JTAM (Jurnal Teori dan Aplikasi Matematika)
http://journal.ummat.ac.id/index.php/jtam
p-ISSN 2597-7512 | e-ISSN 2614-1175
Vol. 9, No. 4, October 2025, pp. 1301-1309

Exploring Cognitive and Gender Factors in Mathematical Creativity: Evidence from Indonesian Vocational Schools

Kristianus Viktor Pantaleon[1*], Jerito Pereira[2], Tommy Tanu wijaya[3], Elisabeth Visera[1]
[1]Department of Mathematics, Universitas Katolik Indonesia Santu Paulus Ruteng, Indonesia
[2]Universidade Nasional Timor Lorosa'e-UNTL, Timor Leste
[3]School of mathematical sciences, Beijing Normal University, China
christianvictor1979@gmail.com

Article History:
Received : 13-05-2025
Revised : 15-08-2025
Accepted : 16-08-2025
Online : 01-10-2025

Keywords:
Cognitive Style;
Gender;
Mathematical Creative Thinking;
Vocational Education.

ABSTRACT

Despite the increasing focus on creativity in mathematics education, research on the combined effects of cognitive style and gender on mathematical creative thinking in vocational high schools is still scarce, especially in Indonesia. This study investigated the influence of cognitive style and gender on the mathematics creative thinking of 60 eleventh-grade students in a vocational high school, classified as Field Independent (FI) or Field Dependent (FD) by the Group Embedded Figures Test (GEFT). Mathematical creativity, which includes fluency, flexibility, and originality, was assessed using an open-ended test that was verified by two experts in mathematics education and pilot-tested for reliability. Data were examined via two-way ANOVA. The findings indicated that FI students markedly surpassed their FD counterparts across genders ($p < 0.001$), although gender disparities were not statistically significant, although females exhibited a tendency for enhanced fluency and inventiveness, while males shown better flexibility. No notable interaction between cognitive style and gender was detected. These findings underscore the superiority of cognitive style over gender in influencing mathematical creativity in vocational environments and present the inaugural empirical evidence for this combination effect within the Indonesian context. They propose that vocational mathematics instruction must be cognitively adaptive providing structured scaffolding and collaborative methods for FD learners, and open-ended, self-directed tasks for FI learners to enhance creativity and problem-solving abilities pertinent to real-world vocational challenges.

https://doi.org/10.31764/jtam.v9i4.31443

A. INTRODUCTION

The development of students' creative thinking abilities has received much attention in 21st-century education, as it is crucial for preparing learners to navigate complex, uncertain, and technology-driven environments. Mathematical creative thinking is increasingly recognized as an essential competency across various fields, particularly as a result of educational reforms driven by STEM integration, technological advancements, and a shift towards curricula centered on problem-solving (Suherman et al., 2021; Whitney-Smith et al., 2022). Mathematical creativity is essential for enhancing learners' cognitive flexibility, adaptability, and capacity to generate unique solutions in academic and professional settings (Bicer et al., 2021; Gajda et al., 2017).

Consequently, mathematical creative thinking skills are essential for fulfilling the demands of modern education and industry (Suherman et al., 2021; Suyitno, 2020; Whitney-Smith et al.,

2022). In vocational education, this competency is crucial as students are required to not only acquire technical skills but also to participate in intricate, adaptive problem-solving processes (Berding et al., 2021; Kovalchuk et al., 2022; Truba et al., 2023). Improving pupils' creative thinking abilities in mathematics is thus a fundamental educational goal in this field.

Creative mathematical thinking is typically defined by fluidity, flexibility, originality, and elaboration (Adiastuty et al., 2020; Githua et al., 2013; Yaniawati et al., 2020). Studies indicate favorable correlations between these elements and academic success, along with their significance for workforce preparedness in evolving, technology-oriented environments (Bicer et al., 2021; Gajda et al., 2017; Izzatin et al., 2020). Fluency signifies the capability to produce numerous mathematical concepts or solutions; flexibility indicates the ability to alter views or methodologies; originality represents the distinctiveness of thoughts; and elaboration pertains to the profundity or extension of responses.

Cognitive style, characterized as a consistent method of information processing, is one of the several individual aspects significantly impacting mathematical creativity. The differentiation between Field Independent (FI) and Field Dependent (FD) learners in mathematics education is well established (Giancola et al., 2022; Singer et al., 2017). FI learners are generally more analytical, self-directed, and proficient in abstraction and issue analysis, rendering them more adept at open-ended mathematics assignments. In contrast, FD learners typically depend on external frameworks, demonstrate heightened context sensitivity, and may encounter challenges in ill-structured or novel problem-solving scenarios (Izzatin et al., 2020; Ratuanik, 2018). Cognitive style differences affect pupils' perception, processing, and application of information, hence influencing their methods of mathematical reasoning and creative problem-solving.

A commonly analyzed element concerning cognitive differences is gender. Certain research indicate that male students frequently exhibit superior spatial reasoning and flexibility, whereas female students are more likely to have enhanced fluency and elaboration in mathematical creativity (Kusumaningsih et al., 2019; Maiti & Pardi, 2023; Ramírez-Uclés & Ramírez-Uclés, 2020). Conversely, several studies suggest negligible or no substantial gender disparities, particularly when instruction is equal and adapted to varied learner attributes (Arifah et al., 2022; Palobo et al., 2024; Permatasari et al., 2020; Piaw, 2014; Sintema & Jita, 2022). These disparate findings underscore the necessity for more nuanced inquiries into the influence of gender on creative mathematical cognition, especially within particular educational settings.

Notwithstanding the increasing focus on mathematical creativity, the majority of empirical investigations have occurred inside general education contexts. Research in vocational schools is limited, despite these settings posing unique cognitive and pedagogical issues (Berding et al., 2021; Kovalchuk et al., 2022). Vocational education frequently encompasses practical, multidisciplinary problem scenarios that need integrative thinking, wherein variations in cognitive style and gender may be more evident. However, limited empirical research has investigated these two characteristics concurrently within the context of vocational education.

Examining the relationship between cognitive style and gender is crucial for creating adaptive learning models that accommodate both analytical and intuitive learners across various gender identities. In Indonesian vocational schools, where educational resources may

be constrained, such comprehension can establish a robust basis for individualized teaching practices that enhance learning results.

This study examines the impact of cognitive style and gender on mathematical creative thinking in Indonesian vocational high school students, addressing existing gaps in the literature. This study aims to provide new empirical evidence to the vocational education literature by analyzing the differences between FI and FD learners, male and female students, and the potential interactions of these variables, thereby informing mathematics teaching practices that cater to diverse learner profiles.

B. METHODS

This research utilized a quantitative methodology with a comparative ex post facto design to investigate the influence of cognitive style and gender on mathematical creative thinking in vocational high school students. Ex post facto designs are frequently employed by researchers to examine the effects of independent variables that cannot be directly changed, such as gender or cognitive style (Kusumaningsih et al., 2019). The study was carried out in SMKS Informatika St. Petrus Ruteng, Manggarai Regency, East Nusa Tenggara, Indonesia, specifically in the XI TKJ (Computer Engineering and Networking) class during the even semester, from April 18 to May 4, 2024, in the 2023/2024 academic year.

1. Participants and Sampling

The subjects of this study were all eleventh-grade students at SMKS Informatika St. Petrus Ruteng. A purposive sampling strategy was utilized (Etikan, 2016) to guarantee that the sample had the requisite properties for comparative group analysis. The selection focused on students actively enrolled in the XI TKJ class during the even semester of the 2023/2024 academic year, who were willing to engage in all phases of the research, did not have diagnosed learning disabilities or special educational needs, and were available during the designated testing sessions. Sixty students fulfilled these criteria and were later divided into four equal groups according to gender (male or female) and cognitive type (field-independent or field-dependent), with 15 students in each group.

2. Instruments

The Group Embedded Figures Test (GEFT), created by Witkin, Oltman, Raskin, and Karp in 1971, was utilized to assess cognitive style, serving as a standardized tool for categorizing learners as Field Independent (FI) or Field Dependent (FD). GEFT has exhibited robust construct validity and reliability across several cultural contexts (Giancola et al., 2022). The instrument comprises a sequence of intricate geometric figures wherein students must identify basic target shapes. Scoring adhered to the initial criteria, with pupils exceeding the median classified as FI and those falling below classified as FD.

The evaluation of mathematical creative thinking utilized an open-ended assessment based on three indicators fluency, flexibility, and originality originating from Torrance's (1974) creativity framework and modified from earlier mathematics education studies (Adiastuty et al., 2020; Yaniawati et al., 2020). The tool was originally designed to conform to the SMK mathematics curriculum. Content validity was assessed by two experts who fulfilled the following criteria: (1) possession of at least a master's degree in mathematics education, (2) a

minimum of five years of teaching or research experience in mathematics at the secondary or vocational school level, and (3) knowledge of vocational school curriculum design in Indonesia. The panel consisted of a university lecturer specializing in mathematics education and a senior mathematics teacher from SMK. Expert feedback resulted in enhancements to the phrasing for clarity, contextual modifications for vocational subjects, and revisions to the scoring system.

A pilot study was subsequently executed with 30 eleventh-grade students from SMK St. Aloysius Ruteng, selected for their comparable academic background to the target demographic, however not participating in the primary study. This phase guaranteed an autonomous assessment of the instrument's efficacy. Construct validity was established by item-total correlation analysis, with all items surpassing the 0.30 criterion, signifying adequate discriminative capability. Cronbach's alpha reliability tests yielded values exceeding 0.70 for each creativity indicator (Taber, 2018), with an overall reliability coefficient of 0.87, indicating substantial internal consistency. All statistical studies for validity and reliability were performed utilizing SPSS version 25.

3. Research Procedure

The research approach commenced with collaboration among school administrators and mathematics instructors to organize the timetable and facilitate the requisite testing sessions. The Group Embedded Figures Test (GEFT) was subsequently administered to all participants, who were then categorized into Field Independent (FI) and Field Dependent (FD) groups according to their GEFT scores. These classifications established the foundation for categorizing the pupils into four groups: Male-FI, Male-FD, Female-FI, and Female-FD.

The mathematics creative thinking test was subsequently evaluated by expert reviewers to confirm its content appropriateness and relevance to the vocational school context. The validated instrument was subsequently pilot-tested with students from a different SMK to assess its clarity, reliability, and applicability. Upon completion, the originality assessment was conducted with the research subjects. The responses were subsequently assessed and methodically input into SPSS version 25 for additional statistical analysis. Figure 1 delineates the research procedure flow, depicting the sequential interrelation of the design, implementation, and data analysis phases.

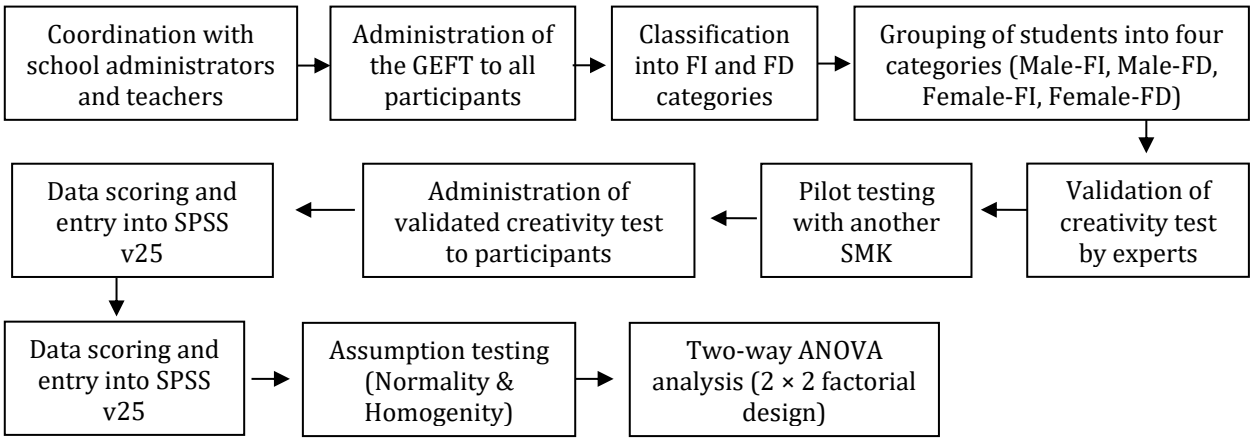

Figure 1. Research Procedure

4. Data Analysis

Prior to executing the primary statistical analysis, assumptions were evaluated utilizing the Kolmogorov–Smirnov test for normality and Levene's test for homogeneity of variances. The primary analysis employed two-way ANOVA, a method commonly utilized to assess main and interaction effects in factorial designs with categorical independent variables (Fitriani et al., 2020). This methodology aligned with the 2×2 factorial design of the study, wherein cognitive style (field-independent/field-dependent) and gender (male/female) functioned as the two independent variables.

C. RESULT AND DISCUSSION

1. Effect of Cognitive Style on Mathematical Creative Thinking

The two-way ANOVA results (Table 1) demonstrated that cognitive style significantly influenced students' mathematics creative thinking scores, $F(1, 73) = 42.41$, $p < 0.001$. Across gender classifications, Field Independent (FI) pupils regularly surpassed their Field Dependent (FD) counterparts. Descriptive statistics indicate that FI male students attained an average score of 81.60, whereas FD men scored an average of 66.53. Correspondingly, FI females had an average of 80.93, whereas FD females had an average of 60.00 (Table 2).

The results corroborate theoretical viewpoints highlighting the significant impact of cognitive style specifically the FI–FD dimension on involvement with mathematical problems. FI learners exhibit analytical thinking, intrinsic motivation, and autonomy in problem-solving (Giancola et al., 2022; Singer et al., 2017), rendering them more adept at open-ended, abstract, and diverse activities that promote creativity. This discovery corresponds with empirical research indicating that FI students possess an edge in addressing non-routine situations and generating innovative solutions (Izzatin et al., 2020; Ratuanik, 2018).

Table 1. Two-Way ANOVA Summary for Mathematical Creative Thinking Scores

Source	SS	df	MS	F	p-value
Cognitive Style	4168.41	1	4168.41	42.41	0.000
Gender	70.21	1	70.21	0.71	0.403
Interaction (Style × Gender)	288.80	1	288.80	2.94	0.091
Error	7229.31	73	99.04		
Total	11756.73	76			

Table 2. Descriptive Statistics of Mathematical Creative Thinking Ability Based on Gender and Cognitive Style

Gender	Cognitive Style	Mean Score
Male	Field Independent (FI)	81.60
Male	Field Dependent (FD)	66.53
Female	Field Independent (FI)	80.93
Female	Field Dependent (FD)	60.00

From a vocational education perspective, data indicates that diminished creativity ratings among FD students may signify difficulties in abstraction and autonomous reasoning in the absence of formal assistance. Consequently, instructional strategies in vocational mathematics must tailor learning experiences to suit various cognitive types, including scaffolding and

guided exploration for FD learners, while presenting open-ended, exploratory problems for FI learners.

2. Effect of Gender on Mathematical Creative Thinking

Gender had no statistically significant main effect, $F(1, 73) = 0.71$, $p = 0.403$. Although specific patterns were noted greater flexibility in males and enhanced fluency and inventiveness in females these disparities were not statistically significant at the overall level. This finding aligns with previous studies suggesting that gender alone does not significantly influence mathematical creativity in equitable and inclusive instructional settings (Permatasari et al., 2020; Piaw, 2014; Sintema & Jita, 2022). Certain research (Maiti & Pardi, 2023; Ramírez-Uclés & Ramírez-Uclés, 2020) indicate gender-related trends; nevertheless, these are frequently contingent upon cultural and contextual factors rather than intrinsic gender characteristics. The trends noted in this study males exhibiting increased flexibility and females displaying enhanced fluency align with previously recognized patterns; however, they must be regarded with caution due to the absence of statistical significance (Kusumaningsih et al., 2019).

3. Interaction Effect between Cognitive Style and Gender

The interaction between cognitive style and gender was not statistically significant, $F(1, 73) = 2.94$, $p = 0.091$. This indicates that the impact of cognitive style on mathematical inventiveness was uniform for both genders. The durability of cognitive style effects across demographic categories is theoretically feasible, particularly in circumstances devoid of instructional bias towards certain gender behaviors (Singer et al., 2017).

Nonetheless, the p-value nearing the 0.05 threshold suggests a trend that merits additional scrutiny. A larger or more diversified sample may yield unique patterns in problem-solving tactics or creative output based on specific combinations of cognitive style and gender. Future research may investigate whether FD males and FD females display divergent responses to structured interventions, or whether FI males and FI females have varying preferences for open-ended versus collaborative work in occupational contexts.

4. Implications for Vocational Mathematics Instruction

These findings highlight the fundamental influence of cognitive style on mathematical creativity in vocational school settings. Acknowledging and embracing cognitive diversity is essential for enhancing pupils' problem-solving abilities in intricate, real-world situations. For FD students, scaffolding, visual aids, collaborative frameworks, and guided inquiry can augment engagement and creativity. For FI students, assignments that promote autonomy, exploration, and diverse solution pathways might enhance creativity. These recommendations correspond with tailored education and cognitive-responsive pedagogy (Berding et al., 2021; Kovalchuk et al., 2022).

Although gender did not exhibit a major impact, the nuanced patterns identified can nevertheless guide micro-level initiatives, including team makeup, peer collaboration, and task design. This study emphasizes the necessity of transcending demographic generalizations to foster an individualized comprehension of learners' cognitive traits as the basis for vocational mathematics instruction.

This study provides new empirical data to the scarce research on the confluence of cognitive style and gender in vocational mathematics education. By contextualizing the investigation within an Indonesian SMK framework, the findings enhance theoretical models of mathematical creativity in a domain where practical, technology-driven problem-solving is paramount. The findings establish a solid foundation for developing adaptive, cognitively responsive teaching practices that are contextually pertinent and pedagogically effective.

D. CONCLUSION AND SUGGESTIONS

This study presents empirical evidence that cognitive style significantly influences the mathematics creative thinking of vocational high school students, with Field Independent learners consistently attaining higher creativity ratings than their Field Dependent counterparts. These findings corroborate and expand upon prior hypotheses on the FI–FD dimension by illustrating their relevance within an Indonesian vocational school context, where mathematical creativity is essential for addressing intricate, technology-driven challenges. The research enhances the literature by demonstrating that, although gender did not have a statistically significant impact, subtle tendencies—such as increased fluency and inventiveness in females and better flexibility in males—may nonetheless guide nuanced instructional choices.

This study's originality resides in its concurrent analysis of cognitive style and gender in the underexplored field of vocational mathematics education, providing a solid basis for the development of cognitively adaptive teaching methodologies. These findings indicate that instructional preparation must transcend demographic generalizations, prioritizing the adaptation of learning experiences to students' cognitive attributes. Field Dependent learners may boost creativity with structured supervision, collaborative activities, and visual assistance, whereas Field Independent learners may thrive with open-ended, exploratory assignments that promote autonomy and divergent thinking.

This research also facilitates avenues for additional investigation. The non-significant but near-threshold interaction between cognitive style and gender indicates the possibility of more intricate correlations that may arise with bigger or more diverse samples. Subsequent research may investigate the influence of extrinsic variables—such as classroom environment, student motivation, pedagogical feedback methods, and availability of digital learning resources—on the interplay between cognitive style, gender, and mathematical inventiveness. Comparisons across regions and disciplines in vocational contexts would enhance the generalizability of findings and aid in the creation of a more comprehensive framework for diversified mathematics instruction in vocational education.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Universitas Katolik Indonesia Santu Paulus Ruteng for the support and facilities provided throughout the course of this research. Appreciation is also extended to Yayasan Santu Paulus Ruteng, whose continuous encouragement and commitment to advancing education have made this work possible. Their contributions and dedication are deeply valued and gratefully acknowledged.

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