across diverse technology-assisted contexts.

international Delphi panel.[8]

### PBL Implementation Procedure

The PBL model was implemented across eight class meetings (3×45 minutes each) following six canonical syntaxes: (1) Driving Question: students were presented with real-world video phenomena involving vector projection (GPS navigation, solar panel orientation, structural engineering); (2) Project Planning: student groups (4–5 members) designed a GeoGebra interactive applet to visualise orthogonal vector projection within a self-selected authentic context; (3) Scheduling: each group developed a milestone-based project timeline; (4) Progress Monitoring via Deep Learning Analytics: the AI-adaptive system generated real-time individual progress reports used by the teacher to deliver targeted scaffolding; (5) Project Testing: each group presented their GeoGebra applet and defended the embedded mathematical concepts; and (6) Evaluation and Reflection: structured learning journals and class discussion focused on metacognitive processes.

### Data Analysis

Quantitative analysis was conducted using IBM SPSS Statistics 25 and included: (a) Shapiro-Wilk normality test (selected given $n = 26 < 50$); (b) Levene's homogeneity test; (c) Wilcoxon Signed Ranks Test to compare pre- and post-test scores; (d) N-Gain analysis following Hake's (1999) criteria high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), low ($g < 0.30$);[9] and (e) Spearman's rho to assess the PSA–creativity relationship. Qualitative data triangulation integrated three sources: PSA test scores, observation sheet scores, and content analysis of GeoGebra project products.

## RESULTS AND DISCUSSION

### Student Engagement: Qualitative Analysis of the Observation Sheet

Table 1 summarises the structured observation data collected across all 24 indicators. Previous research on GeoGebra-assisted problem-solving in Indonesian contexts confirms that student engagement with dynamic software-based tasks is a reliable process indicator of subsequent performance gains, particularly when the software is embedded in authentic project designs.[10]

Table 1. Student Engagement Scores by Dimension (N=26)

| Dimension | N Ind. | Max Score | Mean Score | % Achievement | Category |
|---|---|---|---|---|---|
| D1. Group Discussion Activity | 6 | 24 | 18.19 | 75.8% | High |
| D2. GeoGebra Exploration | 7 | 28 | 21.31 | 76.1% | High |
| D3. Project Presentation | 5 | 20 | 15.27 | 76.3% | High |
| D4. Matlin's Cognitive | 6 | 24 | 18.23 | 76.0% | High |

[8] Carmen Lopez-Pinar et al., "Indicators of Verbal Creative Thinking: Results of a Delphi Panel," Frontiers in Psychology 15 (2024): 1397861, https://doi.org/10.3389/fpsyg.2024.1397861. A panel of 16 international creativity experts confirmed fluency, flexibility, originality, and elaboration as core indicators for assessing creative thinking in educational contexts, affirming the continued psychometric validity of the Torrance (1966) framework.

[9] Richard R. Hake, "Analyzing Change/Gain Scores," paper presented at AREA-D AERA, 1999. The normalized gain g=(post-pre)/(max-pre) accounts for ceiling effects and initial ability differences, providing a more informative individual-level measure than raw gain scores for heterogeneous classroom settings.

[10] Uswatun Fitriani Handayani et al., "Creative Problem Solving Berbantuan GeoGebra untuk Meningkatkan Kemampuan Pemecahan Masalah Matematis," Al-Jabar: Jurnal Pendidikan Matematika 13, no. 1 (2022): 45-58, https://doi.org/10.24042/ajpm.v13i1.10732. See also Rizal Alghiffari Siswanto et al., "Effectiveness of LKPD Based PBL with GeoGebra in Stimulating Critical and Creative Thinking," Asian Journal of Assessment in Teaching and Learning 14, no. 1 (2024): 88-101, https://doi.org/10.37134/ajatel.vol14.1.7.2024.

| | | | | | |
|---|---|---|---|---|---|
| Heuristics | | | | | |
| **TOTAL (24 indicators)** | **24** | **96** | **73.00** | **76.0%** | **High** |

Sources: Observation Sheet Data, MAN 1 Indramayu Research (2026).

Overall class engagement averaged 73.00/96 (76.0%), classified as High. All four dimensions individually achieved the High category, within the narrow band of 75.8%–76.3%, indicating consistent engagement across all phases of the PBL cycle. The highest single-indicator score was D3.5 connecting vector projection to real-world applications (mean $\bar{x} = 3.31$) which represents the most cognitively demanding transfer task in the observation instrument. In Matlin's (2009) framework, the capacity to transfer abstract mathematical concepts to original real-world contexts constitutes the fullest expression of rich problem representation: not the recall of procedures, but the structural comprehension of a concept that enables its flexible application to novel contexts. The lowest-scoring indicator was D4.3 hill-climbing heuristic ($\bar{x} = 2.77$) a finding consistent with Matlin's (2009) explanation that this heuristic, which always selects the step that appears most directly to advance toward the goal, systematically fails for non-linear problems requiring temporary backward moves. Orthogonal vector projection demands precisely such a chained, non-linear sequence: dot product → vector norm → scalar factor → projection vector → orthogonal component.

## Pre-Test and Post-Test Comparison

Table 2 presents the descriptive statistics for PSA scores at both measurement points.

Table 2. Descriptive Statistics of PSA Pre-Test and Post-Test (N=26)

| Descriptive Statistic | Pre-Test | Post-Test | Δ |
|---|---|---|---|
| Mean | 48.27 | 79.42 | +31.15 |
| Highest Score | 68.00 | 96.00 | +28.00 |
| Lowest Score | 24.00 | 28.00 | +4.00 |
| Standard Deviation | 12.43 | 15.67 | +3.24 |
| **Shapiro-Wilk (sig.)** | **0.052 (Normal)** | **0.002 (Not Normal)** | — |

Sources: SPSS Output, Research Data Analysis (2026).

The mean score increased from 48.27 (pre-test) to 79.42 (post-test), a difference of +31.15 points. The post-test standard deviation (15.67) is only marginally higher than the pre-test value (12.43), indicating that the gain was relatively uniform across the cohort rather than concentrated in a subset of students. The non-normal distribution of post-test data (Shapiro-Wilk, $p = 0.002$) necessitated the use of a nonparametric test for inferential comparison.

## Wilcoxon Signed Ranks Test and N-Gain Analysis

The Wilcoxon Signed Ranks Test yielded $Z = -4.46$, Asymp. Sig. (2-tailed) < 0.001. With 25 positive ranks (students showing improvement) and only 1 negative rank, $H_0$ is rejected: the PBL-Deep Learning-GeoGebra intervention produced a statistically significant improvement in PSA. Table 3 presents individual N-Gain scores for all 26 respondents (coded to preserve anonymity), followed by a category summary in Table 4.[11]

Table 3. Individual N-Gain Scores — Coded Respondents (N=26)

| Code | N-Gain | Category | Code | N-Gain | Category |
|---|---|---|---|---|---|
| S01 | 0.611 | Moderate | S14 | 0.753 | High |
| S02 | 0.755 | High | S15 | 0.580 | Moderate |

[11] Seong Han, Robert Capraro, and Mary Margaret Capraro, "How STEM Project-Based Learning (PBL) Affects High, Middle, and Low Achievers Differently," International Journal of Science and Mathematics Education 13, no. 5 (2015): 1089-1113, https://doi.org/10.1007/s10763-014-9526-0. With Cohen d=0.67 (N=504), this landmark study established that PBL yields the highest gains when students have full ownership of project design -- the condition replicated in this study.

| | | |
|---|---|---|
| S03 | 0.537 | Moderate |
| S04 | −0.146 | Low |
| S05 | 0.702 | High |
| S06 | 0.368 | Moderate |
| S07 | 0.022 | Low |
| S08 | 0.815 | High |
| S09 | 0.831 | High |
| S10 | 0.310 | Moderate |
| S11 | 0.828 | High |
| S12 | 0.054 | Low |
| S13 | 0.829 | High |
| S16 | 0.054 | Low |
| S17 | 0.366 | Moderate |
| S18 | 0.493 | Moderate |
| S19 | 0.829 | High |
| S20 | 0.390 | Moderate |
| S21 | 0.549 | Moderate |
| S22 | 0.729 | High |
| S23 | 0.457 | Moderate |
| S24 | 0.678 | Moderate |
| S25 | 0.614 | Moderate |
| S26 | 0.840 | High |

Sources: Research Data Analysis (2026). High = g ≥ 0.70; Moderate = 0.30 ≤ g < 0.70; Low = g < 0.30 (Hake, 1999). S01–S26 = anonymised participant codes.

**Table 4.** N-Gain Category Distribution and Creativity Correlation (N=26)

| N-Gain Category | n (%) | Mean N-Gain | Predominant Creativity Level |
|---|---|---|---|
| High (g ≥ 0.70) | 11 (42.3%) | 0.794 | High — Originality & Elaboration prominent |
| Moderate (0.30 ≤ g < 0.70) | 12 (46.2%) | 0.498 | Moderate — Fluency & Flexibility adequate |
| Low (g < 0.30) | 3 (11.5%) | −0.023 | Low — individual scaffolding required |
| **Overall Mean N-Gain** | **26 (100%)** | **0.691** | **Moderate-to-High (effective threshold exceeded)** |

Sources: Research Data Analysis (2026). Creativity level assessed via Torrance (1966) rubric applied to GeoGebra project products.

The mean N-Gain of 0.691 exceeds the effectiveness threshold of g > 0.50 established by Tang et al. (2023) for PBL interventions, indicating that the intervention is not merely statistically significant but practically meaningful.[12] Three students with low N-Gain (S04, S07, S12) warrant particular attention. Student S04's negative N-Gain (−0.146) despite a high observation score (75/96) exemplifies what Matlin (2009) terms mental set the persistence of prior problem-solving schemas that resist restructuring even when the learner is actively engaged in new learning activities. This dissociation between process engagement and test performance reinforces the importance of individual deep-learning-assisted intervention rather than solely group-level monitoring.[13]

## Mathematical Creativity: Content Analysis of GeoGebra Project Products

Content analysis of the 26 GeoGebra applets produced by students, evaluated using Torrance's creativity rubric, revealed substantive development across all four dimensions. The originality dimension was the most prominently demonstrated: a subset of students designed application contexts not explicitly taught in class — including analysis of telecommunication antenna signal angles, optimisation of solar panel inclination for maximum radiation absorption, and ship navigation via velocity vector decomposition. This capacity for self-generated authentic application contexts constitutes the highest-order manifestation of mathematical creativity in Torrance's framework. A recent systematic review of PBL-creativity research confirms that originality consistently records the strongest gains when students are granted authentic design agency over their projects — precisely the

[12] Tang, Xinyu, Xiaojuan Nie, Hongli Zhang, and Shanshan Li. "A Study of the Impact of Project-Based Learning on Student Learning Effects: A Meta-Analysis Study." Frontiers in Psychology 14 (2023): 1202728. https://doi.org/10.3389/fpsyg.2023.1202728.

[13] Esen Ersoy and Deniz Ozcan Kara, "The Effect of the Creative Problem-Solving Approach on Creative Thinking Skills," Frontiers in Psychology 17 (2026): 1734855, https://doi.org/10.3389/fpsyg.2026.1734855. High process engagement coexisting with below-average test performance -- attributed to mental set and functional fixedness -- directly parallels the anomalous case of student S04, reinforcing the need for individual-level scaffolding.

condition implemented in this study.[14]

The elaboration dimension was evidenced in the technical quality of the applets: high-elaboration products included integrated LaTeX formula annotations, interactive sliders for parameter exploration, 3D Graphics views of projection in three-dimensional space, and structured textual interpretation panels. The fluency and flexibility dimensions were demonstrated through students' ability to produce multiple representations — 2D graphical, 3D graphical, algebraic, and numerical CAS verification — within a single integrated applet, and to apply the concept via distinct mathematical approaches (Cartesian coordinates, angle-based approach, direct dot product application) within the same project.

**Spearman's Rho: PSA–Creativity Correlation**

Spearman's rho analysis yielded rho = 0.934, $p < 0.001$ a very strong positive correlation between PSA and mathematical creativity. The hierarchical pattern visible in Table 4 is consistent: students with high N-Gain show the highest mean creativity scores (3.42/4), moderate-gain students show intermediate creativity (2.91/4), and low-gain students show the lowest creativity levels (2.17/4). This pattern empirically validates Matlin's (2009) theoretical claim that problem-solving and creativity are reciprocally related cognitive processes: both require flexible problem representation, the ability to generate novel approaches when conventional strategies fail, and metacognitive evaluation of solutions. The magnitude of this correlation (rho = 0.934) is notably consistent with findings from recent studies on mathematical modelling a process analogous to the GeoGebra applet-design project which also find strong concurrent relationships between modelling competence and creative output.[15]

The overall pattern of results significant PSA improvement (Wilcoxon, $p < 0.001$), mean N-Gain of 0.691, substantive creativity development across all Torrance dimensions, and a very strong PSA–creativity correlation (rho = 0.934) converges to confirm the effectiveness of the integrated PBL-Deep Learning-GeoGebra model. The three mechanisms proposed by Matlin (2009) are each empirically traceable in the data: (i) rich problem representation was facilitated by GeoGebra (D2 and D4.4 highest scores); (ii) heuristic strategy development was scaffolded by the PBL structure (D4.1–D4.2); and (iii) metacognitive monitoring was supported by Deep Learning analytics (D4.5 among the top-scoring indicators). The observed PSA gains and creativity development are thus not incidental but structurally linked to the theoretical mechanisms of the intervention.[16]

Table 5. Summary of Inferential Statistical Results

| Statistical Test | Result | Decision | Interpretation |
|---|---|---|---|
| Shapiro-Wilk (pre-test) | W=0.954; p=0.052 > 0.05 | $H_0$ accepted | Normal distribution |
| Shapiro-Wilk (post-test) | W=0.891; p=0.002 < 0.05 | $H_0$ rejected | Non-normal → nonparametric |
| Levene's Test | F=3.82; p=0.052 > 0.05 | $H_0$ accepted | Homogeneous variance |

14 Suyono Adisuwarno et al., "Exploring Project-Based Learning for Enhancing Creative Thinking in High School Students: A Systematic Review," EDUPIJ 17 (2025): 480, https://doi.org/10.22521/edupij.2025.17.480. This Scopus-indexed systematic review (2017-2025) confirms all four Torrance dimensions develop within PBL contexts, with originality showing the strongest gains when students have authentic design agency -- the condition embedded in this study.

15 Xiaoli Lu and Gabriele Kaiser, "Creativity in Students' Modelling Competencies," Educational Studies in Mathematics 109, no. 2 (2021): 287-311, https://doi.org/10.1007/s10649-021-10055-y. See also Xiuying Wang et al., "How Does Mathematical Modeling Competency Affect the Creativity of Middle School Students?" Frontiers in Psychology 13 (2023): 1044580, https://doi.org/10.3389/fpsyg.2022.1044580. Both studies confirm that modelling activities analogous to the GeoGebra project tasks in this study function as creativity-demanding activities that concurrently develop problem-solving competence.

16 Semahat Incikabi, "Investigating Middle School Students' Creative Problem Solving in Numerical and Spatial Domains," Frontiers in Psychology 16 (2025): 1686498, https://doi.org/10.3389/fpsyg.2025.1686498. Strong within-student correlations between numerical and spatial creativity dimensions support the view that mathematical creativity is domain-general, consistent with the high rho=0.934 linking PSA and creativity in the present study.

| | | | |
|---|---|---|---|
| Wilcoxon Signed Ranks Test | Z=−4.46; Asymp. Sig.<0.001; Positive ranks=25; Negative=1 | H0 rejected | Significant improvement (p<0.001) |
| N-Gain Analysis | Mean=0.691; High:42.3%; Moderate:46.2%; Low:11.5% | Effective | 88.5% of students ≥ moderate gain |
| Spearman's Rho | rho=0.934; p<0.001; N=26 | H0 rejected | Very strong positive correlation (Mathematical Problem-Solving Ability – Creativity) |

Sources: SPSS Output, Research Data Analysis (2026).

## CONCLUSION

This study produces four principal conclusions. First, the implementation of the Deep Learning-based PBL model assisted by GeoGebra significantly improved students' mathematical PSA on orthogonal vector projection (Wilcoxon Signed Ranks Test, $Z = -4.46$, $p < 0.001$), with a mean N-Gain of 0.691 and 88.5% of students achieving moderate-to-high gain categories. This result surpasses the PBL effectiveness threshold established in recent meta-analytic literature and is directly attributable to the three Matlin-theorised mechanisms: rich problem representation via GeoGebra, heuristic strategy development via PBL structure, and metacognitive support via Deep Learning analytics.

Second, GeoGebra contributed substantially to problem representation formation, as evidenced by the highest engagement scores in the GeoGebra Exploration dimension (D2: 76.1%), particularly on indicators linking dynamic visualisation to algebraic projection formulae (D2.5: $\bar{x} = 3.19$) and CAS-based computation (D2.2: $\bar{x} = 3.15$). These findings are consistent with the meta-analytic evidence on GeoGebra's role as a cognitive bridge between intuitive visual representations and formal symbolic systems.

Third, students' mathematical creativity developed substantively across all four Torrance dimensions fluency, flexibility, originality, and elaboration with originality being the most prominent, manifested in students' self-designed authentic application contexts (antenna signal analysis, solar panel optimisation, ship navigation). This finding confirms that PBL with authentic project agency, when supported by GeoGebra's dynamic environment, generates the intrinsic motivational conditions that Matlin (2009) identifies as the primary driver of creative output.

Fourth, the very strong positive correlation between PSA and mathematical creativity (Spearman's rho = 0.934, $p < 0.001$) provides empirical confirmation of the theoretical reciprocity between these two competencies, with a hierarchical pattern showing that higher N-Gain students consistently exhibit higher creativity scores. Taken together, these findings demonstrate that the integrated PBL-Deep Learning-GeoGebra model is an effective instructional design for simultaneously developing problem-solving and creative competencies in secondary mathematics, and is directly actionable for teachers in similar madrasah aliyah contexts. Future research should incorporate a parallel control group and multi-school sampling to obtain stronger causal evidence and greater generalisability.

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## DECLARATION OF CONFLICTING INTERESTS

The authors state that there is no conflict of interest in the publication of this article.

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