APTISI Transactions on Technopreneurship (ATT)
Vol. 8, No. 2, July 2026, pp. 669−681
E-ISSN: 2656-8888 | P-ISSN: 2655-8807, DOI:10.34306

Geometry Learning Pathways for Creative Thinking via Edupreneurial Approaches

Hendri Handoko[1*], Stevanus Budi Waluya[2], Wardono Wardono[3], Sugiman[4], Li Wei Ming[5]
[1,2,3,4]Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia
[5]Department of Retail Management, Ijiis Incorporation, Singapore
[1]hendrihandoko@students.unnes.ac.id, [2]s.b.waluya@mail.unnes.ac.id, [3]wardono@mail.unnes.ac.id, [4]sugimanwp@mail.unnes.ac.id, [5]liming@ijiis.asia
***Corresponding Author**

Article Info

Article history:

Submission May 17, 2025
Revised October 8, 2025
Accepted March 12, 2026
Published June 12, 2026

Keywords:

Creative Thinking
Cognitive Styles
Geometry
Mathematics
Creative

ABSTRACT

This study highlights the importance of creative thinking as a 21st-century competency that is closely connected to technopreneurship and edupreneurship, emphasizing how students' cognitive styles Field Independent (FI) and Field Dependent (FD) shape their creative performance in geometry learning. The objective of this research is to design and describe a learning trajectory that fosters creative thinking by integrating cognitive diversity into geometry education. **Using a descriptive** qualitative approach, six purposively selected students representing FI and FD groups with high, medium, and low ability levels were examined through the Group Embedded Figures Test (GEFT), creative thinking tests, and semi-structured interviews. Data analysis followed the Miles and Huberman model, comprising data collection, reduction, display, and conclusion. **The findings** show that FI students exhibit stronger creative thinking skills across fluency, flexibility, originality, elaboration, and evaluation, while FD students particularly those with medium and low abilities, experience challenges in conceptual understanding and visual-spatial reasoning, indicating that creative thinking in geometry is strongly tied to spatial imagination. **The study concludes** that the proposed learning trajectory enhances creative education by linking cognitive styles with innovative learning design, offering practical contributions for curriculum development, teacher training, and educational product creation. It further supports the cultivation of innovation-oriented mindsets essential for building edupreneurial ecosystems and aligns with Sustainable Development Goal 4 (Quality Education).

DOI: http://doi.org/10.34306/att.v8i2.723

1. INTRODUCTION

Mathematics plays a crucial role in everyday life and in the advancement of science and technology. As a foundational discipline, mathematics is essential for developing 21st-century skills, including the four core competencies (4Cs): critical thinking, creative thinking, communication, and collaboration [1–3]. Recent studies highlight that creative thinking and problem-solving in STEM fields are closely related to the emergence of digital innovation and entrepreneurship-oriented education [4–6]. This reinforces the relevance of integrating creative and cognitive diversity in mathematics learning within the edupreneurial and technopreneurship framework [7–9]. Educational processes must therefore foster interaction, engagement, and motivation, while also

respecting students' interests and psychological development [7, 8]. Learning should not only be enjoyable but also personalized, taking into account students' diverse cognitive styles their unique ways of processing, storing, and applying information [9, 10].

A defining feature of modern mathematics education is that its delivery is rooted in learning psychology theories established by education experts [11–14]. With a solid understanding of educational psychology, teachers can identify students' prior knowledge and cognitive processes. Moreover, they can design learning activities that align with student conditions and instructional goals [15, 16]. There are two core challenges in organizing education: the first pertains to technical skills how, when, where, and by what method instruction is delivered and the second relates to more abstract aspects, such as student and teacher motivation, creativity, psychology, and willpower [17–19].

In reality, current instructional practices are still dominated by a teacher-centered paradigm. This one-way teaching model fosters student dependence on the teacher, leading to passive learning behavior. Students mostly listen, take notes, and are asked to memorize and solve exercises, resulting in boredom and disengagement from mathematics. This passive approach prevents students from developing independence, causing them to rely on teachers when facing problems [20, 21]. A teacher-centered paradigm undermines students' self-directed learning. In contrast, creative students can analyze complex problems, collaborate independently or in groups, and confidently articulate their ideas during lessons. Creative thinking cultivates self-confidence and accelerates students' comprehension and mastery of subject matter [22–24]. Mathematics education presents intricate challenges; many students perceive it as a difficult subject, often avoided. This is due to its hierarchical nature while not requiring a fixed sequence, learning new concepts often depends on prior mastery.

Davis outlines six reasons why creative thinking should be emphasized in mathematics education:

- Mathematics is too vast and complex for rote learning.
- Students are capable of producing original solutions to problems.
- Teachers should respond to surprising and unique student contributions.
- Rote and routine problem-solving demotivates students and hinders development.
- Originality should be taught, such as through independently derived proofs.
- Real-life applications of mathematics demand creativity [25].

.

Creative thinking is fundamental for discovering new knowledge and generating innovations that benefit both current and future generations [26, 27]. Recent international studies have also emphasized the integration of creativity within entrepreneurship education, showing how innovative thinking processes directly foster entrepreneurial competence and sustainable educational practices. These findings strengthen the relevance of our approach, which connects creative thinking in geometry education with edupreneurial and creativepreneurship frameworks.

One of the mathematical topics that students often find particularly difficult is geometry, especially spatial intersection, distance, and angle problems [28, 29]. Challenges in learning geometry include interpreting three-dimensional figures on a two-dimensional plane requires a high level of abstraction The concepts are complex and often integrated with other mathematical topics such as trigonometry and triangles, Instructional methods largely remain lecture-based or conventional, Learning media and resources are limited in both quantity and quality. These factors make geometry difficult for students, resulting in lower levels of creative thinking in this subject. Students often struggle to analyze, draw, and understand concepts necessary to solve three-dimensional word problems due to insufficient creative problem-solving skills [30–33]. Therefore, strategies are needed to orient mathematics instruction toward enhancing students' creative thinking. This competency is essential and must be nurtured [34, 35].

Given geometry's high level of abstraction and interrelatedness with other concepts, it is crucial to consider students' individual differences in information processing referred to as cognitive styles. As mentioned, a central characteristic of contemporary mathematics instruction is its foundation in educational psychology theories. Understanding these allows teachers to identify students' cognitive abilities and thinking processes, and to design appropriate learning activities [36–38]. Cognitive style as the individual manner of processing,

storing, and using information in response to tasks or environmental demands [39]. It reflects distinctive student learning preferences in terms of receiving and processing information. Several types of cognitive styles exist, but this study focuses on FI and FD styles. These styles represent how individuals analyze and interact with their environment. Field-dependent learners tend to perceive patterns as wholes and struggle to isolate specific aspects of a situation or to deconstruct patterns into components. In contrast, field-independent learners are more analytical, recognizing parts of a problem and breaking down complex patterns into their elements.

2. RESEARCH METHODS

This study adopts a descriptive-qualitative research design aimed at exploring and describing the learning trajectory that supports the development of students' creative thinking in geometry learning [40]. The investigation is framed by students' cognitive styles, categorized as FI and FD. A total of six students were selected through purposive sampling, representing different combinations of cognitive style and mathematical ability level. Each cognitive style group consists of students with high (01), medium (02), and low (03) performance levels. The participants were labeled as follows: SFI-01, SFI-02, SFI-03 FI and SFD-01, SFD-02, SFD-03 FD, respectively.

2.1. Research Participants

The participants involved in this study were six students from a selected school, chosen specifically to represent a diverse range of cognitive styles and performance levels. The selection process began with administering the Group Embedded Figures Test (GEFT) to classify students as FI or FD. From these classifications, three students were purposively selected from each cognitive style group, ensuring variation in geometry performance levels high, medium, and low. This composition allowed the study to capture distinct learning trajectories and examine how cognitive style interacts with students' creative thinking abilities in geometry.

2.2. Data Collection Technique

Data were gathered using the following methods:

- GEFT: This perceptual test was used to determine students' cognitive style, whether FI or FD, by identifying their ability to find embedded figures in complex images [41].
- Creative Thinking Test: This test was designed to assess students' creative thinking in solving geometry problems. The students' responses were analyzed to understand their trajectory in demonstrating creative thinking characteristics [42].
- Semi-structured Interviews: Interviews were conducted using an open-ended question guide to obtain deeper insights into students' cognitive processes, strategies, and reflections while engaging with geometry learning tasks. This helped to triangulate the results of the written tests [43].

2.3. Research Procedure

The research procedure consisted of three main stages, identifying cognitive styles through the GEFT to classify students as FI or FD, grouping participants into high, medium, and low mathematical ability levels, and administering geometry-based creative thinking tasks followed by semi-structured interviews for triangulation [44, 45]. This streamlined approach ensured consistency in data collection while minimizing redundancy and maintaining focus on how each student's cognitive style influenced their creative learning trajectory [46, 47].

2.4. Data Analysis Technique

The research procedure was carried out in several stages [27]. First, the determination of cognitive styles was done by administering the GEFT to categorize students as either FI or FD. The GEFT helped identify each student's cognitive style, which was essential for analyzing their learning trajectory in geometry [48].

3. RESULT AND DISCUSSION

In this study, the GEFT was used to determine students' cognitive styles, categorizing them as FD or FI. The GEFT consists of questions designed to assess students' ability to identify simpler images hidden within more complex ones, with a time limit of 12 minutes. The test is divided into three parts: the first section

includes 7 questions to be completed in 2 minutes, serving as a practice exercise to ensure students understand the instructions and test procedure, and is not scored. The second and third sections each contain 9 questions, which are the actual test items and are scored, with 5 minutes allotted for each section. The scoring criteria for the GEFT are as follows: students receive 1 point for each correct answer and 0 points for incorrect answers [49, 50]. The total score ranges from 1 to 18. A detailed scoring table for the GEFT test is provided below and presented in Table 1.

Table 1. GEFT Test Scoring Criteria

GEFT Score	Cognitive Style Type
0-11	FD
12-18	FI

Out of the 32 students who took the GEFT, 19 students were categorized with a FD cognitive style, while the remaining 13 students exhibited a FI cognitive style. The data is presented in the following table, as shown in Table 2.

Table 2. GEFT Test Results

No	Cognitive Style	Total
1	FD	19
2	FI	13

Data on the learning trajectory of creative thinking were collected through the analysis of student answer sheets and interviews with 18 selected students, chosen using purposive sampling based on considerations of cognitive style and ability. These 18 students were grouped to represent different cognitive ability levels. The high-level group consisted of SFI-01, representing students with a FI cognitive style and high cognitive ability, and SFD-01, representing students with a FD cognitive style and high cognitive ability. The middle-level group consisted of SFI-02, representing students with a FI cognitive style and medium cognitive ability, and SFD-02, representing students with a FD cognitive style and medium cognitive ability [51]. The low-level group consisted of SFI-03, representing students with a FI cognitive style and low cognitive ability, and SFD-03, representing students with a FD cognitive style and low cognitive ability.

The students' answer sheets were analyzed to determine the stages of their creative thinking while solving the test questions. Interviews were conducted after the learning activities to clarify and confirm the stages of creative thinking and the challenges students faced during the learning process or difficulties in solving the problems provided by the teacher [52].

3.1. The subject of the study, categorized as high ability FI (SFD-01)

Presented below with the student's answer sheet for analysis.

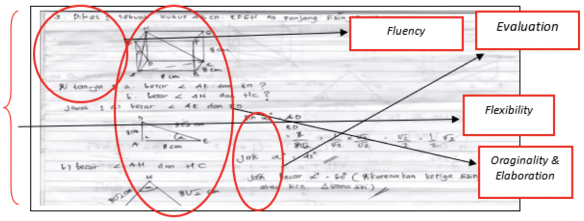

Figure 1. Analysis of the answer sheet of SFD-01

Based on Figure 1, it can be observed that almost all the indicators of creative thinking in SFD-01 are met. From the analysis of SFD-01's answer sheet and in-depth interviews, it was found that SFD-01 demonstrates a good level of creative thinking. On the answer sheet, SFD-01 was skilled in writing down what was known and what was asked, which met the fluency indicator, indicating the ability to identify the problem. Additionally, SFD-01 included a cube diagram in the answer sheet, which demonstrated flexibility in interpreting or understanding the problem with the aid of a visual representation. SFD-01 also showed the ability to evaluate answers, as indicated by summarizing the completed answers, which shows the evaluation capability.

However, the ability to elaborate on the answer step-by-step was somewhat inaccurate. This condition suggests that SFD-01's creative thinking process was disturbed by a noisy and chaotic classroom environment, which affected their concentration in completing the task. In this category, SFD-01 made errors in completing the task due to a lack of understanding of the concept, which was marked by mistakes in all or part of the task solution and an inability to evaluate their own errors. Therefore, SFD-01 also faced difficulties in linking concepts, from one concept to another. Below is an excerpt from the interview between the researcher and SFD-01.

- P : "When working on the problem, are you able to identify the problem and solve it step by step? (from stating what is known, what is asked, and the solution)".
- SFD-01 : "Yes, sir. When I was in middle school, my teacher told me that when solving problems, I must write down what is known, what is asked, and then the solution. I can't just give the answer directly".
- P : "Do you find it difficult to identify the problem?".
- SFD-01 : "No, sir. It's just a matter of writing down what is known, what is asked, and then answering. I just transfer what is in the question to my answer".
- P : "How do you understand the questions in the problems?" (interpreting the problem).
- SFD-01 : "I read the question carefully, sir, while looking for the formula that I will use".
- P : "Do you always draw the shape or figure mentioned in the question first? Do you find it difficult to draw?".
- SFD-01 : "Yes, sir, so I don't get confused when solving the problem later. I don't have trouble drawing".
- P : "Do you solve the problem based on your own ideas or someone else's?".
- SFD-01 : "It's my own idea, sir. I first understand the question given by the teacher, then I look for the formula to solve it".
- P : "At the end of the solution, do you always conclude the answer you found?".
- SFD-01 : "Yes, sir, I usually check again to see if my answer is correct or not".

3.2. Subject of research with medium cognitive ability, FI (SFI-02)

The following is the student's answer sheet (SFI-02) analyzed based on the indicators of creative thinking:

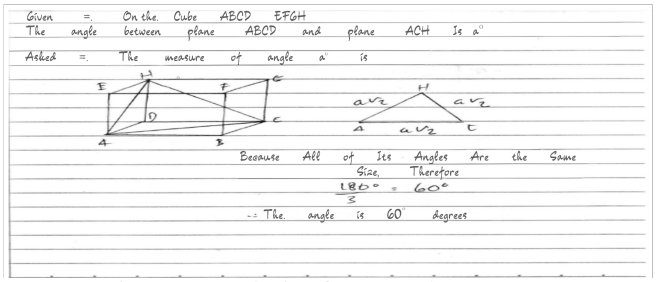

Figure 2. Analysis of answer sheet SFI-02

From the analysis of the answer sheet shown in Figure 2, it is evident that SFI-02 is proficient in writing down what is known and what is asked, fulfilling the fluency indicator, which refers to the ability to identify problems. Additionally, SFI-02 is skilled at drawing a cube diagram on the answer sheet, which reflects flexibility, or the ability to interpret/understand a problem with the help of a diagram. SFI-02 also demonstrates the ability to evaluate the answer, as shown by writing a summary of the completed solution, indicating an evaluation skill. However, the ability to detail the answer step-by-step with clear procedures is somewhat lacking.

Further insights into SFI-02's creative thinking process can be seen from the interview, as follows:

- P : ”When solving problems, do you complete them in an organized manner?” (from writing knowns, asked, and answers).
- SFI-02 : ”Yes, the teacher told us to do it that way”.
- P : ”Oh, is it difficult for you to work in an organized manner?”
- SFI-02 : ”No, it’s fine”.
- P : ”How do you understand the questions on the test?” (interpreting the problem).
- SFI-02 : ”I read it slowly while thinking about what is being asked”.
- P : ”Do you draw anything? If so, what’s the purpose?”.
- SFI-02 : ”Yes, it makes things clearer”.
- P : ”Do you always summarize the answer after solving the problem?”.
- SFI-02 : ”Yes, I do”.

Based on observations, interviews, and the analysis of the answer sheet, it can be concluded that SFI-02 exhibits a good level of creative thinking skills. This is supported by the improvement observed across meetings, as well as from the analysis of the answer sheet and interviews, although SFI-02 occasionally makes careless mistakes and lacks precision in determining the steps to solve the problems.

3.3. FD medium ability category research subject (SFD-02)

Based on observations, interviews, and excerpts from the answer sheet, it can be concluded that SFD-02 demonstrates a good level of creative thinking skills. This is evident from the observed improvement in skills across meetings, as well as from the analysis of the answer sheet and interviews. However, SFD-02 still shows occasional carelessness and a lack of detail in outlining the steps for solving problems. Below is the answer sheet of SFD-02, analyzed based on the indicators of creative thinking:

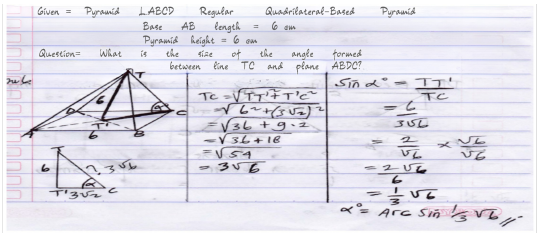

Figure 3. Analysis of answer sheet SFD-02

From the analysis of the answer sheet, observations, and interviews as illustrated in Figure 3, it can be concluded that SFD-02 demonstrates a good level of creative thinking skills. This is evident from the observed improvement in skills across meetings, as well as from the analysis of the answer sheet and interviews. However, SFD-02 still faces challenges with the evaluation aspect of creative thinking, as they sometimes forget to summarize the final answer, indicating that their evaluation skills are still lacking. Here’s the detailed analysis based on creative thinking indicators:

SFD-02 exhibits fluency, which refers to the skill of identifying problems, as shown by their ability to write down what is known and what is being asked. Fluency in problem identification provides valuable information for problem-solving. Additionally, SFD-02 displays elaboration skills by clearly outlining the steps for solving the problem. They are also capable of interpreting the problem through visual aids, as shown by the way they drew a cube in their answer sheet. However, the challenge SFD-02 faces is their tendency to forget to conclude the final answer, reflecting a weakness in their evaluation skills.

The following interview excerpts further illustrate SFD-02’s creative thinking abilities:

- P : ”When you are working on the problem, do you do it step by step?” (from writing down the known, the question, and the answer).

- SFD-02 : ”Yes, but sometimes I forget”.
- P : ”Do you find it difficult to work in an orderly manner?”.
- SFD-02 : ”No, I don’t”.
- P : ”How do you understand the questions in the problem?” (interpreting the problem).
- SFD-02 : ”I read it, then look for what is being asked”.
- P : ”Do you draw it? If so, what is the purpose?”.
- SFD-02 : ”Sometimes I draw it, sometimes I don’t. I often forget. The purpose is to understand better”.
- P : ”At the end of solving the problem, do you always summarize the answer you’ve found?”.
- SFD-02 : ”Yes, but I sometimes forget”.

Based on the observations, interviews, and analysis of the answer sheet, SFD-02 shows a good level of creative thinking skills, with noticeable improvement in each meeting. However, there is still room for improvement in the evaluation aspect of their thinking process.

3.4. Research Subject of Low Ability Category FI (SFI-03)

Based on the analysis of the answer sheet, observations, and in-depth interviews, it was found that SFI-03 is a student who demonstrates a moderate learning trajectory in creative thinking. This is evidenced by the answer sheet from the questions given by the researcher, as follows:

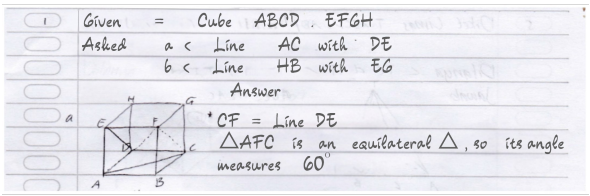

Figure 4. Analysis of answer sheet SFI-03

From the analysis of the answer sheet, observations, and in-depth interviews as presented in Figure 4, it was found that SFI-03 demonstrates moderate creative thinking skills. This is evident from the answer sheet provided by the researcher, as follows: SFI-03 is skilled at writing down what is known and asked, which meets the fluency indicator of creative thinking. This indicates the ability to identify problems and use the information for problem-solving. However, SFI-03 is not yet proficient in elaborating on the answer, as seen in the steps of problem-solving, which lack detail, even though the final answer is correct. Drawing a cube on the answer sheet reflects flexibility, a skill in interpreting a problem using visuals. SFI-03 struggles with evaluating answers, as the final conclusion is often not included, meaning SFI-03 has not fully developed the evaluation skill. Further analysis of SFI-03’s creative thinking skills can be seen from the following interview with the researcher:

- P : ”When solving the problem, do you follow a step-by-step process?” (Writing down what is known, asked, and answered).
- SFI-03 : ”Yes, I write down what is known, asked, and then answer it”.
- P : ”Do you have difficulty solving problems step by step?”.
- SFI-03 : ”No, I don’t”.
- P : ”How do you understand the questions on the test?” (Interpretation of the question).
- SFI-03 : ”I read it carefully”.

- P : ”Do you draw? If so, what’s the purpose?”.
- SFI-03 : ”Yes, I do, but sometimes I forget. The purpose is to help me understand the problem”.
- P : ”At the end of the problem-solving process, do you always conclude the answer?”.
- SFI-03 : ”Yes, but I often forget”.

Based on observations and the interview, as well as the answer sheet, SFI-03 has a moderate learning trajectory in creative thinking.

3.5. Research subject of low ability category FD (SFD-03)

From the data collected through observations and in-depth interviews, it was found that SFD-03 is a student who possesses moderate creative thinking skills.

To summarize the comparative findings, the following table presents differences in creative thinking outcomes based on cognitive styles (FI vs. FD) and ability levels (high, medium, low):

Table 3. Summary of Creative Thinking Outcomes Based on Cognitive Styles and Ability Levels

Cognitive Style	Ability Level	Creative Thinking Level	Strong Indicators	Weak Indicators
Field Independent FI	High	High	Fluency, Flexibility, Evaluation, Originality	–
Field Independent FI	Medium	High–Moderate	Fluency, Flexibility, Evaluation	Elaboration
Field Independent FI	Low	Moderate	Fluency, Flexibility	Originality, Evaluation
Field Dependent FD	High	High	Fluency, Flexibility, Evaluation	Elaboration
Field Dependent FD	Medium	Moderate	Fluency, Elaboration	Evaluation
Field Dependent FD	Low	Moderate–Low	Fluency	Elaboration, Evaluation

The summary Table 3 above illustrates that FI students generally exhibit higher levels of creative thinking across all indicators, particularly in fluency, flexibility, and evaluation, whereas FD students tend to struggle in elaboration and evaluation aspects, especially at lower ability levels.

This is evidenced by the answer sheet provided for the problem given by the researcher, as follows:

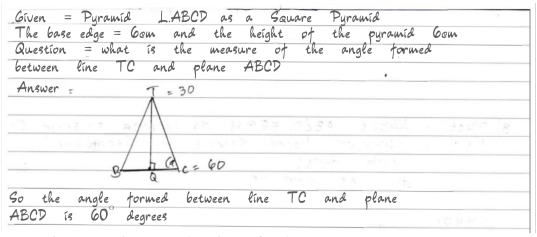

Figure 5. Analysis of Sheet Answer SFD-03

From the analysis of Figure 5, it was found that SFD-03 is fairly skilled in identifying problems that will serve as information for solving them. This demonstrates their fluency in thinking, as shown by their ability to write down what is known and what is asked. However, SFD-03's skill in elaborating the answer with correct steps is still lacking, as evidenced by the insufficiently detailed answers. The cube diagram included in the answer sheet demonstrates their flexibility, or the ability to interpret or interpret a problem using visual aids. Although the diagram was not entirely complete or clear, the effort to draw it has been recognized as a skill in problem interpretation (flexibility). At the end of the answer sheet, SFD-03 demonstrates evaluation skills by writing a summary of the completed answers, indicating they possess adequate evaluation skills.

Further analysis of SFD-03's creative thinking learning trajectory can be seen in the following interview between the researcher and SFD-03:

- P : "When working on the problems, do you do it in a systematic order or not?" (from writing what is known, what is asked, and answering).
- SFD-03 : "Yes, sir, I do it in order, known, asked, then answered".
- P : "Do you find it difficult to work in a systematic order?".
- SFD-03 : "Not really, sir, but if the problem is difficult, sometimes I find it hard to organize it".
- P : "How do you understand the questions in the problems?" (giving interpretation of the problems).
- SFD-03 : "I usually read them first, and if I don't understand the meaning, I ask my friends, sir".
- P : "At the end of the problem-solving, do you always summarize the answer you have found?".
- SFD-03 : "Yes, sir, but sometimes I forget".

Based on the observations, interviews, and analysis of the answer sheet, SFD-03 shows a moderate learning trajectory for creative thinking. The observations indicate improvement, though not significantly large, but if analyzed deeper, the improvements seen in each meeting suggest that SFD-03 has the desire to improve their creative thinking skills [30].

4. MANAGERIAL IMPLICATIONS

The findings of this study provide several important managerial implications for educators, school administrators, policymakers, and edupreneurs in promoting creativity-based learning and technopreneurial education. First, for educators, understanding students' cognitive styles FI and FD is essential in designing adaptive learning trajectories that foster creative thinking through personalized instruction. Teachers can use differentiated approaches to enhance fluency, flexibility, and originality by integrating project-based and visual learning strategies into geometry lessons.

Second, for school managers and administrators, the results highlight the importance of institutional support for continuous professional development programs that train teachers to apply creativity-centered and innovation-driven teaching models. Schools should encourage collaboration between educators to design learning environments that align with 21st-century skills, especially creativity and problem-solving.

Third, for policymakers, this study underlines the need to incorporate cognitive diversity frameworks into national curriculum standards and policies to support inclusive, equitable, and innovative education. Such policies can strengthen creative competencies that contribute to Sustainable Development Goal 4 (Quality Education).

Finally, for edupreneurs and technopreneurs, the proposed learning trajectory offers opportunities to develop educational products, digital platforms, and teacher training workshops that embed creative and cognitive diversity principles. These innovations can enhance both pedagogical effectiveness and entrepreneurial value, supporting the creation of scalable education solutions that align with the evolving demands of digital learning ecosystems.

5. CONCLUSION

Based on the analysis of creative thinking ability test results and interviews, this study concludes that FI students in the high and medium categories demonstrate strong learning trajectories because they are able to fulfill all creative thinking indicators. FI students in the low category show a moderate learning trajectory, particularly because the originality indicator has not been fully achieved. Meanwhile, FD students in the high category also show a good learning trajectory by meeting all creative thinking indicators, while FD students in the medium and low categories still require further support, especially in elaboration and evaluation skills. These difficulties are mainly related to weak visual-spatial abilities, limited accuracy in visualizing geometric objects, forgetting formulas or calculation procedures, and lack of thoroughness in evaluating answers.

The implication of these findings is that geometry learning should be designed through adaptive and differentiated instructional strategies that consider students' cognitive styles and levels of creative thinking ability. Teachers need to provide learning activities that strengthen visual-spatial understanding, encourage students to elaborate their ideas, and guide them in evaluating their solutions more carefully. In addition, the use of visual representations, structured problem-solving guidance, and reflective evaluation tasks can help students improve originality, elaboration, and accuracy in solving geometry problems. This study also supports SDG 4: Quality Education by promoting inclusive and innovative learning practices that enhance students' creative potential and cognitive diversity.

Future research is recommended to involve a larger and more diverse sample to obtain broader and more generalizable findings. Further studies may also integrate technology-based learning media, dynamic geometry software, or visual-spatial learning tools to examine their effectiveness in improving students' creative thinking trajectories. In addition, future research can explore specific instructional models that are most suitable for supporting FI and FD students across different ability levels, particularly in strengthening elaboration, evaluation, and originality in geometry learning.

6. DECLARATIONS

6.1. About Authors

Hendri Handoko (HH) https://orcid.org/0000-0002-2229-9686
Stevanus Budi Waluya (SB) https://orcid.org/0000-0002-8834-1138
Wardono Wardono (WW) https://orcid.org/0000-0001-6586-9856
Sugiman (SS) https://orcid.org/0000-0002-1656-6661
Li Wei Ming (LW) https://orcid.org/0009-0003-3283-3955

6.2. Author Contributions

Conceptualization: HH; Methodology: SB; Software: WW; Validation: LW and SS; Formal Analysis: WW and SB; Investigation: HH; Resources: SS; Data Curation: WW; Writing Original Draft Preparation: LW and HH; Writing Review and Editing: HH and SS; Visualization: LW; All authors, HH, SB, WW, SS and LW, have read and agreed to the published version of the manuscript.

6.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.4. Funding

The author would like to express sincere gratitude to the Ministry of Religious Affairs of the Republic of Indonesia (Kementerian Agama Republik Indonesia) for the invaluable support and opportunities provided throughout the course of this research. This study would not have been possible without the academic guidance, encouragement, and funding facilitated by the Ministry. The author also extends heartfelt thanks to all lecturers, colleagues, and research participants who contributed their time and insights, making this study meaningful and impactful.

6.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] U. Azmi, Safrijal, and M. Rahmi, "Analysis of 4c skills (critical thinking, creativity and innovation, collaboration, and communication) of physics education students in facing the industrial revolution 4.0," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 2, pp. 695–703, 2024.

[2] N. Lutfiani, D. Apriani, E. A. Nabila, and H. L. Juniar, "Academic certificate fraud detection system framework using blockchain technology," *Blockchain Frontier Technology*, vol. 1, no. 2, pp. 55–64, 2022.

[3] T. Irham and B. Jabu, "Development of the 4c teaching model to improve students' mathematical critical thinking skills," *International Journal of Educational Methodology*, vol. 8, no. 3, pp. 493–504, 2022, [Online]. Available: https://eric.ed.gov/?id=EJ1357642.

[4] M. A. Adeoye and H. A. Jimoh, "Problem-solving skills among 21st-century learners toward creativity and innovation ideas," *Thinking Skills and Creativity*, vol. 6, no. 1, pp. 52–58, 2023.

[5] Y.-S. Su, H.-W. Cheng, and C.-F. Lai, "Study of virtual reality immersive technology enhanced mathematics geometry learning," *Frontiers in psychology*, vol. 13, p. 760418, 2022.

[6] B. Thornhill-Miller, A. Camarda, M. Mercier, and J.-M. Burkhardt, "Creativity, critical thinking, communication, and collaboration: Assessment, certification, and promotion of 21st century skills for the future of work and education," *Journal of Intelligence*, vol. 11, no. 3, p. 54, 2023.

[7] R. Firdaus and R. Firdaus, "Implementation of the addie model for developing multimedia learning media and gamification on space objects material on elementary school," *JUTIF: Jurnal Teknik Informatika*, vol. 5, no. 4, pp. 365–373, 2024.

[8] S. Li, J. Zhou, T. Xu, D. Dou, and H. Xiong, "Geomgcl: Geometric graph contrastive learning for molecular property prediction," in *Proceedings of the AAAI conference on artificial intelligence*, vol. 36, no. 4, 2022, pp. 4541–4549.

[9] R. Parker, B. S. Thomse, and A. Berry, "Learning through play at school – a framework for policy and practice," *Frontiers in Education*, vol. 7, 2022.

[10] C. Sriliasta and D. S. S. Wuisan, "Stepping forward: Enhancing cognitive learning outcomes through hybrid rccr-based learning on circulatory system material," *International Transactions on Artificial Intelligence*, vol. 2, no. 1, pp. 49–59, 2023.

[11] A. Alfiyanto, W. Walidin, and S. Mahmud, "Characteristics of learning theories in education according to psychological development," *Jurnal Konseling Pendidikan Islam*, vol. 5, no. 1, pp. 171–187, 2024.

[12] A. Kristian, T. S. Goh, A. Ramadan, A. Erica, and S. V. Sihotang, "Application of ai in optimizing energy and resource management: Effectiveness of deep learning models," *International Transactions on Artificial Intelligence*, vol. 2, no. 2, pp. 99–105, 2024.

[13] W. Wan, H. Geng, Y. Liu, Z. Shan, Y. Yang, L. Yi, and H. Wang, "Unidexgrasp++: Improving dexterous grasping policy learning via geometry-aware curriculum and iterative generalist-specialist learning," in *Proceedings of the IEEE/CVF International Conference on Computer Vision*, 2023, pp. 3891–3902.

[14] M. Akteruzzaman, S. B. Sattar, and S. M. J. Anwar, "Motivation in l2 learning: An analysis with self-determination theory," *Multidisciplinary Reviews*, vol. 6, no. 1985, 2023.

[15] N. Ramadhona, A. A. Putri, and D. S. S. Wuisan, "Students' opinions of the use of quipper school as an online learning platform for teaching english," *International Transactions on Education Technology*, vol. 1, no. 1, pp. 35–41, 2022.

[16] H. Yang and S. Kyun, "The current research trend of artificial intelligence in language learning: A systematic empirical literature review from an activity theory perspective," *Australasian Journal of Educational Technology*, vol. 38, no. 5, pp. 180–210, 2022.

[17] A. Arta, M. A. Faizal, B. N. Asiyah, and Mashudi, "The role of edupreneurship in gen z in shaping independent and creative young generation," *Maro: Jurnal Ekonomi Syariah dan Bisnis*, vol. 6, no. 2, pp. 231–241, 2023.

[18] C. Lukita, M. Hardini, S. Pranata, D. Julianingsih, and N. P. L. Santoso, "Transformation of entrepreneurship and digital technology students in the era of revolution 4.0," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 5, no. 3, pp. 291–304, 2023, https://doi.org/10.34306/att.v5i3.356.

[19] D. P. Larey, A. Le Roux, and L. Jacobs, "Evoking edupreneurial leadership towards social justice among historically disadvantaged communities," *International Journal of Leadership in Education*, vol. 27, no. 2, pp. 412–428, 2024.

[20] C.-C. Chen and Y.-Y. Huang, "Knowledge mapping of educational entrepreneurs and corresponding strategies for school management by principals in primary and secondary education," *Journal of Edu-*

cation Research, no. 374, pp. 75–91, 2025.
[21] U. Rahardja, Q. Aini, D. Manongga, I. Sembiring, and I. D. Girinzio, "Implementation of tensor flow in air quality monitoring based on artificial intelligence," *International Journal of Artificial Intelligence Research*, vol. 6, no. 1, p. 23, 2023.
[22] E. F. Ferro *et al.*, "Self-perception of the level of achievement of the disciplinary and pedagogical standards in physical education students of two universities in santiago de chile," *Retos: Nuevas Tendencias en Educación Física, Deporte y Recreación*, vol. 48, pp. 197–206, 2023.
[23] M. M. Yousefabadi, T. Ghasemnezhad, and Y. Akbarie, "The effect of anxiety, motivation and self-confidence in language learners' reading proficiency," *NeuroQuantology*, vol. 20, no. 16, pp. 4966–4976, 2022.
[24] A. Sijabat, F. Festiyed, A. Razak, S. Diliarosta, L. Lufri, and N. Leonie, "Development of ulos learning model with ar to foster cultural appreciation," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 7, no. 1, pp. 72–83, 2025, https://doi.org/10.34306/att.v7i1.471.
[25] M. Samaniego, N. Usca, J. Salguero, and W. Quevedo, "Creative thinking in art and design education: A systematic review," *Education Sciences*, vol. 14, no. 2, p. 192, 2024.
[26] S. A. Ferdaus and D. Novita, "The implementation of the merdeka curriculum in english subject at a vocational high school in indonesia," *Briliant: Jurnal Riset dan Konseptual*, vol. 8, no. 2, p. 297, 2023.
[27] I. Hartaji, I. Nursit, and A. H. Fathani, "Identification of students' mathematical creative thinking ability in number pattern problems solving," *Numerical: Jurnal Matematika dan Pendidikan Matematika*, vol. 7, no. 1, pp. 233–241, 2023.
[28] G. Carella, M. Conte, C. Cautela *et al.*, "Designing entrepreneurs: Structuring an educational framework for design-driven entrepreneurship," in *Education and New Developments 2025–Volume I*. inScience Press, 2025, pp. 361–365.
[29] A. Žakelj and A. Klančar, "The role of visual representations in geometry learning," *European Journal of Educational Research*, vol. 11, no. 3, pp. 1393–1411, 2022.
[30] M. Nobutoshi, "Metacognition and reflective teaching: A synergistic approach to fostering critical thinking skills," *Research Advances in Education*, vol. 2, no. 9, pp. 1–14, 2023.
[31] E. Purnomo *et al.*, "Enhancing problem-solving skills through physical education learning: A comprehensive analysis," *Retos: Nuevas Tendencias en Educación Física, Deporte y Recreación*, vol. 58, pp. 435–444, 2024.
[32] S. Lee-Cultura, K. Sharma, and M. Giannakos, "Children's play and problem-solving in motion-based learning technologies using a multi-modal mixed methods approach," *International Journal of Child-Computer Interaction*, vol. 31, p. 100355, 2022.
[33] I. D. Girinzio, A. Ramadan, D. B. Saputra, G. Mustika, and Sulistio, "Improve critical thinking students in indonesia for new learning management system," pp. 111–121, 2023.
[34] M. H. R. Chakim, P. A. Sunarya, V. Agarwal, I. N. Hikam *et al.*, "Village tourism empowerment against innovation, economy creative, and social environmental," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 5, no. 2sp, pp. 162–174, 2023, https://doi.org/10.34306/att.v5i2sp.342.
[35] P. Ramseook-Munhurrun, P. Naidoo, and S. Armoogum, "Navigating the challenges of female leadership in the information and communication technology and engineering sectors," *Journal of Business and Socio-economic Development*, vol. 5, no. 1, pp. 55–70, 2025.
[36] A. Ledentsov, "Knowledge base reuse with frame representation in artificial intelligence applications," *IAIC Transactions on Sustainable Digital Innovation (ITSDI)*, vol. 4, no. 2, pp. 146–154, 2023.
[37] A. Suryani, S. Soedarso, W. Windiani, T. Hanoraga, S. H. B. Harmadi, and Y. Setyaningsih, "The social dimensions of creativepreneurship education: Unleashing youth's creative potentials through teamwork and collaborative creativity," *International Journal of Pedagogical and Social Studies*, vol. 7, no. 1, pp. 43–58, 2022.
[38] N. Lutfiani and L. Meria, "Utilization of big data in educational technology research," *International Transactions on Education Technology*, vol. 1, no. 1, pp. 73–83, 2022.
[39] A. Wilson, R. Kask, and L. W. Ming, "Exploring circular digital economy strategies for sustainable environmental, economic, and educational technology," *International Transactions on Education Technology (ITEE)*, vol. 2, no. 2, pp. 129–139, 2024.
[40] E. J. Tisdell, S. B. Merriam, and H. L. Struckey-Peyrot, *Qualitative Research: A Guide to Design and Implementation*. John Wiley & Sons, 2025.

[41] S. Jablonski and M. Ludwig, "Teaching and learning of geometry—a literature review on current developments in theory and practice," *Education sciences*, vol. 13, no. 7, p. 682, 2023.
[42] K. M. I. Rosyida and B. K. Prahani, "Enhancing students' critical thinking skills in physics: Exploring problem-based learning and mobile technology integration in rotational dynamics education," *Advances in Mobile Learning Educational Research*, vol. 5, no. 1, pp. 1301–1313, 2025.
[43] A. G. Prawiyogi, S. Purnama, and L. Meria, "Smart cities using machine learning and intelligent applications," *International Transactions on Artificial Intelligence*, vol. 1, no. 1, pp. 102–116, 2022.
[44] C. Isert, K. Atz, and G. Schneider, "Structure-based drug design with geometric deep learning," *Current Opinion in Structural Biology*, vol. 79, p. 102548, 2023.
[45] J. L. Willson, A. Nuche, and R. Widayanti, "Ethical considerations in the development of ai-powered healthcare assistants," *International Transactions on Education Technology (ITEE)*, vol. 2, no. 2, pp. 109–119, 2024.
[46] X. Fang, L. Liu, J. Lei, D. He, S. Zhang, J. Zhou, F. Wang, H. Wu, and H. Wang, "Geometry-enhanced molecular representation learning for property prediction," *Nature Machine Intelligence*, vol. 4, no. 2, pp. 127–134, 2022.
[47] V. El Ardeliya, J. Taylor, and J. Wolfson, "Exploration of artificial intelligence in creative fields: Generative art, music, and design," *International Journal of Cyber and IT Service Management*, vol. 4, no. 1, pp. 40–46, 2024.
[48] I. Arifah, N. S. Ramadhani, Y. Kusumawati, and A. Setiawan, "Feel supported and not alone": A qualitative study of supports needed by pregnant women in preventing anemia," *J Promot Health Edu*, vol. 12, no. 2, pp. 168–179, 2024.
[49] D. Komalasari, L. Ahdiani *et al.*, "Implementing edupreneurship in early childhood education: Enhancing holistic development through creative learning projects," *International Journal of Education and Humanities*, vol. 5, no. 4, pp. 653–661, 2025.
[50] H. Tussa'diah and N. Y. Kartika, "Critical discourse analysis on linguistic ideology of the netizens comments," *ADI Journal on Recent Innovation*, vol. 4, no. 2, pp. 110–121, 2023.
[51] M. Fuster Rabella, "Evolving ai capabilities and the school curriculum: Emerging implications and a case study on writing," OECD Publishing, Paris, OECD Education Working Papers 338, 2025. [Online]. Available: https://doi.org/10.1787/647880aa-en
[52] T. Hongsuchon, U. Rahardja, A. Khan, T.-H. Wu, C.-W. Hung, R.-H. Chang, C.-H. Hsu, and S.-C. Chen, "Brand experience on brand attachment: The role of interpersonal interaction, feedback, and advocacy," *Emerging Science Journal*, vol. 7, no. 4, pp. 1232–1246, 2023.