



## Exploring cultural technological mathematics learning in vocational schools for creative thinking

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### Article Info

#### Article history:

Received: Jan 10, 2026

Revised: Feb 24, 2026

Accepted: March 20, 2026

#### Keywords:

Creative Thinking; Design Thinking; Ethnomathematics; Technology-Integrated Learning; Vocational Mathematics Education.

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### Abstract

**Background:** Mathematics education in vocational schools faces challenges in fostering students' creative thinking, particularly in understanding abstract concepts and generating alternative solutions. Classroom practices often emphasize procedural replication, while teachers encounter difficulties in addressing diverse learning needs, highlighting the need for innovative, contextual, and culturally responsive approaches.

**Aims:** This study aims to strengthen vocational students' creative thinking in mathematics by designing an integrated instructional model that combines pedagogy, technology, and cultural elements.

**Methods:** A qualitative design thinking approach was applied through the stages of Empathize, Define, Ideate, Prototype, and Test/Evaluate. Data were collected using questionnaires, interviews, and classroom observations to identify student and teacher needs. The proposed model was further examined through a meta-analysis using effect size calculations to synthesize findings from relevant empirical studies.

**Results:** The findings indicate that students need more flexible, innovative, and culturally meaningful learning experiences. An instructional prototype, Gema-Batik, was developed by integrating Project-Based Learning, ethnomathematics, GeoGebra, and jBatik within a design thinking framework. The model emphasizes problem orientation, exploration, digital modeling, motif creation, and presentation, targeting creative thinking indicators such as fluency, flexibility, originality, and elaboration. Meta-analytic results show a high pooled effect size, indicating strong potential to enhance creative thinking and related competencies.

**Conclusion:** The Gema-Batik model offers a novel, culturally grounded, and technology-integrated approach that contributes both theoretically and practically to vocational mathematics education, particularly in fostering creative thinking aligned with the demands of creative industries.

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**To cite this article:** Wijayanti, W. F., Dwijayanti, I., & Harun, L. (2026). Exploring cultural technological mathematics learning in vocational schools for creative thinking. *Journal of Advanced Sciences and Mathematics Education*, 6(1), 315-328.

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## INTRODUCTION

Creativity is a fundamental competency in vocational mathematics education, as it underpins students' ability to innovate, solve complex problems, and adapt to the evolving demands of the 21st-century workforce. In vocational contexts, where learning is closely connected to practical applications and industry needs, creativity enables students to transform mathematical knowledge into functional and contextually relevant solutions. This competency is not only pedagogically important but also institutionally emphasized through national education policies (Shermukhammadov, 2022). The "Peraturan Menteri Pendidikan Dasar dan Menengah Republik Indonesia Nomor 10 Tahun 2025" highlights that graduates are expected to demonstrate higher-order thinking skills, including creative thinking, as part of their core competencies. Creative thinking in mathematics involves generating original ideas, applying flexible strategies, and constructing meaningful solutions to real-world problems (Weng et al., 2022). These abilities are essential for

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supporting innovation in vocational fields, particularly those related to creative industries (Chang et al., 2022; Foster & Yaoyuneyong, 2016; Weng et al., 2022). Therefore, strengthening creative thinking in vocational mathematics education becomes a strategic priority for aligning educational outcomes with workforce demands

In line with this priority, international assessments further emphasize the urgency of developing creative thinking skills in mathematics education. The PISA 2022 report (OECD, 2023) defines creative thinking as the ability to generate, evaluate, and refine ideas that are both original and effective, highlighting its central role in problem solving and lifelong learning. However, empirical data indicate that Indonesian students' performance in this domain remains relatively low compared to international benchmarks (OECD, 2023). Only a small proportion of students are able to reach higher proficiency levels, while the majority remain at basic levels of creative thinking. This gap reflects a mismatch between expected competencies and actual learning outcomes in mathematics education. The situation is further supported by the Global Innovation Index, which places Indonesia in a middle-ranking position with relatively modest creativity performance. These findings collectively signal the need for systematic efforts to enhance creative thinking through more effective instructional designs. Consequently, improving students' creative thinking is not only a pedagogical concern but also a national educational challenge.

Consistent with these large-scale findings, empirical studies further confirm that students' creative thinking in mathematics remains at a relatively low level. Several studies report that only a limited proportion of students are able to achieve high scores in creative thinking assessments, while many struggle to meet key indicators such as fluency, flexibility, originality, and elaboration (Alabbasi et al., 2022; Rosen et al., 2023; Shively et al., 2018). These difficulties are not merely statistical but are also reflected in students' learning experiences. In many cases, students face challenges in understanding mathematical concepts and applying them beyond routine procedures. Local findings from vocational schools reinforce this pattern, showing that a significant number of students struggle with conceptual understanding, problem-solving beyond examples, and confidence in mathematical tasks. Teachers also report difficulties in adapting instruction to diverse student needs and encouraging active engagement. These combined findings highlight that the issue of low creative thinking is both systemic and contextual, requiring targeted instructional interventions

Building on these findings, the challenges identified are closely related to how mathematics is commonly perceived and taught in classrooms. Mathematics is often viewed as a difficult subject, particularly in topics such as geometric transformations, where students tend to rely on memorizing formulas rather than developing meaningful conceptual understanding. This approach leads to superficial learning, where students are able to reproduce procedures but struggle to apply concepts in new situations (Cibro et al., 2021; Koskinen & Pitkaniemi, 2022). As a result, mathematical knowledge becomes fragmented and easily forgotten, limiting students' problem-solving abilities. This condition not only affects conceptual understanding but also restricts students' capacity to think creatively when solving mathematical problems. The dominance of procedural teaching practices further reinforces passive learning behaviors among students. Therefore, these challenges underscore the need for instructional approaches that are more engaging, contextual, and supportive of deeper cognitive processes

In relation to these classroom challenges, instructional practices often emphasize final answers rather than the processes involved in generating ideas. Students tend to depend on teacher-provided examples and demonstrate limited initiative in exploring alternative solution strategies. This pattern indicates that opportunities for developing creative thinking are still insufficient in current classroom environments. Although some teachers have begun to incorporate varied learning media, the integration of digital technology and culturally relevant approaches remains limited. As a result, learning experiences often fail to connect mathematical concepts with real-life contexts and

students' cultural backgrounds (Rubel & McCloskey, 2021; Vos, 2018). This gap suggests that existing instructional approaches have not yet effectively addressed how creative thinking can be fostered in meaningful and sustainable ways. Consequently, there is a need for innovative learning designs that integrate multiple dimensions of learning, including pedagogy, technology, and culture.

Responding to this need, recent studies have explored the integration of pedagogical models, cultural contexts, and digital technologies to enhance mathematics learning. Project-Based Learning has been shown to promote active engagement and independent exploration, enabling students to develop creative problem-solving skills (Suhirman & Ghazali, 2022). Similarly, ethnomathematics provides meaningful contexts by linking mathematical concepts with cultural practices, allowing students to interpret and construct knowledge in more relevant ways (Sa'id et al., 2021; Ditasona, 2018). Digital tools such as GeoGebra support dynamic visualization, helping students understand abstract mathematical concepts through interactive representations (Wiyanti & Hadi, 2023; Furner, 2024). In addition, jBatik integrates fractal mathematics with cultural design, offering opportunities for students to express creativity through digital batik motif creation (Sumardi, 2023). Furthermore, technology-supported project-based learning has also been shown to enhance computational thinking and mathematical resilience, indicating its broader impact on higher-order competencies (Valerian Amadeus et al., 2025). These approaches demonstrate that combining pedagogy, culture, and technology can create more engaging and meaningful learning environments. Collectively, these findings indicate that such integration holds strong potential for fostering creative thinking in mathematics education.

Despite these promising developments, the effectiveness of these approaches remains context-dependent, particularly in vocational education settings. Project-Based Learning is most effective when students are given authentic problems and sufficient autonomy, while ethnomathematics requires meaningful integration with mathematical concepts rather than superficial application. Similarly, digital tools such as GeoGebra and jBatik offer strong potential but are often underutilized or not optimally aligned with vocational learning objectives. Vocational students tend to prioritize practical outcomes and procedural mastery, which may limit engagement in exploratory and creative processes. This indicates that the integration of pedagogy, technology, and culture must be carefully adapted to vocational contexts. Instructional designs need to balance creativity with relevance to professional and industry-oriented competencies. Therefore, a more comprehensive and context-sensitive model is required to effectively address these challenges.

Collectively, these studies highlight that innovative instructional models integrating pedagogy, technology, and culture have significant potential to enhance students' creative thinking and higher-order competencies. However, most previous research has tended to examine these elements in isolation, focusing either on technology-supported project-based learning or on ethnomathematics-oriented approaches without a comprehensive integration. As a result, there remains a critical gap in developing a holistic instructional model that systematically combines Project-Based Learning, GeoGebra, and jBatik within a culturally grounded framework to strengthen creative thinking in vocational mathematics education. Building on this gap, the present study offers a novel contribution by developing an integrated instructional model that combines Project-Based Learning, ethnomathematics, GeoGebra, and jBatik within a Design Thinking framework. Unlike prior studies that have addressed these components separately, this study proposes a comprehensive and context-sensitive approach specifically tailored to the characteristics of vocational mathematics learning. This integration not only emphasizes the development of creative thinking but also aligns mathematical learning with cultural relevance and professional competencies required in creative industry contexts. To operationalize this contribution, the study formulates the following research questions: (1) How does the integration of Project-Based Learning, ethnomathematics, GeoGebra, jBatik, and design thinking influence students' creative thinking in vocational mathematics

classrooms?; (2) In what ways does this integrated model support students in overcoming difficulties in understanding abstract mathematical concepts?; and (3) To what extent does the model reinforce creative competencies in alignment with the vocational school graduate profile for creative industries?

## METHOD

### Research Design

This study employed a qualitative approach within a Design Thinking framework, complemented by a meta-analysis to strengthen the evidence base of the proposed model. The qualitative component was used to explore in depth the problems and needs of students and teachers in vocational mathematics learning contexts. Meanwhile, the meta-analysis was conducted to synthesize empirical findings from previous studies and to project the potential effectiveness of the proposed instructional model. The Design Thinking stages applied in this study included Empathize, Define, Ideate, Prototype, and Test/Evaluate. This combination of qualitative inquiry and quantitative synthesis allows for both contextual understanding and evidence-based justification of the proposed design.

### Participant

The participants consisted of 186 vocational high school students from grades X, XI, and XII, and 10 mathematics teachers from five schools in Semarang: SMKN 3, SMKN 4, SMKN 5, SMKN 8, and SMK Penerbangan. A purposive sampling technique was employed based on school location and program characteristics. Schools categorized as urban were those situated in the city center with established facilities and diverse student intake (SMKN 3, SMKN 4, SMKN 5), while suburban schools were located on the outskirts with more limited resources and community-based student intake (SMKN 8, SMK Penerbangan). This operationalization ensured variation in context, allowing the study to capture both urban and suburban challenges in vocational mathematics education.

**Table 1.** Student Respondents

School	Number of Students	%
SMKN 3 SEMARANG	32	17%
SMKN 4 SEMARANG	71	38%
SMKN 5 SEMARANG	33	18%
SMKN 8 SEMARANG	32	17%
SMK PENERBANGAN SEMARANG	18	10%
TOTAL	186	100%

A total of 186 students from five vocational schools in Semarang participated in the study (Table 1). The largest proportion came from SMKN 4 Semarang (38%), followed by SMKN 5 (18%), SMKN 3 (17%), SMKN 8 (17%), and SMK Penerbangan (10%). This distribution shows variation across institutions, with SMKN 4 contributing the highest number of respondents.

**Table 2.** Teacher Respondents

School	Number of Teachers	%
SMKN 3 SEMARANG	2	20%
SMKN 4 SEMARANG	3	30%
SMKN 5 SEMARANG	2	20%
SMKN 8 SEMARANG	1	10%
SMK PENERBANGAN SEMARANG	2	20%
TOTAL	10	100%

Ten mathematics teachers from the same five schools were also involved (Table 2). The highest proportion was from SMKN 4 Semarang (30%), while SMKN 3, SMKN 5, and SMK Penerbangan each contributed 20%, and SMKN 8 contributed 10%. This spread reflects input from

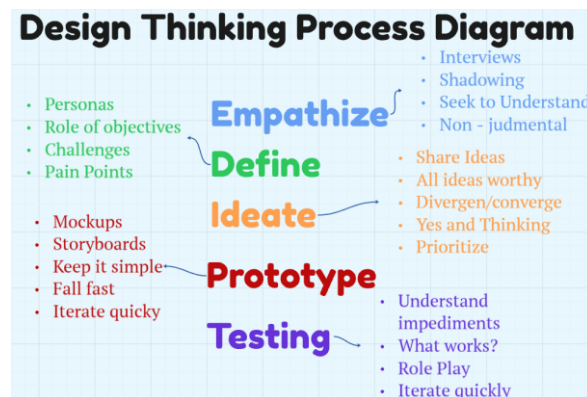
both urban and suburban schools, ensuring contextual diversity in perspectives on vocational mathematics learning.

### Instrument

The study utilized questionnaires, interview guides, and observation sheets to collect data from both students and teachers. These instruments were developed based on the Design Thinking framework and were designed to capture cognitive, affective, and contextual aspects of mathematics learning. Content validity was ensured through expert review involving mathematics education specialists, while reliability was supported through consistency checks and triangulation of multiple data sources. The instruments were further refined through feedback from practicing teachers and validated through Focus Group Discussions (FGD). The development of the Gema-Batik model was also informed by these instruments, incorporating project-based learning steps, contextual worksheets, creative thinking indicators, and the integration of GeoGebra and jBatik.

### Procedures

The research procedures were designed to address the research problems and followed the five stages of Design Thinking (Empathize, Define, Ideate, Prototype, and Test/Evaluate). In this study, the final stage (*Test/Evaluate*) was carried out through a literature meta-analysis, synthesizing effect sizes from previous studies to assess the potential effectiveness of the Gema-Batik Model (Utomo et al., 2024).



**Figure 1.** Design Thinking Process

This study began by profiling mathematics learning problems in the empathize stage to understand the needs of both students and teachers in vocational mathematics learning contexts. Data were collected through validated questionnaires, structured interviews, and classroom observations (Carlgren et al., 2016; Liedtka, 2018; Riyadi et al., 2024). The credibility of the instruments was ensured through expert validation and Focus Group Discussions (FGD). The collected data were then analyzed descriptively using an empathy map to construct a comprehensive profile of the identified learning problems.

Building on these findings, the study proceeded to the define and ideate stages, which focused on generating alternative solutions. This process employed Point of View and How Might We techniques (Pande & Bharathi, 2020; Garbuio & Lin, 2021), supported by brainstorming and mind mapping activities (Mengue-Topio et al., 2024; Sun et al., 2022). In addition, user personas were developed to represent diverse learner characteristics. The resulting ideas were synthesized and strengthened through meta-analysis (Utomo et al., 2024), leading to the formulation of three potential solution models.

In the prototype stage, the study focused on designing and validating the Gema Batik instructional model, which integrates Project-Based Learning, ethnomathematics, GeoGebra, and jBatik. The prototype was visualized using AI-assisted diagramming tools to generate schematic

representations of the instructional flow. These tools were used solely for visualization purposes and did not affect the integrity of the data. The prototype artifact is presented in Appendix E, and its validation was conducted through expert judgment and Focus Group Discussions involving mathematics education experts and postgraduate students (Utomo et al., 2024).

Finally, the study evaluated the potential effectiveness of the Gema-Batik model in the test and evaluation stage. This evaluation was conducted through a meta-analysis of studies published over the past decade, providing evidence that such integrative approaches can enhance students' creative thinking, problem-solving skills, and higher-order cognitive competencies (Utomo et al., 2024).

### Data Analysis

Qualitative data were analyzed using thematic coding. Responses were coded, grouped into categories, and refined into themes. Trustworthiness was ensured through triangulation and peer checking. For example, "I'm afraid my answer is wrong" was coded as fear of error, forming the theme lack of confidence. Quantitative data were analyzed using effect size, with Cohen's  $d$  applied to measure mean differences between experimental and control groups (Nugroho et al., 2020).

$$ES = \frac{\bar{x}_E - \bar{x}_C}{SD_{pooled}}$$

Where:

$$SD_{pooled} = \sqrt{\frac{(n_E - 1)SD_E^2 + (n_C - 1)SD_C^2}{n_E + n_C - 2}}$$

$ES$  = Effect size (commonly denoted by  $\alpha$  or  $\Delta$ )

$\bar{x}_E$  = Mean of the experimental group

$\bar{x}_C$  = Mean of the control group

$n_E$  = Number of samples in the experimental group

$n_C$  = Number of samples in the control group

$SD_{pooled}$  = Pooled standard deviation

$SD_E$  = Standard deviation of the experimental group

$SD_C$  = Standard deviation of the control group

In addition, Cohen's was used to analyze differences in proportions,

$$ES_h = 2 \cdot (\arcsin\sqrt{p_1} - \arcsin\sqrt{p_2})$$

Where  $p_1$  and  $p_2$  represent the proportions in each group

Effect sizes were then interpreted according to Cohen's criteria (Nugroho et al., 2020): 0.00–0.20 (low), 0.20–0.50 (moderate), 0.50–1.00 (high), and >1.00 (very high). The combination of qualitative exploration and meta-analysis, supported by CI reporting, provided both contextual understanding and evidence-based projections of the potential effectiveness of the Gema Batik model.

## RESULTS AND DISCUSSION

### Results

The descriptive and explorative analysis revealed three recurring themes in mathematics learning. First, students experienced significant difficulties in understanding abstract concepts. A total of 32.3% of students identified geometric transformations as particularly challenging, often describing them as confusing and difficult to visualize. Second, issues related to fear and lack of confidence were prominent. Approximately 79.6% of students reported anxiety about not understanding the lesson, 75.3% struggled with applying formulas, and 59.7% hesitated when analyzing tasks due to fear of making mistakes. In addition, more than half of the students (56.5%) reported low confidence in completing assignments. Third, the findings indicated limited

opportunities for creative learning. Although 74.7% of students still faced difficulties in understanding concepts, 78.5% expressed a preference for more flexible and open-ended mathematics instruction, and 62.9% showed a desire to explore multiple problem-solving strategies and articulate their reasoning.

Complementary findings from teacher questionnaires reinforced these themes. All teachers (100%) noted difficulties with students' learning approaches, 60% observed passivity and reluctance to ask questions, 80% reported limited exploration of problem-solving strategies, and 70% emphasized that instruction remained dominated by conventional methods focused on final answers rather than cognitive processes. Teachers described students as "waiting for instructions" or "imitating examples without trying alternatives." Triangulation with curriculum documents confirmed that the lack of contextualization and minimal use of interactive media contributed to low levels of creative thinking. To integrate these perspectives, an empathy map was developed, providing a concise visualization of student and teacher viewpoints and guiding the design of targeted solutions.

To integrate these perspectives, an empathy map was developed to represent student and teacher viewpoints. The map was used to identify design requirements, such as the need for contextualized worksheets, opportunities for multiple problem-solving strategies, and the integration of interactive media, thereby guiding the refinement of the Gema-Batik Model.

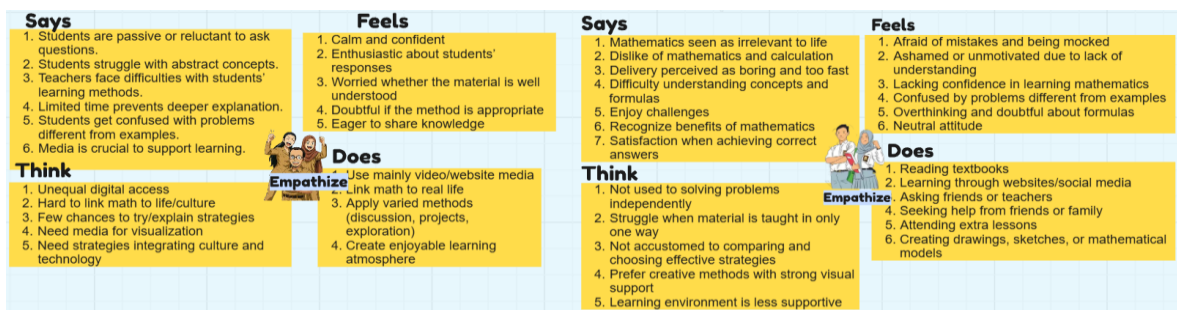


Figure 2. Empathy Map – Teachers and Students

From the combined empathy maps of students and teachers, several key issues emerge. Students often feel insecure in mathematics learning, expressing fear due to their dislike of calculation and difficulty in understanding concepts and formulas, consistent with findings that low interest contributes to challenges in learning mathematics (Itter & Meyers, 2017; Stoehr, 2017). They are not accustomed to solving problems independently or comparing strategies, as teachers tend to provide examples and exercises without encouraging students to share their own ideas (Noviangraeni & Siswono, 2017). Lessons are frequently perceived as boring and too fast, with learning media dominated by videos and lacking interactive variety, which reduces student engagement, although technology-based approaches can stimulate greater involvement and motivation (Wiyanti & Hadi, 2023). Students also need innovative learning that connects mathematics to real-life and local culture, supported by technology to foster creative thinking (Ditasona, 2018). At the same time, teachers emphasize the necessity of designing cooperative models with accessible online media to create enjoyable learning experiences that meet students' needs and enhance creative skills (Utomo et al., 2024).

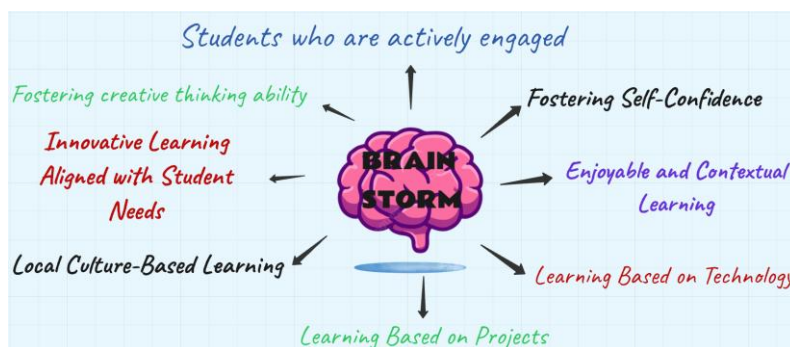
In the define stage, the problems identified during the empathize stage were further clarified through the establishment of a Point of View (POV), represented by *User Personas* and *How Might We* (HMW) questions. The user personas, constructed from questionnaires and interviews, helped designers understand the needs, characteristics, experiences, and goals of both students and teachers (Awalurahman et al., 2025)

User : Teacher	Needs	User : Student	Needs
Most users have taught for over ten years and remain enthusiastic about teaching. However, they still struggle to design strategies that are engaging and relevant to students' lives, while students' creative thinking skills remain low.	<ul style="list-style-type: none"> <li>Understanding interactive learning media</li> <li>Media with visualization and simulation of mathematical concepts</li> <li>Technology-based learning</li> <li>Approaches relevant to students' real lives</li> </ul>	The user sees mathematics as uninteresting and worries about low grades, but as part of Generation Z, they are already comfortable with digital technology, which opens up chances to make learning more engaging.	<ul style="list-style-type: none"> <li>Real-world relevant methods</li> <li>Varied resources</li> <li>Interactive media</li> <li>Innovative models integrating technology and local culture</li> <li>Student confidence</li> </ul>
	<b>Insight</b> <ul style="list-style-type: none"> <li>Students become active and engaged in learning</li> <li>Students understand concepts and find solutions independently</li> <li>Students compare strategies and choose the most effective</li> <li>Learning is enjoyable and engaging</li> </ul>		<b>Insight</b> <ul style="list-style-type: none"> <li>Engaging mathematics learning</li> <li>Environment based learning</li> <li>Teachers using interactive media</li> <li>Innovative models integrating technology and local culture</li> </ul>

**Figure 3.** User Personas – Teachers and Students

The word *How* is used to frame questions arising from user problems, while *might* indicates possible answers or solutions. This structure generated guiding questions such as: how might mathematics learning be made more enjoyable and engaging; how might teachers deliver material more effectively; how might students avoid boredom; and how might their creative thinking be improved. Each question opens the door to possible solutions such as: aligning lessons with student needs, using interactive media, applying student-centered models, and designing contextual, innovative learning experiences that encourage exploration and reflection.

In the ideation stage, brainstorming and mind mapping were conducted to generate eight initial ideas aligned with student and teacher needs (Nugroho et al., 2020). These ideas were then screened using four criteria, feasibility, cultural relevance, technological access, and curricular fit. Concepts that met fewer than three criteria were eliminated, leaving three potential instructional design alternatives. The elimination logic ensured that only designs with strong contextual and technological grounding were retained. These three ideas were further synthesized with findings from recent literature and validated through FGD, resulting in prototypes that reflect both student and teacher needs.



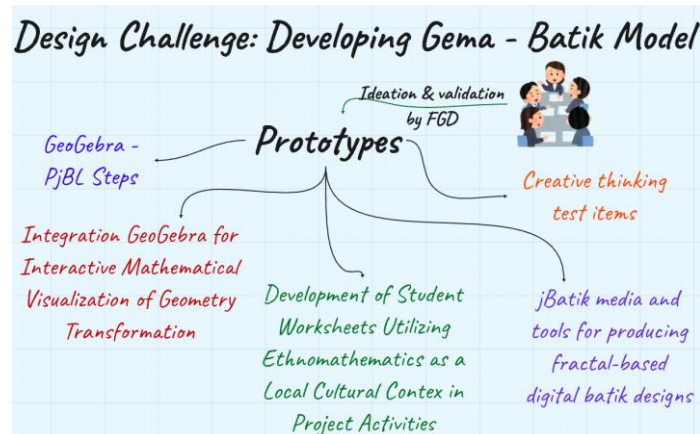
**Figure 4.** Brainstorming of Ideas

The alternatives included Project-Based Learning (PjBL), ethnomathematics, GeoGebra, and jBatik. These solutions were synthesized with findings from recent literature to justify their relevance and novelty. Geometry transformation, for instance, is widely recognized as a difficult topic, often taught through memorization rather than meaningful understanding (Jablonski & Ludwig, 2023; Malatjie & Machaba, 2019; Uygun, 2020). Enhancing creative thinking was therefore identified as a key objective, as it represents an essential achievement in mathematics learning (Noviangraeni & Siswono, 2017). PjBL encourages student autonomy and creative problem-solving (Suhirman & Ghazali, 2022), and when combined with ethnomathematics, it significantly improves students' creative thinking (Nurislamiati & Irfan, 2022). Ethnomathematics itself provides cultural contexts that make mathematics more relevant and expressive (Sa'id et al., 2021; Ditasona, 2018)). GeoGebra supports dynamic visualization and exploration, enabling students to manipulate mathematical concepts and build deeper understanding (Wiyanti & Hadi, 2023; Furner, 2024)

Meanwhile, jBatik integrates fractal mathematics with Indonesian cultural heritage, fostering creativity through digital batik design (Sumardi, 2023). Based on these findings, three instructional design alternatives were proposed:

1. Learning design supported by jBatik
2. GeoGebra – PjBL integrated learning design
3. PjBL–Ethnomathematics integrated learning design

Based on the ideation process, a prototype learning design named Gema-Batik was developed. This integrated model combined Project-Based Learning (PjBL) with Ethnomathematics, supported by GeoGebra hypermedia and the jBatik application. The prototype was visualized through diagramming, providing a clear representation of the learning flow and key activities.



**Figure 5.** Gema-Batik Prototype Components Formulated

Expert validation indicated that the prototype was feasible and aligned with curriculum requirements, while also offering opportunities for students to engage in creative exploration. The meta-analysis examined three instructional designs in mathematics learning: GeoGebra–PjBL, PjBL with ethnomathematics, and jBatik. Using Mendeley (2020–2025) with keywords such as *GeoGebra*, *project-based learning*, *ethnomathematics*, *jBatik*, and *creative thinking*, 982 records were identified; after duplicate removal and screening, 73 studies were retained. Full-text eligibility yielded 9 experimental or quasi-experimental studies with complete quantitative data, which were analyzed for effect sizes. To reduce bias, incomplete or descriptive reports were excluded. While only three studies directly measured creative thinking, six others addressed related constructs (HOTS, problem solving, computational thinking, resilience), and these were synthesized narratively to strengthen interpretation. Details of the PRISMA flow, coding, and calculations are provided in the Supplementary File.

**Table 3.** Main Table: Studies on Creative Thinking

Author & Year	Treatment	Outcome	Effect Size (ES)
Wiyanti & Hadi, 2023	GeoGebra–PjBL	Creative thinking	0.27
Nurislamiati & Irfan, 2022	PjBL–Ethnomathematics	Creative thinking	2.42
Purnamasari & Dhoruri, 2025	PjBL–Ethnomathematics	Creative thinking	0.62

These results show that ethnomathematics-based PjBL tends to produce stronger improvements in creative thinking compared to GeoGebra–PjBL. To maintain analytic clarity, the creative-thinking meta-analysis is presented separately. Additional studies on related constructs such as HOTS, problem solving, computational thinking, and resilience are reported in Table 4 as supporting evidence. These outcomes are not averaged together with creative-thinking effect sizes but are synthesized narratively to illustrate complementary strengths of jBatik and GeoGebra–PjBL.

**Table 4.** Supporting Table: Studies on Related Outcomes

Author & Year	Treatment	Outcome	Effect Size
Maulana et al., 2021	jBatik 1	HOTS / learning outcomes	2.30
Sumardi, 2023	jBatik 2	HOTS / learning outcomes	0.43
Sumardi et al., 2023	jBatik 3	HOTS / learning outcomes	0.50
Suherman et al., 2020	GeoGebra-PjBL	HOTS / problem solving	5.90
(Valerian Amadeus et al., 2025)	GeoGebra-PjBL	Computational thinking (0.80, Large); Mathematical resilience (0.50, Medium)	—

These supporting studies confirm that jBatik and GeoGebra-PjBL are also effective for higher-order thinking skills, mathematical connection, computational thinking, and resilience. Importantly, Valerian Amadeus et al., (2025), strengthens the analysis by providing recent evidence that GeoGebra-PjBL significantly improves computational thinking and moderately enhances mathematical resilience. These outcomes are synthesized narratively to illustrate complementary strengths, while the creative – thinking meta-analysis remains distinct.

Taken together, these findings suggest that while ethnomathematics-based PjBL shows strong direct effects on creative thinking, the integration of jBatik and GeoGebra-PjBL provides complementary strengths that broaden the impact on related higher-order skills. To ensure methodological rigor, pooled effect sizes were recalculated using inverse-variance weighting under a random-effects model. The results of this calculation are presented in Table 5.

**Table 5.** Pooled Effect Size

Summary Table	Value
Pooled Effect Size (random-effects)	0.96
95% Confidence Interval	[0.81 – 1.10]
Standard Error (SE)	0.0755
Weighting Method	Inverse-variance
Sensitivity & Coding	See Supplementary File

Table 5 presents the pooled effect size for the included studies using a random-effects model. The weighted effect size was 0.96 (95% CI [0.81–1.10]), indicating a high level of effectiveness according to Cohen's criteria. The calculation used inverse-variance weighting to reduce bias from small-sample studies. Although heterogeneity was expected due to differences in outcome focus and instructional design, the pooled result remains robust and interpretable. Sensitivity checks and full coding details are provided in Supplementary Table 3.

These findings confirm that the three instructional designs make significant contributions to the development of students' creative thinking skills, each in its own distinctive way. jBatik opens space for students to express creativity through digital fractal-based media, GeoGebra enriches the learning process with interactive mathematical visualization, and ethnomathematics provides a cultural context that deepens the meaning of mathematical concepts. The meta-analysis further indicates that combining GeoGebra, ethnomathematics, Project-Based Learning (PjBL), and jBatik—summarized in the acronym Gema-Batik offers a relevant and promising instructional strategy. This integration brings together technological visualization, local cultural context, project-based learning, and creative digital media. Within the framework of design thinking, such a combination is expected to strengthen both critical and creative thinking, enabling students not only to grasp abstract mathematical concepts but also to connect them with familiar cultural elements, visualize them digitally, and ultimately produce tangible outputs such as complete batik designs.

## Discussion

The findings suggest that the three instructional designs may support students' creative thinking in different ways. jBatik offers a medium for creative expression through digital fractal design, GeoGebra enriches learning with interactive visualization, and ethnomathematics provides cultural context that adds meaning to mathematical concepts. Although based on a limited set of

studies, the meta-analysis points to promising directions for vocational mathematics education, where creativity, cultural relevance, and digital literacy are essential. Integrating GeoGebra, ethnomathematics, PjBL, and jBatik—summarized as Gema-Batik—emerges as a potentially relevant instructional strategy. This combination of visualization, cultural context, project-based learning, and creative digital media may strengthen critical and creative thinking, enabling students to connect abstract concepts with familiar cultural elements and produce tangible outputs such as batik designs.

This meta-analysis synthesized studies from 2020–2025 that examined three instructional designs in mathematics education: GeoGebra-PjBL, PjBL with ethnomathematics, and jBatik. The results revealed clear differences in their contributions to students' learning outcomes. Ethnomathematics-based PjBL consistently produced stronger effects on creative thinking, with effect sizes ranging from moderate to large (Nurislamiati & Irfan, 2022; Purnamasari & Dhoruri, 2025). This finding confirms that embedding cultural context into project-based learning makes mathematical concepts more meaningful and fosters creativity. GeoGebra-PjBL showed smaller effects on creative thinking (Wiyanti & Hadi, 2023), but very large impacts on problem solving (Suherman et al., 2020) and computational thinking (Valerian Amadeus et al., 2025). Meanwhile, jBatik demonstrated high effectiveness for HOTS and learning outcomes (Maulana et al., 2021; Sumardi, 2023; Sumardi et al., 2023).

Viewed through the framework of design thinking, each instructional design reflects a systematic process. In the profiling stage, the ideas emerged from different contexts: jBatik from local cultural motifs and fractal mathematics, GeoGebra-PjBL from the need for interactive visualization, and ethnomathematics-based PjBL from integrating cultural knowledge into mathematics. During the ideate and define stages, these designs addressed the problem of low creative thinking skills and proposed solutions that combine culture, technology, and project-based learning. The classroom implementations served as prototypes, and the meta-analysis confirmed their effectiveness, with all three designs achieving high average effect sizes (jBatik 1.62, GeoGebra-PjBL 2.33, ethnomathematics-PjBL 2.83).

These findings suggest that each design contributes uniquely to mathematics learning. jBatik emphasizes creative digital media (Maulana et al., 2021), GeoGebra-PjBL strengthens abstract reasoning and computational literacy (Suherman et al., 2020; Valerian Amadeus et al., 2025), and ethnomathematics-based PjBL deepens cultural meaning in mathematical concepts (Nurislamiati & Irfan, 2022; Purnamasari & Dhoruri, 2025). Together, they provide complementary strengths that address cognitive, affective, and cultural dimensions of learning.

The synthesis of these approaches into Gema-Batik represents a promising instructional strategy. By integrating technology, culture, project based learning, and creative digital media, Gema-Batik fosters both critical and creative thinking. Students not only understand abstract mathematical concepts but also connect them with familiar cultural elements, visualize them digitally, and produce tangible outputs such as complete batik designs. This integration demonstrates that effective mathematics instruction can be achieved through diverse, context-sensitive strategies that align with design thinking principles.

### **Implications**

The study offers both theoretical and practical contributions. Theoretically, it demonstrates that combining pedagogy, technology, and culture can holistically enhance creative thinking in vocational mathematics education. Practically, the Gema-Batik model provides teachers with a structured yet flexible approach that can be adapted to diverse learning contexts. It also supports the vocational mandate to prepare graduates for creative industries by linking mathematics learning with cultural and technological innovation

### Limitations

This study relied on qualitative exploration and meta-analysis rather than direct experimental implementation. While meta-analysis provides strong evidence of effectiveness, the actual application of the Gema-Batik model in classrooms has not yet been tested through controlled trials. The sample was limited to vocational schools in Semarang, which may restrict generalizability to other regions.

### Suggestions

Future research should implement the Gema-Batik model in classroom experiments to measure its direct impact on students' creative thinking and learning outcomes. Comparative studies across different regions and school types would strengthen external validity. Additionally, longitudinal research could explore how sustained use of the model influences students' creativity, resilience, and cultural appreciation over time.

## CONCLUSION

This study was designed to address four main objectives: (1) profiling the problems of mathematics learning in vocational high school, (2) ideating alternative instructional solutions, (3) prototyping innovative products, and (4) examining their potential effectiveness through literature review and meta-analysis. The meta-analysis suggests that three instructional designs (GeoGebra-PjBL, PjBL with ethnomathematics, and jBatik) may support the development of students' higher-order skills. Ethnomathematics-based PjBL appears most promising for creative thinking, GeoGebra-PjBL shows potential for problem solving, computational thinking, and resilience, while jBatik may contribute to HOTS and learning achievement. While these results provide preliminary evidence, they are based on a limited set of studies and have not yet been tested through classroom trials of the integrated model. Within this scope, the research objectives were addressed: profiling highlighted challenges of low creative thinking, ideation generated culturally contextualized and technology-assisted solutions, prototyping was represented by classroom implementations reported in prior studies, and effectiveness was explored through meta-analysis. In conclusion, the integration of GeoGebra, ethnomathematics, Project-Based Learning, and jBatik (summarized as Gema Batik) emerges as a relevant and potentially promising instructional strategy. It combines technology, culture, project-based learning, and creative digital media to foster both critical and creative thinking. Practically, the Gema Batik model may serve as a reference point for vocational mathematics teachers, while future research should focus on classroom trials, adaptation to diverse contexts, and scaling for broader implementation.

## ACKNOWLEDGMENT

The researcher would like to express sincere gratitude to SMK Negeri 3, SMK Negeri 4, SMK Negeri 5, SMK Negeri 8, and SMK Penerbangan Semarang for their invaluable cooperation during the data collection process. Appreciation is also extended to the mathematics teachers and students who participated actively and provided meaningful insights that enriched this study. Special thanks are addressed to the MGMP Matematika Kota Semarang for facilitating discussions and expert validation, as well as to colleagues and academic mentors whose guidance and constructive feedback contributed significantly to the completion of this research

## AUTHOR CONTRIBUTION STATEMENT

WFW was responsible for the conceptualization of the study, preparation of the original draft, editing, and visualization. ID contributed to the methodology, conducted formal analysis, and assisted with writing, review, and editing. LH provided validation and supervision throughout the

research process. WFW also managed data access and curation, ensuring transparency and reproducibility of the findings.

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