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Mapping Mathematical Literacy in Combinatorics through Keirsey Temprament Groups and Metacognitive Questions (MQ): A Multiple Case Study of Four Undergraduates

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Abstract

In a combinatorics course, several students still struggle to determine when to use the Multiplication Rule or the Addition Rule, indicating a challenge in mathematical literacy within the context of selection. Meanwhile, there are few studies that map this literacy while simultaneously considering Keirsey's metacognitive questions and temperament in real-world problem-solving situations. This multi-embedded case study research aims to map the mathematical and metacognitive literacy profiles of four students taking a Combinatorics course at a university. Data was collected through an adaptation of the Keirsey Temperament Sorter, one UTS question about breakfast menu choices containing four metacognitive questions (understanding, connection, strategy, and reflection), and semi-structured interviews. Student responses were thematically coded and mapped onto the OECD's formulate–employ–interpret components. The results in this study showed that only Guardian-type students approached a complete literacy profile; Artisan, other Guardian, and Rational types generally only met the initial formulate and interpret component, while employ and advanced interpret were still weak. The implication is that incorporating metacognitive questions into assessments can help lecturers diagnose the need for verification and justification scaffolding that is sensitive to differences in temperament.

Keywords: Mathematical literacy; Keirsey temperament groups; Metacognitive questions; Combinatorics; Higher education

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INTRODUCTION

Mathematical literacy is one of the most important competencies in 21st-century education, emphasizing an individual's ability to think logically, reason, and use mathematical concepts and procedures to solve problems that arise in daily life. This competency not only encompasses procedural and algorithmic mastery but also involves a deep understanding of real-world situations that can be mathematically modeled (Simbolon & Nurjanah, 2024; Susanta et al., 2023). This means that someone who is mathematically competent is not only able to solve problems using specific methods but also able to identify problems in everyday life, analyze their structure and relationships, and construct mathematical representations that can be used to understand, predict, or make rational decisions. In the context of higher education, specifically in the combinatorics mathematics course, mathematical literacy encompasses students' ability to understand, interpret, and apply counting principles in various real-world situations involving the selection, arrangement, and grouping of objects (Ghani et al., 2021). Although mathematical literacy is often associated with various complex real-world contexts, the empirical study in this research specifically focuses on the application of basic combination principles, particularly the multiplication and addition rules, as these two rules are the main foundation of combinatorics and are also prone to misconceptions. When students are faced with problems that require the application of these two basic rules, confusion often arises in distinguishing when the multiplication rule needs to be used and when the addition rule is more appropriate. This situation is what makes the context of combinatorics a relevant field for studying mathematical literacy skills in greater depth.

Various previous studies have emphasized the importance of mathematical literacy in mathematics learning, particularly through innovative approaches such as problem-based learning models (Paloloang et al., 2020; Prihatiningtyas & Buyung, 2023), the use of digital technology (Nugroho et al., 2024; Nurgabyl et al., 2023), problem-solving strategies (Samosir et al., 2022), and level 5 evaluation-based questions at the university level (Ayu et al., 2023). Paloloang et al. (2020), through a seven-year meta-analysis, found that Problem-Based Learning (PBL) consistently improves students' mathematical literacy because it encourages exploration, collaboration, and contextual problem-solving. In line with this, Prihatiningtyas and Buyung (2023) reported that the implementation of ethnomathematics-based PBL using Tidayu culture was able to strengthen students' abilities in the formulate, employ, and interpret stages when solving contextual problems. Digital technology-based research also shows a significant contribution. Nugroho et al. (2024) proved that a mixed reality-based digital algebra book can improve numeracy literacy as well as understanding of algebraic concepts. Meanwhile, Nurgabyl et al. (2023) affirm that developing PISA-based evaluative tasks can shape and strengthen mathematical literacy through the context of international assessment. Samosir et al. (2022) found a direct relationship between problem-solving ability and mathematical literacy, where students with effective problem-solving strategies showed higher literacy performance. The research findings of Ayu et al. (2023) indicate that no students have fully achieved the level 5 mathematical literacy indicators, which require evaluation and argumentation skills based on mathematical results.

In addition to previous research findings, a bibliometric analysis of mathematical literacy was also conducted using data from Semantic Scholar (Figure 1) for the period from 2000 to 2025.

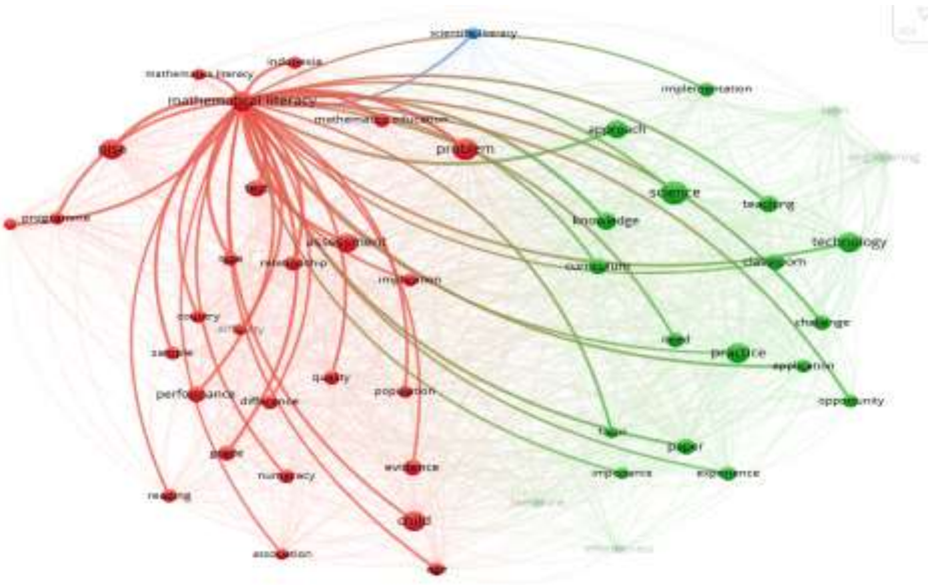

Figure 1. Results of Bibliometric Analysis from Semantic Scholar: Mathematical Literacy (2000 – 2025)

The results of the bibliometric analysis in Figure 1 show three main clusters representing the trends in mathematical literacy research between 2000 and 2025. The first cluster is the red cluster, which is the largest and focuses on mathematical literacy, including PISA tests, assessments, numeracy, implications, and difficulty. The dominance of this cluster indicates that research on mathematical literacy over the past two decades has focused on assessing and evaluating students' abilities, particularly in relation to PISA-based studies. Studies in this cluster generally focus on test results, performance achievement, cross-country comparisons, and the analysis of the relationship between demographic variables and literacy scores. The second cluster is the green cluster, which focuses on mathematical literacy, including STEM, teaching, practice, implementation, and application. This cluster focuses on how mathematical literacy is built through learning design, technology implementation, and STEM integration. The third cluster is the blue cluster, which is smaller than the red and green clusters and focuses on mathematical literacy combined with scientific literacy. This cluster reflects a research direction that emphasizes the integration between mathematical understanding and scientific thinking.

These three clusters indicate that mathematical literacy has been extensively studied from the perspectives of performance, learning design, and cross–disciplinary integration. However, there has been no study that integrates the affective aspect (Keirsey's temperament groups) and the cognitive aspect (thinking processes through MQ) in mapping mathematical literacy in combinatorics material. MQ itself is a set of questions designed to stimulate students' thinking process in solving problems. This instrument was developed based on Zimmerman's (2008) metacognition theory and the IMPROVE model introduced by Mevarech & Kramarski (2003), which includes four types of questions: understanding, connection, strategy, and reflection. In other words, MQ serves as a bridge to help students become aware of their thinking processes, connect concepts, choose strategies, and reflect on the results obtained. Affective and cognitive aspects cannot be separated from learning because they greatly influence how students solve problems. Rivai et al. (2023) showed that affective variations such as learning styles have a direct impact on how students solve PISA problems, which are closely related to the three components of OECD (2023) mathematical literacy: formulate–employ–interpret. If learning styles alone already cause variations in the thinking (cognitive) process, then it is even more likely that Keirsey's temperament groups, such as Guardian, Artisan, Idealist, and Rational, will influence students' approaches to understanding problems, choosing strategies, and reflecting on mathematical literacy tasks.

Without that integration, several consequences arise, both theoretically and practically. From a theoretical perspective, the existing theoretical framework only describes what should be done (formulate – employ – interpret) but does not explain why students differ in doing so. From a practical standpoint, without information about students' temperament groups and their metacognitive tendencies, lecturers will find it difficult to determine the appropriate teaching methods, task variations, and scaffolding to meet students' needs. Additionally, mathematical literacy assessments become less accurate because they only measure the final answer without revealing the thinking process. As a result, reflective and non-reflective students often appear equal, making it difficult to distinguish their metacognitive abilities. In fact, these differences can actually manifest in two forms: orally and in writing. Orally, lecturers find it relatively easier to assess students' thought processes through the explanations or arguments they present. However, some students lack confidence in their oral presentations, making written forms important for revealing reflection processes that are sometimes hidden in verbal communication.

The novelty of this research lies not only in the integration of the Keirsey temperament groups and the MQ but also in the new conceptual findings regarding how these two aspects interact in shaping students' mathematical literacy patterns, as presented in Figure 2. In the context of this case study, the relationship between Metacognitive Questions (MQ) and Keirsey temperament groups is not seen as a generalizable pattern, but rather as a way to understand how each individual responds to metacognitive questions based on their personal tendencies. MQ serves as a tool that "opens up" their thinking process when solving combinatorics problems directly connected to the three main components of mathematical literacy: formulate, employ, and interpret. Understanding and connection – type MQs act as the foundation in the formulate stage, helping students understand the context and build problem representations. Strategy-type MQs serve as indicators in the employ stage, when students choose and apply solution procedures. Meanwhile, reflection – type MQs are an expression of the interpret stage, as they encourage students to interpret results, evaluate the process, and draw logical conclusions. Because temperament groups influence MQ tendencies, they indirectly affect students' mathematical literacy performance. Students with the Guardian type tend to be strong in the formulation stage; artists excel in the employ stage; idealists strengthen the formulation and interpretation aspects; and rationalists are dominant in the reflective interpretation stage. This difference shows that personality provides a unique color to how individuals understand and use mathematics.

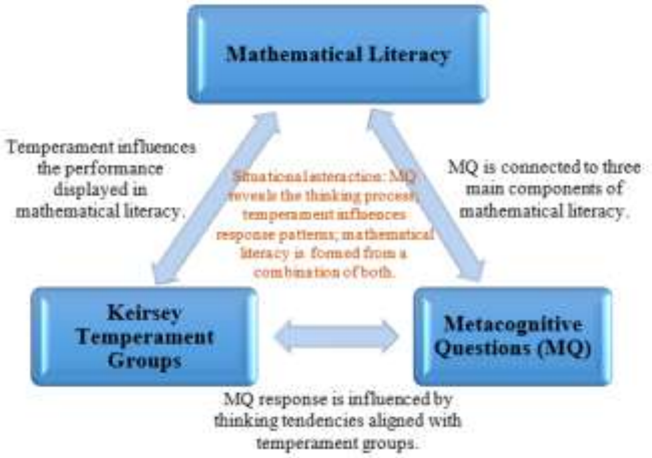

Figure 2. Integration of Temperament Groups and MQ in Mathematical Literacy

The pattern in Figure 2 shows an interactive model that explains how mathematical literacy is formed through the reciprocal relationship between Keirsey temperament groups and metacognitive questions (MQ). The triangle diagram used is not just a visual form; it reflects an interconnected conceptual structure where no single component stands alone. Each element contributes dynamically and contextually to the understanding and performance of mathematical literacy.

On the left side of the triangle, there is a relationship between Keirsey's temperament groups and mathematical literacy. The statement "temperament influences the mathematical literacy performance displayed" indicates that characteristics of temperament groups in this study such as Guardian, Artisan, Idealist, or Rational can influence how individuals approach mathematical problems, choose strategies, and demonstrate understanding. This confirms that mathematical literacy is not just about cognitive ability but is also influenced by individuals' inherent affective tendencies and thinking styles. On the right side, the relationship between metacognitive questions (MQ) and mathematical literacy is explained through the statement that MQ is connected to the three main components of mathematical literacy. The evidence indicates that MQ serves as a reflective tool for accessing the thinking processes underlying problem formulation, concept application, and result interpretation. MQ not only measures knowledge but also reveals self-awareness and self-control in mathematical thinking, which is at the core of deep literacy. The relationship between MQ and temperament groups is shown on the bottom side of the triangle, with the emphasis that how someone answers metacognitive questions is not neutral but rather influenced by the typical thought patterns of their temperament.

A key statement unites all three components in the middle of the triangle. This key statement affirms that mathematical literacy is the result of a situational interaction between thinking awareness and individual character. These three components form a pattern that leads to mathematical literacy, which is formed through a complex and multidimensional process, not merely the outcome of mathematics learning.

Based on the description, there are four problem formulations in this study. First, what is the pattern of MQ responses shown by four students when working on one combinatorics problem in the Combinatorics course at one university? Second, how is the mathematical literacy ability of the four students viewed based on the three OECD components when solving the same combinatorics problem? Third, what is the relationship between the MQ response pattern (as an indicator of metacognitive processes) and performance on each component of mathematical literacy? Fourth, are there differences in the MQ response profiles and mathematical literacy patterns related to the Keirsey temperament groups among the four students in this case study?

This study aims to describe the response patterns of MQ (understanding, connection, strategy, reflection) that emerged in four students while working on a combinatorics problem in a Combinatorics course at a university and to map their mathematical literacy skills across the three OECD components: formulate, employ, and interpret. Furthermore, this study aims to analyze the relationship between metacognitive processes revealed through the MQ and performance on each component of mathematical literacy. The ultimate goal is to explore the role of Keirsey's temperament groups in influencing the MQ response patterns and mathematical literacy performance patterns in the cases of the four students.

METHOD

Research Design

This study uses a qualitative approach with an exploratory case study design, specifically a multiple-embedded case study. This design was chosen because it can describe the variation in affective, cognitive, and mathematical literacy performance aspects within the same context. In addition to studying more than one case, this research examines four students, each with different temperament groups, unique MQ response patterns, and varying levels of mathematical literacy performance, who all attended the Combinatorial Mathematics course on the same campus and in the same class. The researcher was fully involved in the learning and data collection process throughout this study.

Participants

The participants in this study were all students enrolled in the Combinatorial Mathematics course in the class under investigation ($n = 4$) during the fall semester of the 2025/2026 academic year. Because there are only four people in each class, the participant selection technique uses total sampling (census). The decision to use total sampling is intended to obtain a complete picture of affective, cognitive, and mathematical literacy performance variations within the same context. The four students participated in the entire research process, from completing the Keirsey Personality Questionnaire and solving combinatorial problems with Metacognitive Questions (MQ) to follow-up interviews. The general characteristics of the participants are shown in Table 1.

Table 1. Characteristics of Research Participants

ID	Gender	Academic Term	Prerequisite Course Status (calculus)	Temperament Group
S1	F	9	Passed	Artisan
S2	M	7	Passed	Guardian
S3	M	7	Passed	Guardian
S4	M	7	Passed	Rational

Instruments and Procedures

The temperament inventory (questionnaire) instrument used in this study is an adaptation of the Keirsey Temperament Sorter II (KTS-II). The adaptation was made to adjust to the research context in higher education and the characteristics of the participants so that it could more accurately record students' thinking tendencies while still maintaining the representation of the four personality dimensions. Each statement on the adaptation instrument is systematically mapped to the original Keirsey indicators, thus not altering the conceptual structure or meaning of the personality construct. This instrument uses a dichotomous (yes/no) response format, just like the original Keirsey instrument.

To ensure the construct validity and item relevance to the research context, this instrument has undergone a content validity process conducted by an expert lecturer in the field of education and language. The expert assessed the suitability of the indicators, the clarity of the language, and the relevance of the statements to Keirsey's theoretical constructs. The assessment results indicate that all aspects (content validation, language, and instructions) were deemed satisfactory, indicating that the instrument is suitable for use.

Reliability testing was not conducted in this study because the purpose of using the questionnaire was only to group the temperamental tendencies of each student in the case study, not to create a new psychological measurement tool that needed to be tested for internal stability. Additionally, this adapted questionnaire follows the established structure of the original Keirsey, and therefore expert evaluation is considered sufficient to ensure the questionnaire is suitable for use in this research context.

The scoring rules for the temperament questionnaire in this study follow the basic principles of the Keirsey Temperament Sorter, which is to group the statement items into four dichotomous personality dimensions as shown in Figure 3.

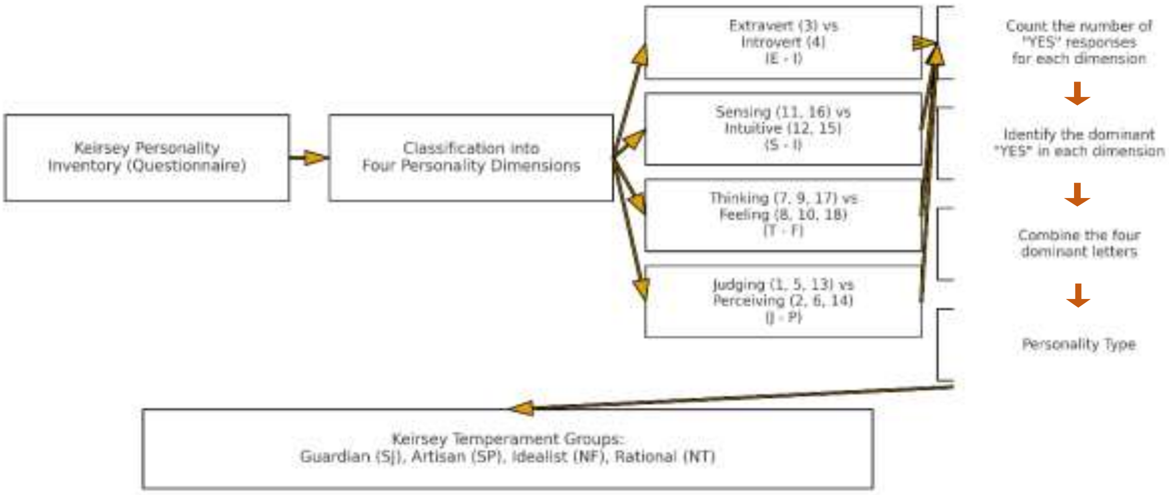

Figure 3. Keirsey Scoring and Classification Procedure

The instrument contains 18 statements with yes/no answers. The score for each pole of a dimension is calculated by the number of "Yes" responses to the statements representing that pole.

- E – I (Extrovert vs Introvert): number 3 = Extrovert; number 4 = Introvert. A "yes" answer indicates a tendency toward one of the orientations (extrovert = active, social; introvert = reflective, comfortable alone).
- S – N (Sensing vs. Intuition): numbers 11 and 16 = Sensing; numbers 12 and 15 = Intuition. Sensing = concrete and factual processing; intuition = abstract and possibility – oriented thinking.

- T – F (Thinking vs Feeling): items 7, 9, and 17 = Thinking; items 8, 10, and 18 = Feeling. Thinking = logic-based decisions; feeling = considering values and empathy.
- J – P (Judging vs. Perceiving): items 1, 5, and 13 = Judging; items 2, 6, and 14 = Perceiving. Judging is structured and planned; perceiving is flexible and spontaneous.

The final score for each dimension is obtained by summing the "Yes" responses for each pole's group of statements. The four dominant letters are combined to determine the participant's temprament group, which is then classified into Keirsey's four temperament groups: Guardian (SJ), Artisan (SP), Idealist (NF), and Rational (NT).

Next, the test instrument used was one essay question from the midterm exam for the Combinatorial Mathematics course (in the context of choosing a breakfast menu), which applied the product rule and the sum rule, along with four metacognitive questions (MQ) (understanding, connection, strategy, and reflection). These four MQ are not given after the questions are completed but are an integral part of the question body, so students answer them simultaneously with the problem-solving process. This strategy was chosen so that MQ could record students' thought processes in real-time, rather than just a later reflection that is prone to forgetting or self-justification.

Content validity was assessed by two lecturers (Mathematics Education and the Quality Assurance Unit). Empirical validity and statistical reliability tests (e.g., KR-20 or Cronbach's Alpha) were not conducted because the MQ is a tool for exploring the thinking process, not a quantitative measurement tool. The response analysis was conducted thematically, focusing on the emergence of "formulate", "employ", and "interpret" according to the OECD's mathematical literacy components. All tasks are mapped in a blueprint that connects test items, MQ types, conceptual objectives, and mapped literacy components (Table 2). Information is provided first as data to answer the following multiple-choice questions:

Grace wants to order breakfast from the inn:

- If he doesn't choose pancakes or toast, he has 3 main course options, 2 side dish options, and 4 drink options.
- If they choose pancakes or waffles, there's an additional option for maple syrup (optional).
- If he chooses toast, there are 4 bread topping options available.
- If they choose toast and pancakes/waffles at the same time, all combinations apply.

Table 2. Item Blueprint × MQ × Mathematical Literacy Components (OECD)

No	MQ	Goal MQ	Theoretical Indicators (Mevarech & Kramarski)	Question	OECD Literacy Component
1a	Understanding	Training students to understand problem structures by mapping various situations (cases) before performing combinatorial calculations.	Able to identify the problem structure by distinguishing between various relevant conditions or cases before selecting a solution strategy.	How many cases (situations) need to be considered in the question above? What is the difference between each of these cases?	Formulate: Understand the context, identify variables, and formulate the problem structure.
1b	Connection	Connecting real-world experiences and mathematical concepts.	Able to connect the concepts being studied with everyday experiences and integrate two mathematical rules (Product Rule and Sum Rule) within a single context.	Have you ever encountered similar problems in real life (e.g., ordering food, tickets, or clothes)? How does this combine the Product Rule and the Sum Rule simultaneously?.	Formulate: Formulate a mathematical model and connect it to real life.

No	MQ	Goal MQ	Theoretical Indicators (Mevarech & Kramarski)	Question	OECD Literacy Component
1c	Strategy	Choosing and implementing the most efficient procedures or strategies to solve a problem.	The individual is able to plan the steps for solving a problem, choose the appropriate strategy, and perform the necessary mathematical procedures.	If you were asked to calculate the total possible breakfast combinations, what strategy would you use? Calculate the total combinations by writing out each step completely.	Employ: Apply mathematical procedures, perform calculations.
1d	Reflection	Training students' metacognitive awareness of the benefits of problem decomposition and predicting how conditions change.	Able to evaluate the benefits of the problem-solving strategies used and predict the impact of changing conditions on calculation results.	What are the benefits of breaking down a large problem into several cases? If the number of toppings increases, how does it affect the total number of combinations? Prove it.	Interpret: Explaining, interpreting, and providing mathematical reasoning for situations or changes in conditions.

In this study, the mapping between Metacognitive Questions (MQ) aspects and the OECD's mathematical literacy processes (formulate, employ, and interpret) was conducted conceptually by designing the instrument blueprint from the outset. The MQ-understanding and MQ-connection aspects are mapped to the formulate process, as both are specifically designed to explore how students build initial problem representations (understanding the context, identifying relevant information) and connect the problem context with appropriate combinatorial concepts (e.g., the product rule and sum rule), thus serving as the foundation for formulating a mathematical model. The MQ-strategy aspect is mapped to the employ process, as the items in this section are focused on tracing how students plan, choose, and execute problem-solving strategies, including how they organize cases and apply operational rules appropriate to the problem structure. Meanwhile, MQ-reflection (I and II) is mapped to the interpret process, as the reflection questions are aimed at uncovering how students interpret the meaning of solutions in the context of the real world, assess the reasonableness of the results, and validate or prove changes in conditions within the given situation. This conceptual mapping was then used as the basis for a numerical coding scheme ($1 =$ met; $0 =$ not met) for each formulate, employ, and interpret indicator for each subject.

The data collection phase was followed by face-to-face interviews conducted after students completed the midterm exam questions with embedded MQ in the faculty room on the agreed-upon day to ensure comfort. The type of interview used is semi-structured, meaning the researcher follows a list of questions but still allows students to explain their thinking process naturally. The interview focused on exploring the reasons behind MQ's answers, how students understand the context of combinatorics, and any temperamental factors that might influence their problem-solving strategies. The questions asked included "Why did you choose to divide the problem into several cases?", "Which part of the problem did you find most confusing?", "How did you decide to use the Product Rule or the Sum Rule?", and "What were your considerations when choosing that strategy?" This entire procedure ensures that the metacognitive processes not visible in written answers can be well recorded. The interview was recorded using a mobile phone, then transcribed verbatim and analyzed alongside MQ's answers to map out formulate, employ, and interpret. All documentation results are compiled into a Word file as part of the data triangulation process between tests, the MQ, and interviews.

Before the midterm exam was administered, students received an ethical consent form and were given a complete explanation several days in advance regarding the purpose of the questionnaire, the fact that one midterm exam question (question number 1) would be used as research material, potential risks, and the participants' right to refuse or discontinue participation at any time without consequence. Student willingness is indicated by signing a consent form to participate in the research. All personal student data is kept confidential through anonymization. Only data relevant to the analysis of temperament group trends, mathematical literacy, and MQ responses will be reported.

Data analysis

Data analysis in this study was conducted in stages and followed the typical flow of a multiple-embedded case study design, as presented in Figure 4. First, MQ response encoding. This initial coding yielded codes that marked how students understood the context, connected concepts, planned strategies, and reflected on the results. Second, mapping the results of MQ coding to OECD mathematical literacy components using the instrument blueprint. Third, thematic analysis of interviews using open coding and axial coding to facilitate the researcher's understanding of metacognitive processes not fully reflected in written responses. Fourth, cross-case comparison, where each student was first analyzed individually to identify patterns of mathematical literacy and performance. Next, the patterns of each case were compared to find similarities and differences based on Keirsey's temperament types. This cross-case comparison provides a comprehensive overview of how affective (temperament) and cognitive (metacognitive processes) variations interact in shaping mathematical literacy performance.

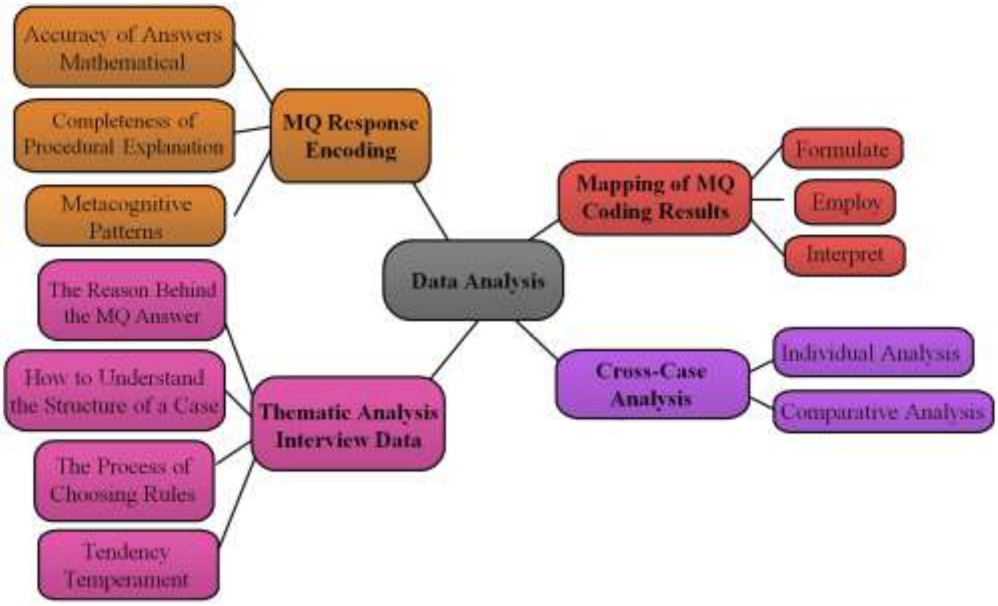

Figure 4. Data Analysis Flowchart

The analysis process is supported by a code table (coding scheme) that summarizes the MQ response categories and their mapping to OECD literacy components, ensuring consistent coding. (Lincoln & Guba, 1986) say that there are four ways to keep data valid. First, data triangulation was performed by evaluating written responses to essay and multiple-choice questions, analyzing interview outcomes, and reviewing Keirsey's temperament tendencies. This step is taken so that the findings are not solely based on one type of data, ensuring the research results remain valid and reliable. Second, member checking was done by compiling a summary of each student's thinking patterns and then presenting the research findings to them. This process aims to minimize misinterpretations and ensure the researcher's interpretation aligns with the participants' original experiences. Third, expert judgment involves two expert lecturers, one from the mathematics education department and one from the Indonesian language and literature department, who also serve as the Quality Assurance Unit. They help validate the content of the Keirsey questionnaire adapted for use to ensure it aligns with the original construct, is clear in its language, and is relevant for students in the mathematics education department taking the combinatorics course. Fourth, the audit trail is compiled to document the entire analysis process, making the research transparent and verifiable.

RESULTS

Student Personality Profile

Based on the results of the Keirsey Temperament Sorter questionnaire, each participant or subject was categorized into four temperament groups. In this study, the temperament category structure for the four research subjects is summarized in Figure 5. Subject 1 belongs to the Artisan (SP) group, Subjects 2 and 3 are in the Guardian (SJ) group, while Subject 4 falls into the Rational (NT) category. This information serves as the basis for grouping student response profiles on the MQ instrument and OECD mathematical literacy components.

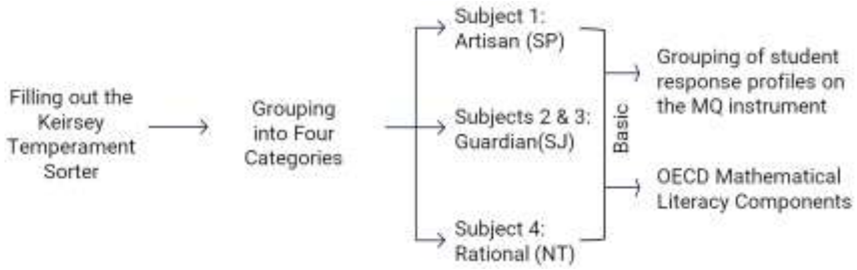

Figure 5. Student Personality Profile Based on Keirsey Temperament

MQ Response Results (per Subject)

The Metacognitive Questions (MQ) instrument consists of three aspects: Understanding, Connection, Strategy, and Reflection (I and II). Table 3 presents a summary of the MQ response mapping for each subject based on their accuracy in answering each aspect of the MQ. A checkmark (✓) indicates the subject answered correctly (met the requirement), while the cross (×) indicates the subject answered incorrectly and/or did not answer (did not meet the requirement).

Table 3. Summary of MQ Mapping for Each Subject

Subject	Temperament Groups	MQ				
		Understanding	Connection	Strategy	Reflection	
					I	II
S1	Artisan (SP)	×	√	×	√	×
S2	Guardian (SJ)	√	√	√	√	×
S3	Guardian (SJ)	×	√	×	√	×
S4	Rational (NT)	√	√	×	√	×

Data shows that all students were able to answer connection and reflection I questions correctly, while none of the students answered reflection II.

OECD Mathematical Literacy Coding Results

The mapping of MQ responses to OECD mathematical literacy components was done based on an instrument blueprint that connects MQ aspects with the three literacy processes: Formulate, Employ, and Interpret. Each student response was analyzed and given a numerical code ($1 = met$; $0 =$ not met) according to the indicators for each process. The coding results for each subject are shown in Table 4.

Table 4. OECD Mathematical Literacy Coding Results

Subjek	F1	F2	E1	E2	I1	I2
S1	0	1	0	0	1	0
S2	1	1	1	1	1	0
S3	0	1	0	0	1	0
S4	1	1	0	0	1	0

Brief description of the indicator:
F1 = Identify the context & structure of the case (formulate).
F2 = Connect concepts (product/sum rule).
E1 = Solution strategy.
E2 = Accuracy of calculation results.
I1 = Interpret the benefits of case decomposition.
I2 = Prediction/proof.

Summary of Performance for Each Subject Based on MQ and OECD Literacy Coding

Case Subject 1: (S1 Artisan)

The test results on this study show that Subject 1, with an Artisan temprament group, only met the connection and reflection I questions, while the understanding, strategy, and reflection II questions were not met, as shown in Figure 6. The inability of the S1 student to identify the problem structure from the beginning is reflected in their written answer: they only listed three cases to consider, namely not choosing pancakes/toast, choosing pancakes/waffles, and choosing toast.

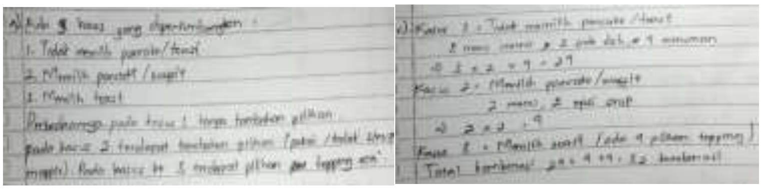

Figure 6. Subject 1's Unsuccessful Answer Results

In the interview, S1 explained that he intentionally omitted the fourth case because he felt the "case of choosing toast and pancakes/waffles at the same time" was already represented by the other two cases. Errors at this understanding stage then led to strategic errors: in number 1c, S1 directly summed the number of variations from the three cases he obtained from number 1a without rechecking the accuracy of the case classification. He realized his mistake during the interview and said, "*I only wrote down the three cases that needed to be considered because I thought the fourth piece of information, which was 'choosing toast and pancakes/waffles at the same time', was already represented by the second and third pieces of information", and when working on question 1c, I simply added up the number of variations from the three cases obtained in question 1a to identify the total combinations. Because the answer to question 1a might be wrong, does that mean question 1c is also wrong, ma'am? I just realized it now, ma'am*". From the OECD's perspective on mathematical literacy, a bachelor's degree only meets the basic level (F2) of the Formulating indicator and partially meets the Interpreting (I1) indicator, while the other literacy components are not met. This condition is consistent with not obtaining the correct calculation results.

Case Subject 2: (S2 Guardian)

Subject 2 on this study with a Guardian temprament group, demonstrated strong performance across almost all aspects of MQ. They met the indicators for understanding, connection, strategy, and reflection I, but did not meet reflection II. In the final stage of this reflection, S2 did not provide the requested formal proof, even though their calculations were correct. In the interview, S2 explained that she decided not to do Reflection II, not because she was unable, but because she felt proof was no longer necessary. He stated that the previous steps were clear and convincing enough: "*I didn't write an answer to reflection question II because I felt confident enough in the accuracy of my answer to reflection question I. So I didn't feel the need to write the proof again". In my mind, the steps I took previously were sufficient validation. I'm more focused on the accuracy of the final result, ma'am, than on the process of proving it. Perhaps I considered that proof just prolonged an answer whose truth was already clear*". From the OECD's mathematical literacy perspective, S2 meets all literacy indicators except for Advanced Interpretation (I2), which is related to formal justification. Thus, although the results of the S2 combination calculation are correct, formal proof for reflection II is the only missing aspect.

Case Subject 3: (S3 Guardian)

Subject 3 on this study with a Guardian temprament group, exhibited a typical response pattern. It only met the connection and reflection I indicators, but not the understanding, strategy, and reflection II indicators. Conceptually, S3 failed to interpret the context of the problem accurately, which also impacted the solution strategy. The form of the error is shown in Figure 7. The main error lies in how S3 reads the case situation.

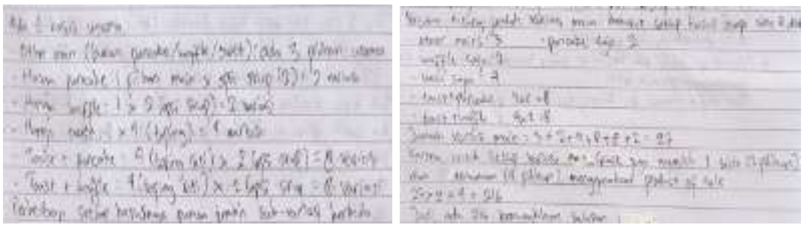

Figure 7. Subject 3's Unmet Answer Results

In the interview, he explained, "*I interpreted the sentence as two different cases, ma'am, not as the same case with variations in syrup options. For the steps or plan to find the total combinations in question 1c, I used the answer from question 1a and then summed all possible variations. And the total number of possibilities is* 216". Within the OECD's mathematical literacy framework, S3 only meets the basic level of Formulating (F2) and partially Interpreting (I1). The other literacy components are not met, which directly impacts the inaccuracy of the total combination calculation obtained.

Case Subject 4: (S4 Rational)

Subject 4 on this study with a rational temprament group, showed a relatively strong response pattern in the conceptual aspect. He answered correctly on the understanding, connection, and reflection I questions but incorrectly on the strategy aspect and did not answer reflection II, as shown in Figure 8. Overall, S4 successfully built the case structure accurately and understood the problem context, but the strategic steps he used were not appropriate within the framework of combinatorial rules.

Figure 8. Subject 4's Unsuccessful Answer Results

In an interview, S4 explained that he considers each additional option (such as syrup on pancakes/waffles or toppings on toast) as a new case that must be calculated separately. He said, "*I wrote down that the main menu has five items, ma'am: pancakes, waffles, toast, oatmeal, and omelets. Then I separated the calculations. For pancakes/waffles, I counted two variations because there's an option with or without syrup. For toast, I counted four toppings or none. I treat every addition, such as syrup or toppings, as a new case. That's why I created several calculation groups and added them all together. As long as the options are different, it means it's a new case that needs to be added*".

DISCUSSION

Synthesis of OECD MQ Patterns and Mathematical Literacy

[1] MQ Understanding and Connection ↔ Formulate Component

The research findings indicate that achievement at the formulate stage appears to be influenced by MQ–understanding and MQ–connection. Understanding serves as the foundation for the initial representation of the problem, while connection plays a role in activating and integrating relevant knowledge to build conceptual relationships. When the context is fully understood and stable (as with S2 and S4 subjects), the problem formulation can be built systematically by identifying variables and mapping the entire case. Conversely, when the initial representation is incomplete or incorrect (as with S1 and S3 subjects), the formulation becomes fragile even though the subjects are able to connect contextual information with the basic concepts of combinatorics, namely the Product Rule and the Sum Rule. This ability is evident in the way they map situations into "separate cases". This empirical finding confirms that all subjects have adequate conceptual linking, meaning the ability to bridge contextual problems with mathematical concepts. These findings align with Nisa et al. (2020) and Lockwood & Ellis (2022), who emphasize the importance of initial representation as a filter for the direction of thinking while also supporting the view of Mevarech & Kramarski (2003) that connections serve not only to recall previously learned concepts but also to retrieve knowledge appropriate to the problem situation to build more meaningful conceptual relationships.

[2] MQ Strategy ↔ Employ Component

In this study, the employ stage is specifically linked to the MQ strategy because it is designed to explore how students plan, select, and manage problem-solving strategies. Thus, the MQ strategy profile for all subjects is interpreted as a reflection of their metacognitive readiness to engage in the employ process, making the connection between the employ stage and MQ strategy conceptual rather than a forced adjustment. Research findings on mathematical literacy using PISA-model questions indicate that success at the employ stage is highly dependent on students' ability to choose the right strategies, not just on their mastery of concepts or routine procedures (Rahmadhani et al., 2024). This pattern is in line with what was found for Subject 2, which showed that the formulate and employ components were connected: S2 made a complete initial representation by using MQ–understanding and MQ–connection, explicitly formulating variables and cases, and then systematically choosing and carrying out strategies at the employ stage, making sure that the steps taken matched the problem structure.

Conversely, Subject 4 demonstrated a well-structured approach, correctly identifying the four parts of the case, but failed to complete the calculation process despite using the correct strategy. They first used the product rule to figure out how many different breakfasts there could be in each case. Then they used the sum rule to figure out how many different breakfasts there could be in total. More specifically, the strategic error of Subject 4 is evident in the application of the multiplication rule when determining the number of breakfast variations. In the case of "Grace orders pancakes or waffles, but not toast", the number of possibilities should be $2 \times 2 \times 4 \times 2 = 32$, because there are two main course options (pancakes/waffles), two side dish options (fruit cup/none), four drink options, and two syrup options. However, S4 only wrote $2 \times 2 = 4$, thus neglecting some aspects that still vary. Similarly, in the case of "Grace did not order pancakes/waffles but ordered toast", the correct combination is $3 \times 1 \times 4 \times 4 = 48$ (three possibilities for the main dish or none, one side dish option of toast, four spread options, and four drink options), but S4 only wrote 5 as the final result without breaking down the factors involved. In the case of "Grace ordered toast and pancakes or waffles at the same time", the correct total variations are $2 \times 2 \times 1 \times 4 \times 4 = 64$, while S4 wrote $5 \times 2 \times 5 = 50$ with a composition of factors inconsistent with the decision structure on the menu. This error pattern indicates that S4 is capable of identifying case separation in general but does not consistently include all changing aspects in the multiplication rule.

From the standpoint of mathematical literacy and the MQ strategy, the results demonstrate that S4's inadequacy at the employ stage is attributable not only to a deficient understanding of multiplication rules but also to constraints in the planning and oversight of problem-solving strategies. S4 seems to have stopped at the initial intuition about "how many factors are multiplied", without rechecking whether all the choice components (main menu type, presence of toast, spread options, and drinks) were represented in the calculation. This condition suggests that without the support of a mature MQ strategy, a strong formulation is an important but not sufficient prerequisite. The S4 error aligns with the findings of Nopriana et al. (2023) that students still experience significant difficulty in understanding and applying the rules of addition and multiplication to combinatorial problems, even though they are familiar with the formulas used. Mahatri et al. (2023) also found that most students could say the rules for addition and multiplication, but they often made mistakes when it came to figuring out the "number of factors" to be multiplied. This meant that some parts of probability (menu) were left out of the calculations.

A sharp contrast is also evident in Subject 1 and Subject 3. Both had adequate conceptual linking to the basic concepts of combinatorics (Product Rule and Sum Rule), but the initial representation they constructed was incorrect, making the formulation fragile. When moving to the employ stage, the weaknesses in this formulation continued to result in the selection of strategies that were not contextually appropriate: S1 and S4 tended to use unstructured, intuitive strategies, while S3 relied on routine procedures that were no longer relevant to the problem situation. This pattern indicates that the relationship between MQ–understanding/connection (at the formulate stage) and MQ–strategy (at the employ stage) is complementary: a strong initial representation opens up space for appropriate strategies, while metacognitive proficiency in MQ strategy determines whether the strategy is planned, executed, and monitored effectively. Thus, failure at the employ stage can be understood not merely as a procedural issue but because of a fragile, formulated combination and limited metacognitive readiness.

[3] MQ Reflection ↔ Interpret Component

Within the OECD's framework for mathematical literacy, the interpret stage refers to students' ability to reconnect the results of calculations or mathematical models to real-world contexts, interpret the meaning of solutions, and consider their reasonableness and implications for the problem situation. Students must now not only "get the answer", but also consider if it is reasonable, relevant, and consistent with prior assumptions. Meanwhile, in Metacognitive Questions (MQ), reflection questions are designed to raise students' awareness of their thinking processes and the results of their problem-solving efforts. Questions at the reflection stage generally encourage students to (1) re-explain the meaning, function, or benefits of the solution; (2) assess the truth and fairness of the solution; and (3) re-examine (verify) the steps and assumptions already used. Based on the similarity of these characteristics, the interpretation component in mathematical literacy conceptually aligns with MQ reflection, as both emphasize the activity of interpreting solutions within a context, evaluating the accuracy of results, and verifying changes in conditions or assumptions accompanying the solution.

In this aspect, all subjects were able to correctly answer reflection question I, which asked them to explain the function and benefits of the solution they obtained. However, none of them successfully answered reflection question II, which required proof and validation of the change in conditions in the situation provided in reflection question I. This finding is consistent with the research results (Kholid & Nissa, 2022), which emphasize that a complete formulate-use-interpret ability is needed for students to make reflective judgments about the solutions they produce. This means students cannot simply calculate or determine the answer. They need to formulate the problem correctly, perform calculations accurately, and interpret the results of the calculations completely and continuously. By doing so, they can reflectively assess whether the resulting solution is correct, relevant, and meaningful within the context of the problem at hand.

On the other hand, research on metacognition shows that reflection questions play an important role in encouraging students to evaluate the reasonableness of their answers, reexamine their steps, and test the assumptions they used. Students with better metacognitive skills tend to actively monitor and reflect on the problem-solving process, while students with low metacognitive skills tend to stop at obtaining a numerical answer without further verification (Kusaka & Ndihokubwayo, 2022). In this context, the results of this study, where all subjects were able to answer reflection I (explain the function and benefits of the solution) but failed on reflection II, which required proof and validation of the change in conditions, reinforce previous findings that the dimensions of interpretation, evaluation of fairness, and the habit of formal verification still remain weak points for students. Thus, the conceptual link between the interpretation stage in mathematical literacy and MQ reflection is not only based on definitional consistency but is also empirically confirmed through similar patterns of weakness in interpreting the meaning of solutions and verifying against changing conditions.

Keirsey Temperament Sorter Synthesis per Case

Artisan Case (S1)

In this study, case of S1 (artisan), the responses provided show a strong tendency to rely on intuition when facing problems. This is evident in his ability to build good connections between concepts, although his use of formal procedures is still weak and not always demonstrated sequentially. This finding is consistent with the characteristics of Artisans according to Anggorowati et al. (2024), who are strong in connecting concepts but weak in formal procedures and abstract analysis. The main error stems from an incomplete understanding of the context (omitting one case in a combinatorics problem). This result indicates the use of shortcut strategies without thorough checking, signifying weak metacognitive control, particularly in the monitoring stage (the process of checking, evaluating, and overseeing the flow of thought while solving problems) (Zheng, 2025). Meanwhile, the failure to answer Reflection II because the answer in Reflection I was felt to be absolutely correct indicates an intuitive tendency based on personal perception, rather than formal verification. This pattern aligns with the findings of Suwarno et al. (2024) and Wheeler et al. (2002) that Artisan types excel in intuitive processing but are less consistent in deductive reasoning and mathematical proof (procedural details).

Guardian Case (S2 and S3)

In this study, case of S2, which is of the Guardian (SJ), shows the relatively strongest MQ profile. This subject is able to fulfill almost all components of MQ (understanding, connection, strategy, and reflection I), although they are still inconsistent in the reflection II aspect. This indicates that S2 has sufficiently developed procedural abilities and metacognitive control in monitoring the thinking process, although there is still a gap between internal cognitive processes and written expression. Although S2 believed their answer was correct, the lack of proof in reflection II meant the solution was not scientifically validated. This pattern reflects a tendency among some Guardian types to justify answers based on belief rather than formal argumentation, as explained by Sheromova et al. (2020). This is also in line with the findings of Reuter (2023), which showed that many learners view mathematics as a purely procedural activity, not as an argumentative practice. Therefore, the advantage of a master’s degree in terms of connection and strategy does not automatically translate into the ability to present formal proof.

Conversely, S3, which is also a Guardian (SJ), actually showed an MQ profile similar to S1, which is an Artisan type (SP). This finding indicates that two subjects with different temprament groups (Artisan and Guardian) can have relatively similar MQ profiles.

Interestingly, S2 and S3, both of whom are Guardians, showed sharply different MQ profiles. These findings are consistent with several studies that confirm that temprament groups and metacognition are more accurately assessed at the individual level, rather than being rigidly generalized to all members of a specific type (Eminarti & Nasution, 2025).

Rational Case (S4)

In this study, case of S4 reveals that a fully systematic problem-solving strategy does not always follow the rational type. S4 is able to understand the context and identify the structure of the case well but still makes mistakes in the strategy aspect because they do not consistently include all components of the choice in the multiplication rule, resulting in some possibilities being missed and the employ stage being incomplete. This pattern aligns with the findings of Laamena & Laurens (2021), which show that some students have been able to identify relevant information and build mathematical models but are still weak in monitoring and evaluating strategies, leading to errors in the implementation and solution-checking stages. Similarly, studies on combinatorial strategies report that using the product rule without systematically organizing cases often leads to incomplete or incorrect calculations, even though students understand the problem situation (Da, 2023). On the other hand, these results differ from research on problem-solving profiles based on Keirsey types in the context of ethnomathematics, which showed that Rational-type students were able to complete all stages of Polya's problem-solving process for every problem presented (Agustiani et al., 2024). These differences indicate that the rational temprament group does not necessarily guarantee success in all problem contexts, particularly in combinatorial tasks that require systematic strategies and strong metacognitive regulation.

Limitations

This study has several limitations that need to be considered when interpreting the findings. The participants in this study numbered only four people, so the results obtained cannot be generalized to a wider population. Thus, the findings are more accurately positioned as a contextual description of the setting and characteristics of the subjects studied, rather than as a universally applicable claim. Additionally, the data analysis in this study heavily relies on the quality of both verbal and written reflections provided by the students. Limitations in students' ability to express their thinking processes both orally and in writing can affect the depth, clarity, and completeness of the data obtained. This condition has the potential to mean that some aspects of the thinking process or mathematical literacy are not fully captured in the data.

Another limitation lies in the scope of the material being studied. This study only used one combinatorics test question as a research instrument, which limited the diversity of problem situations that could reveal variations in mathematical literacy skills and responses to Metacognitive Questions (MQ). From the perspective of qualitative data collection, the interviews used are semi-structured. This approach does indeed provide flexibility for researchers to explore participants' answers more freely, but it also opens up the possibility of variations in the depth of data between subjects. Some participants may provide more detailed and reflective explanations, while others may give shorter answers, resulting in an imbalance in the level of detail and completeness of the data.

CONCLUSION

This study aims to describe the response patterns of Metacognitive Questions (understanding, connection, strategy, reflection) from four students when solving a combinatorics problem, map their mathematical literacy abilities based on the three OECD components (formulate, employ, interpret), analyze the relationship between MQ response patterns and mathematical literacy performance, and explore the role of Keirsey temperament groups (Artisan, Guardian, Rational) in shaping MQ and mathematical literacy profiles. Overall, the research findings indicate that all subjects were able to answer connection and reflection I questions correctly, but none met the reflection II indicator. This condition indicates that the students are relatively capable of explaining the benefits of the solution and performing problem decomposition but are not yet accustomed to providing formal justification or verifying changes in conditions in similar situations.

The core findings of the research on mapping mathematical literacy show that only one subject, a student with a Guardian character (S2), almost met all the components of formulating, employing, and interpreting. The other three subjects only partially met the components, especially at the basic formulation level related to concept connections and at the initial interpretation level. The advanced components of "employ" and "interpret" appear to be the main weaknesses. This finding aligns with MQ analysis, which states that responses to MQ–understanding and MQ–connection serve as the foundation for the formulate component; when students' context representations are complete and structured, they tend to be better able to construct cases and choose appropriate strategies. Conversely, when initial representations are still incorrect or incomplete, these errors "spread" to strategy selection and calculation results. The MQ strategy is closely related to the employ component, while MQ reflection serves as an important indicator for the interpret component.

From a Keirsey temperament perspective, this study indicates that personality traits do not function deterministically but rather interact with metacognitive processes in each individual. In this study, the Artisan-type students (S1) appear strong in building conceptual connections but weak in monitoring formal strategies and procedures. The Guardian student (S2) emerged as the most procedurally strong subject, although he still tends to be reluctant to write out formal proofs completely. Another Guardian (S3) showed a profile similar to the Artisan in terms of initial representational weaknesses, while the Rational (S4) appeared strong in understanding context and mapping cases but was not yet consistent in managing multiplication rules and monitoring factor completeness.

The implications of the findings above are that mathematical literacy (formulate–employ–interpret) is more accurately understood as the result of a situational interaction between metacognitive processes, as reflected by MQ, and affective characteristics such as temperament, rather than simply as a standalone procedural or cognitive ability. Practically speaking, integrating MQ into the body of the question, rather than just as a reflection at the end, proved effective in revealing students' thinking processes in a more "real-time" manner. In this way, lecturers can distinguish between students who only focus on the final answer and those who truly reflect on the steps they took. The failure in all subjects in Reflection II is also an important signal that learning combinatorics in higher education needs to explicitly emphasize the habit of verifying, proving, and evaluating the reasonableness of solutions.

On the other hand, this study has some limitations. The number of participants was only four students from one class, so the findings generated are highly contextual and cannot be generalized to a wider population. The instrument used was also limited to a single combinatorics question with a single context (choosing a breakfast menu), so the variety of situations capable of eliciting mathematical literacy profiles and the range of MQ responses was still minimal. Additionally, the depth of the data is highly dependent on the quality of the written responses and interviews; differences in verbal and written abilities among subjects can influence the extent to which their thought processes are exposed. Semi-structured interviews do allow for exploration, but they also lead to variations in the depth of data between participants, so the details of cognitive and metacognitive processes that are uncovered are not always equivalent.

RECOMMENDATION

Based on the findings above, some practical recommendations can be proposed to improve the quality of students' combinatorics learning and mathematical literacy. First, lecturers are advised to integrate Metacognitive Questions (MQ) directly into the combinatorics problem text (understanding, connection, strategy, reflection), so that students' thinking processes at the formulate–employ–interpret stage can be recorded and used as a basis for feedback. Second, learning needs to emphasize case modeling exercises and differentiating the use of the addition and multiplication rules, for example, with the help of tree diagrams or case tables. Third, the finding that all subjects failed on reflection II calls for efforts to cultivate a culture of verification and proof in the classroom. Fourth, differentiating scaffolding based on student profile tendencies (e.g., in this study the Artisan, Guardian, and Rational types) is also important to ensure that the support provided aligns with each student's strengths and weaknesses in terms of concept connection, strategy monitoring, and formal proof expression. Fifth, the MQ responses can be used to help lecturers identify key weaknesses in context understanding, concept connections, strategies, and reflection so that learning improvements can be more targeted. Thus, MQ is not only a research instrument but also a means of continuous evaluation and development in classroom practice.

From a research perspective, future studies should involve a larger number of participants and diverse contexts to test the consistency of the relationship between MQ, mathematical literacy, and temperament; quasi-experimental research can be recommended to test the effectiveness of MQ-based learning that considers Keirsey temperament. In addition, longitudinal studies and comparisons with other personality or learning style models can provide a more profound understanding of how students' metacognitive profiles and mathematical literacy develop and vary over a longer period.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state that they have no conflict of interest related to the research, authorship, or publication of this article.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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