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Mathematical Reasoning Profile of Vocational Students in STEM-Based Contextual Problems Viewed from Field Independent and Field Dependent Cognitive Styles

Victor Istas Purba [a,1,*], Tri Dyah Prastiti [b,2], Thesa Kandaga [c,3]

[1,2,3] Master's Program in Mathematics Education, Faculty of Mathematics and Natural Sciences Education, Universitas Terbuka, Indonesia.
[1] 501312234@ecampus.ut.ac.id; [2] tridyahprastiti@ecampus.ut.ac.id, [3] thesa.official@ecampus.ut.ac.id
*Correspondent Author; victoristas9@gmail.com

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ABSTRACT

This study profiles the mathematical reasoning of vocational high school (SMK) students in the Electrical Power Installation Engineering (TITL) program when solving STEM-based contextual problems, examined through field independent (FI) and field dependent (FD) cognitive styles. An explanatory sequential mixed-methods design was applied to 40 eleventh-grade students. The Group Embedded Figures Test (GEFT) classified cognitive style, while a researcher-developed STEM-based Mathematical Reasoning Test (TKPM), scored against five NCTM indicators, measured reasoning; six subjects (3 FI, 3 FD) were then explored through task-based clinical interviews analysed using Braun and Clarke's thematic analysis. Results show that 45% of students were FI and 55% FD. All six subjects fell into the Very Low category (mean 18.61 of 100), with 61.1% of indicator cells scoring zero. Reasoning declined steadily from conjecturing and manipulation (1.28 of 4) to drawing conclusions (0.61), justification (0.33), and validity checking (0.22). FI students displayed analytic independence (specific data enumeration, distractor filtering, and metacognitive self-correction) and excelled at open statistical reasoning, whereas FD students were strong in well-practised procedures (two of three perfect scores on matrix addition) but weak in meaning decomposition, scoring zero on justification and validity. Notably, the advantage reversed by task type: FI led on open reasoning, FD on structured procedure. Overall, the FI style more strongly supported STEM reasoning, though not uniformly. The findings offer an empirical basis for cognitively responsive mathematics instruction and underscore that reasoning errors (correct procedure but wrong conclusion) pose real workplace-safety risks in electrical work

Introduction

Mathematics plays a central role in shaping logical, systematic, and critical thinking, abilities needed not only in academic contexts but also in the world of work, particularly in engineering. The Ministry of Education, Culture, Research, and Technology (Kemendikbudristek, 2022) asserts that vocational high school (SMK) students are required not merely to master computational procedures but also to use mathematics to analyse and solve real problems related to their field of expertise. One key ability underpinning this demand is mathematical reasoning. Bjuland and Fauskanger (2022) define mathematical reasoning as a structured thinking process involving the analysis of relationships between concepts, evidence-based decision making, and the provision of mathematically defensible justification. Without adequate reasoning, mathematics learning becomes trapped in the rote memorisation of formulas without meaningful conceptual understanding (Herman, Darhim, & Dahlan, 2022).

The implementation of mathematical reasoning standards at the SMK level in Indonesia still shows a clear gap, especially in constructing logical arguments and drawing evidence-based conclusions. Permatasari and Setiawan (2022) and Hidayat and Sariningsih (2022) report that the mathematical reasoning ability of Indonesian SMK students remains low because instruction tends to emphasise rote procedures rather than the development of meaningful reasoning. In the Electrical Power Installation Engineering (TITL) program, the demand for reasoning becomes critical because students must analyse circuits, calculate power, interpret voltage-current graphs, and determine cable capacity and protection; errors in reasoning may lead to technical failure and occupational safety risks (Pratiwi, Maharani, & Astuti, 2021).

This phenomenon was confirmed by a preliminary study of the mid-semester assessment results in Grade XI TITL mathematics at SMK Negeri 2 Samarinda. In Grade XI TITL 1 (35 students), only 6 students (17.14%) were able to solve the contextual problems correctly, while 12 students (34.29%) began the solution steps but did not complete them; in Grade XI TITL 2 (36 students), only 11 students (30.56%) succeeded. These data confirm the gap between students' procedural ability and their mathematical reasoning ability.

Differences in ability between students are influenced not only by instructional factors but also by cognitive characteristics. Witkin, Moore, Goodenough, and Cox (1977) distinguish cognitive style into field independent (FI) and field dependent (FD). FI students tend to analyse information independently and devise their own strategies, whereas FD students require external guidance to understand problem structure (Mutlu & Polat, 2022). At the same time, the Science, Technology, Engineering, and Mathematics (STEM) approach is regarded as relevant to twenty-first-century demands because it integrates four disciplines to solve real problems and has been shown to improve mathematics learning outcomes (Baran, Canbazoglu Bilici, & Mesutoglu, 2021; Moore, Johnston, & Glancy, 2021).

Various prior studies have examined these three variables, but separately. Baran et al. (2021) and Moore et al. (2021) examined the effectiveness of STEM without addressing cognitive style; Syarifah, Usdiyana, and Prabawanto (2022) studied STEM among SMK students without considering cognitive style; Mutlu and Polat (2022) reviewed FI-FD cognitive style but not in a STEM or vocational context; while Huda, Mujib, and Ramdhani (2024), Permatasari and Setiawan (2022), and Sari and Mampouw (2021) examined reasoning by cognitive style in pure-mathematics contexts at the junior and senior secondary levels. Thus, the simultaneous intersection of three variables, namely mathematical reasoning, STEM-based contextual problems, and FI-FD cognitive style, among SMK TITL students, has never been undertaken. It is this gap that the present study seeks to fill.

The novelty of this study is formulated in three aspects. First, in substance, the study profiles the mathematical reasoning process of SMK TITL students in depth through a combination of written tests and task-based clinical interviews, so that it does not stop at learning outcomes but probes the thinking process behind students' answers. Second, methodologically, the study compares the reasoning profiles of FI and FD students within an authentic STEM context in the electrical engineering field. Third, in terms of instrumentation, the study develops a Mathematical Reasoning Test (TKPM) specific to the STEM-TITL context, covering all five NCTM reasoning indicators within real vocational problem situations.

Based on this, the study aims to: (1) describe the general mathematical reasoning profile of SMK TITL students in solving STEM-based problems; (2) describe the population's cognitive-style profile based on the GEFT; (3) analyse the reasoning profile of FI students; (4) analyse the reasoning profile of FD students; (5) conclude which cognitive style better supports STEM-based mathematical reasoning; and (6) identify the similarities and differences in reasoning profiles between FI and FD students.

Method

This study employed a mixed-methods approach with an explanatory sequential design (Creswell & Creswell, 2023) consisting of two sequential and complementary phases. The first phase was quantitative descriptive, involving 40 Grade XI students of the Electrical Power Installation Engineering (TITL) program at SMK Negeri 2 Samarinda. In this phase, Group Embedded Figures Test (GEFT) scores were analysed using descriptive statistics to obtain the population's cognitive-style profile (distribution, mean, standard deviation, and the proportions of FI and FD), and the STEM-based TKPM scores were analysed per NCTM indicator to portray the class's general reasoning ability. The results of this phase became the basis for selecting six main subjects through purposive sampling.

The second phase was qualitative exploratory, using a case-study design with six selected subjects (three FI and three FD). Subject selection considered the clarity of the cognitive-style category, variation in TKPM ability (high, medium, low), verbal ability, and willingness to participate. Subject identities were anonymised with the codes SFI-01 to SFI-03 and SFD-01 to SFD-03. In-depth reasoning was probed through analysis of answer sheets and task-based clinical interviews using the think-aloud technique, which enabled the researcher to reach dimensions of reasoning not revealed in writing, such as hesitation, self-correction, and metacognitive strategies (Koichu & Zazkis, 2022).

The GEFT (Witkin et al., 1977) measures the perceptual-analytic ability to separate a simple geometric figure from a complex background, with a reliability coefficient of 0.82 to 0.92, and has been validated in the Indonesian context (Arifin & Setiawan, 2022; Sari & Mampouw, 2021). Parts II and III each contain nine scored items (maximum score 18); classification follows the cut-off of Witkin et al. (1977): scores of 0–9 are FD and 10–18 are FI. The TKPM was developed by the researcher with reference to five NCTM indicators, namely (a) making conjectures, (b) mathematical manipulation, (c) drawing logical conclusions, (d) constructing proof and justification, and (e) checking the validity of arguments, integrated with the STEM-TITL context. Content validity was computed using the Content Validity Ratio. The TKPM items administered to the main subjects were three contextual case-study problems: Problem 1 (descriptive statistics on industrial lamp power consumption), Problem 2 (sequences and series on power-load growth), and Problem 3 (matrices on the load distribution of two buildings). Each item was scored using an analytic rubric of 0–4 per indicator, so that the maximum score per item was 20 and the total was 60 (converted to a 0–100 scale).

Scoring was conducted by the researcher and verified by a second rater (a mathematics teacher), with inter-rater agreement maintained through an inter-rater procedure (Cohen's Kappa). Qualitative data analysis used Braun and Clarke's (2021) Thematic Analysis with a deductive-inductive approach across six phases: familiarisation, initial coding, searching for themes, reviewing themes, defining themes, and producing the report. Data trustworthiness was ensured through source and method triangulation, thick description, audit trail, and member checking. Source triangulation was obtained from semi-structured interviews with the mathematics teacher and the TITL productive teacher.

Results and Discussion

3.1 Students' Cognitive-Style Profile Based on the GEFT

Cognitive-style identification was performed on all 40 students. GEFT scores ranged from 5 to 16 with a mean of 10.00, a median of 10.00, and a standard deviation of 3.63; the distribution was relatively symmetric. Based on the cut-off of Witkin et al. (1977), 18 students (45%) were field independent and 22 students (55%) were field dependent. The mean of the FI group was 13.50 (range 12–16) and that of the FD group was 7.14 (range 5–11). The mean difference of 6.36 points, almost twice the population standard deviation, indicates a sharp contrast, so that the comparison of reasoning profiles rests on a robust grouping. The largest concentration (40%) actually lay in the low-score band, signalling that the ability to restructure the perceptual field, which is closely related to analytic reasoning, has not developed evenly. The recapitulation is presented in Table 1.

Table 1. *Recapitulation of the Cognitive-Style Profile of the Study Population*

Cognitive Style	Number	Percentage	Mean	Range
Field Independent (FI)	18	45%	13.50	12–16
Field Dependent (FD)	22	55%	7.14	5–11
Total	40	100%	10.00	5–16

The dominance of FD students (55%) and their concentration in the low band align with tendencies reported in the Indonesian context (Sari & Mampouw, 2021; Huda et al., 2024) and carry direct pedagogical implications. If the majority of the class processes information globally and relies on external guidance, then abstract instruction with few contextual examples is precisely what most disadvantages that majority group.

3.2 General Profile of Mathematical Reasoning Ability

The general profile is portrayed through the six subjects' TKPM achievement, which represents the range of class ability. The most striking finding: all six subjects, without exception, fell into the Very Low category (scores 0–39), with final scores ranging from 10.00 to 26.67 and a mean of 18.61. Even the highest achievement (26.67) remained far below the threshold of the Low category (40). Details are presented in Table 2.

Table 2. *STEM-Based TKPM Achievement Scores of the Six Study Subjects*

Subject	Style	Problem 1 (/20)	Problem 2 (/20)	Problem 3 (/20)	Total (/60)	Score (/100)
Lyra	FI	13	3	0	16	26.67
Ramadhan	FI	11	2	0	13	21.67
Rehan	FI	10	2	0	12	20.00
Azka	FD	2	3	6	11	18.33
Tegar	FD	3	0	6	9	15.00
Noril	FD	5	0	1	6	10.00

Examination of the 90 score cells (6 subjects × 3 problems × 5 indicators) reveals the depth of the problem: 55 cells (61.1%) scored 0, only 10 cells (11.1%) reached good quality (score ≥ 3), and only 3 cells (3.3%) attained the maximum score of 4. These three full scores are theoretically meaningful: one was earned by an FI student (Lyra) on the making-conjectures indicator in Problem 1, and two by FD students (Tegar and Azka) on the mathematical-manipulation indicator in Problem 3. In other words, the peak of FI achievement lay in reasoning (conjecturing), whereas the peak of FD achievement lay in procedure (manipulating), a miniature contrast of the two cognitive styles.

When scores are averaged per NCTM indicator across the six subjects, a highly consistent stepped pattern emerges, declining as the reasoning demand rises (Table 3). The making-conjectures and mathematical-manipulation indicators were equally highest (1.28), then declined sharply for drawing conclusions (0.61) and justification (0.33), and were lowest for validity checking (0.22).

Table 3. *Mean Score per NCTM Indicator (0–4 Scale)*

NCTM Indicator	Combined (6)	FI (3)	FD (3)
(a) Making Conjectures	1.28	1.44	1.11
(b) Mathematical Manipulation	1.28	1.11	1.44
(c) Drawing Conclusions	0.61	0.89	0.33
(d) Proof & Justification	0.33	0.67	0.00
(e) Validity Checking	0.22	0.44	0.00

This profile can be described as reasoning that is blunt at the source and nearly extinguished downstream: students can begin to think (conjecture, manipulate symbols) but fail to carry it through into a conclusion that is proven and tested for validity. The same pattern was reinforced by the teacher's account in triangulation, that students are "strong in procedure, weak in reasoning," and that the "checking back" stage is the least frequently performed. This finding strengthens Bjuland and Fauskanger's (2022) definition that places defensible justification at the core of reasoning: it is precisely at that core that students collapse. The root of the problem is threefold: untrained material (standard deviation), conceptual misconception (the nature of geometric growth), and the disconnect between procedure and meaning (matrix operations and unit referents), consistent with the findings of Anggraini, Wijaya, and Hartono (2022) on SMK students' learning difficulties rooted in weak reasoning.

3.3 Mathematical Reasoning Profile of Field Independent Subjects

FI subjects built conjectures through specific data enumeration rather than a global impression. SFI-01 (Rehan) and SFI-02 (Lyra) both counted the distribution before any formal calculation; SFI-02 even labelled each datum with a serial number and earned the only full score (4) for the conjecture indicator across the entire dataset. In the interview, SFI-01 recounted: “The spread, Sir. I did a quick rough count: there are six lamps below 90, two above 90, and one exactly 90. From there I could already guess the average would be below 90.” Analytic independence was also evident in filtering distractor information: SFI-01 deliberately ignored the phrase “three production shifts,” which was irrelevant to the available data.

In basic manipulation, FI subjects were skilled: the mean (776 ÷ 9 = 86.2 watts) and median (88 watts) were computed correctly. However, manipulation stalled precisely at the standard deviation: not one FI subject completed it to a final figure. SFI-02 mistakenly used the sequence formula for the standard deviation, then realised it independently when prompted: “Now that I think about it, 776 over 9 is the same as the mean, so it doesn’t make sense for a standard deviation.” This ability to judge the reasonableness of one’s own result signals metacognition that remained active. In Problem 3, although the answer sheet was blank, in the interview SFI-03 was able to reconstruct P + Q and correct his conclusion spontaneously: “so 80 is greater than 40, right, Sir? That means Building B is larger, not A. I had it reversed earlier.”

This profile is a direct manifestation of the field independent characteristics described by Witkin et al. (1977): the ability to restructure the field and isolate relevant elements from a complex background. The metacognitive control that Koichu and Zazkis (2022) note is revealed only through clinical interviews becomes an important methodological value: without prompting, FI self-correction is invisible and the profile appears as low as that of FD. Overall, the FI profile excels in analytic independence, data decomposition, and self-monitoring, with its main weakness lying in the completeness and precision of procedural execution

3.4 Mathematical Reasoning Profile of Field Dependent Subjects

FD conjectures were typically built from a global impression. SFD-02 (Noril) guessed the average was below 90 watts because “the figures in the 70s and 80s dominate,” admitting that he did not calculate. SFD-01 (Tegar) was even reluctant to conjecture on Problem 3: "If I haven't calculated, I don't dare to guess," a reluctance characteristic of a processor who relies on procedural certainty. It was precisely in well-practised manipulation that FD subjects showed their distinctive strength: SFD-01 performed the matrix addition neatly and entirely correctly (score 4), as did SFD-03, so that the two contributed two of the three full scores in the entire dataset. This strength stems from attachment to worked examples, as SFD-01 admitted: "in class the teacher taught that if you combine, you add. I just followed the example we had done before."

However, pattern attachment becomes a source of error when the format changes. SFD-02 applied matrix multiplication and the determinant, the "most frequently practised" operations, even though the problem asked for addition, thereby obtaining 2,500 amperes, which is implausible. Drawing conclusions became the vulnerable point because of weak meaning decomposition: SFD-01 added the loads correctly (Building B = 80 amperes) but wrongly concluded that 80 amperes exceeded the 60-ampere limit, whereas the limit applies per load type. This was not a calculation error but an error in interpreting the referent. The two most demanding indicators, constructing proof and checking validity, received an absolute zero score across all FD subjects.

The FD profile is consistent with field dependent characteristics, namely processing information holistically and depending on external structure. The most theoretically meaningful point is the FD strength in well-practised manipulation, which, together with the cross-problem reversal of advantage, affirms Mutlu and Polat's (2022) thesis that different cognitive styles produce consistently different problem-solving patterns. The total FD failure on justification and validity shows that the demands of meaning decomposition and independent evaluation are the most vulnerable point for a global processor. Thus, the FD profile is strong in well-practised, well-structured procedural manipulation but weak in meaning decomposition and nearly devoid of the ability to construct proof or check validity independently.

3.5 Cross-Problem Reversal of Advantage and the FI–FD Comparison

One of the most factual findings is the existence of a cross-problem reversal of advantage. When achievement is broken down per item (Table 4), the advantage of FI and FD is not uniform but shifts depending on task type.

Table 4. *Mean Achievement per Problem by Cognitive Style (Max 20)*

Problem	Type of Demand	FI	FD	Superior
Problem 1 (Statistics)	Open reasoning: conjecturing, interpreting, justifying	11.33	3.33	FI (≈3.4×)
Problem 2 (Sequences/Series)	Modelling & algebraic manipulation	2.33	1.00	FI (slight)
Problem 3 (Matrices)	Structured procedure: element addition	0.00	4.33	FD (absolute)

On Problem 1, which demands open reasoning, the FI group was decisively superior (about 3.4 times). Conversely, on Problem 3, which demands a structured and patterned procedure, a complete reversal occurred: the FD group was absolutely superior (4.33 versus 0.00). This fact strengthens Mutlu and Polat's (2022) thesis that differences in cognitive style are not merely a matter of high versus low, but a difference in the location of strength that interacts with task type. The implication is clear: assessing reasoning solely on one problem type risks misjudging students' potential, so that a diversity of task types in assessment becomes important.

The per-indicator comparison (Table 5) answers the fifth and sixth research questions. Overall, the field independent cognitive style better supports STEM-based mathematical reasoning: the mean final score is higher (22.78 versus 14.44) and it is superior on four of the five indicators, with the advantage widening on the higher-order reasoning indicators (conclusions, justification, validity). However, this advantage is not uniform: on mathematical manipulation, FD was slightly superior, and on Problem 3, FD outperformed FI absolutely.

Table 5. *Comparison of Mean Reasoning Scores per Indicator (0–4 Scale)*

NCTM Indicator	FI	FD	Difference (FI–FD)	Superior
Making Conjectures	1.44	1.11	+0.33	FI
Mathematical Manipulation	1.11	1.44	−0.33	FD
Drawing Conclusions	0.89	0.33	+0.56	FI
Proof & Justification	0.67	0.00	+0.67	FI
Validity Checking	0.44	0.00	+0.44	FI
Mean Score (0–100)	22.78	14.44	+8.34	FI

Because authentic STEM problems demand not mere calculation but modelling, concluding, and validating (Moore et al., 2021), the FI cognitive style is generally more aligned with the demands of STEM reasoning. This conclusion must be stated cautiously: the FI advantage is not an advantage of intelligence but an advantage of the fit between the way information is processed and the demands of the task. The similarities between the two groups, both being Very Low and both collapsing downstream in reasoning, suggest that the weakness in higher-order reasoning is a structural problem of instruction rather than merely a matter of individual cognitive style. Meanwhile, the differences between the two groups indicate the direction for differentiation: FI students need an emphasis on the discipline of completeness and precision of execution, whereas FD students need gradual scaffolding to decompose meaning and to release their dependence on patterns.

This finding carries an urgency that extends beyond the classroom. The case of SFD-01 is highly illustrative: he calculated the combined load correctly (80 amperes) but wrongly concluded it was safe because he did not distinguish the per-load-type limit from the building total. In real installation practice, such a reasoning error, correct procedure but wrong conclusion, may likewise produce a wrong technical decision (Pratiwi et al., 2021). This is the core reason why mathematical reasoning, not mere computational skill, is a prerequisite for safety in electrical work. This study has limitations: the main subjects numbered six students at a single school, so the profile is in-depth and contextual rather than statistically generalisable; the TKPM examined comprised three items, so the probability and function-transformation contexts were not fully represented; and as a profiling study, it describes the state of affairs and does not test the effectiveness of any treatment..

Conclusion

In general, the mathematical reasoning ability of SMK Electrical Power Installation Engineering students in solving STEM-based contextual problems falls into the Very Low category, with a consistent stepped pattern: relatively strong on the making-conjectures and manipulation indicators (1.28 of 4), declining on drawing conclusions (0.61), and lowest on constructing justification (0.33) and checking validity (0.22). The root of the weakness lies in untrained material, conceptual misconception, and the procedure-meaning disconnect. The population's cognitive-style profile shows 45% FI students and 55% FD students, with the class leaning toward field dependent.

Field independent students display reasoning marked by analytic independence, namely making conjectures through specific data enumeration, filtering distractor information, and correcting their own errors when prompted, with strength peaking on the statistics problem and weakness in the completeness of procedural execution. Field dependent students display reasoning marked by pattern attachment, namely strength in well-practised procedural manipulation, even contributing two of three maximum scores on matrix addition, but building conjectures from a global impression, struggling to decompose meaning, and rarely constructing proof or checking validity independently.

The field independent cognitive style generally better supports STEM-based mathematical reasoning (final score 22.78 versus 14.44, superior on four of five indicators); however, this advantage is not uniform: on structured procedural tasks, FD students outperformed FI absolutely. The similarities between the two groups lie in the same achievement category and the same strength upstream and weakness downstream in reasoning, while the main difference lies in the location of strength and the response when wrong. These findings provide an empirical basis for teachers to design instruction responsive to students' cognitive styles, to habituate the complete reasoning cycle from conjecturing to checking back, and to use a variety of problem types so that the potential of each cognitive style is captured fairly. Further research is recommended to pilot instructional interventions to improve the weakest indicators, justification and validity checking, and to broaden the coverage of subjects and STEM contexts.

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