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Investigating Metacognitive Awareness and Mathematical Resilience in Linear Programming Problem Solving among University Students: An Exploratory Factor Analysis (EFA)

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ABSTRACT

Metacognition and mathematical resilience are important cognitive-affective resources for mathematical problem solving, but their interaction in linear programming remains insufficiently understood. This study examined the factor structure and practical manifestation of both constructs among undergraduate mathematics education students using an explanatory sequential mixed-methods design. The quantitative phase involved 35 students who completed metacognition and mathematical resilience questionnaires. Item validity, Kaiser-Meyer-Olkin measures, Bartlett's test, exploratory factor analysis, and Cronbach's alpha were used to evaluate the instruments, followed by correlation and regression analyses. The qualitative phase involved three purposively selected students representing high, moderate, and low profiles; their written solutions and semi-structured interviews were analyzed and triangulated. The metacognition instrument showed an overall Cronbach's alpha of 0.84, while the mathematical resilience instrument obtained 0.70. Factor analysis indicated multidimensional structures encompassing metacognitive knowledge, skills, experiences, and mathematical resilience. Integrated findings showed that students with stronger metacognitive awareness planned, monitored, and evaluated strategies more systematically, maintained effort when computations became difficult, and recovered more effectively from errors. Students with moderate profiles required structured prompts, whereas students with low profiles showed weaker monitoring, limited reflection, and greater anxiety. These findings suggest that metacognitive regulation and mathematical resilience operate as complementary resources during linear programming problem solving. The validated questionnaires may support subsequent research, while metacognitive scaffolding and resilience-oriented instruction may strengthen students' problem-solving competence in applied mathematics. The small sample limits broad generalization and warrants further validation.

ABSTRAK

Metakognisi dan resiliensi matematis merupakan sumber daya kognitif-afektif yang penting dalam pemecahan masalah matematika, tetapi interaksi keduanya pada konteks program linier belum dipahami secara memadai. Penelitian ini mengkaji struktur faktor dan manifestasi praktis kedua konstruk pada mahasiswa pendidikan matematika dengan desain metode campuran sekuensial eksplanatori.

Tahap kuantitatif melibatkan 35 mahasiswa yang mengisi angket metakognisi dan resiliensi matematis. Validitas butir, ukuran Kaiser-Meyer-Olkin, uji Bartlett, Exploratory Factor Analysis, dan Cronbach's alpha digunakan untuk mengevaluasi instrumen, kemudian dilanjutkan dengan analisis korelasi dan regresi. Tahap kualitatif melibatkan tiga mahasiswa yang dipilih secara purposif untuk mewakili profil tinggi, sedang, dan rendah; jawaban tertulis serta wawancara semi-terstruktur dianalisis dan ditriangulasi. Instrumen metakognisi memperoleh Cronbach's alpha keseluruhan sebesar 0,84, sedangkan instrumen resiliensi matematis sebesar 0,70. Analisis faktor menunjukkan struktur multidimensional yang mencakup pengetahuan, keterampilan, dan pengalaman metakognitif serta resiliensi matematis. Hasil integrasi menunjukkan bahwa mahasiswa dengan kesadaran metakognitif lebih kuat mampu merencanakan, memantau, dan mengevaluasi strategi secara lebih sistematis, mempertahankan usaha ketika perhitungan menjadi sulit, serta lebih efektif bangkit dari kesalahan. Mahasiswa dengan profil sedang memerlukan arahan terstruktur, sedangkan mahasiswa dengan profil rendah menunjukkan pemantauan yang lebih lemah, refleksi terbatas, dan kecemasan lebih tinggi. Temuan ini menunjukkan bahwa regulasi metakognitif dan resiliensi matematis berfungsi sebagai sumber daya yang saling melengkapi dalam pemecahan masalah program linier. Angket yang tervalidasi dapat mendukung penelitian lanjutan, sedangkan scaffolding metakognitif dan pembelajaran berorientasi resiliensi berpotensi memperkuat kompetensi pemecahan masalah mahasiswa dalam matematika terapan. Ukuran sampel yang kecil membatasi generalisasi dan memerlukan validasi lanjutan.

INTRODUCTION

Mathematics education plays a fundamental role in developing students' logical, critical, and analytical thinking skills (Baiduri and Ulfah, 2022; Herdiansyah et al., 2024; Ulfah, 2022). However, many undergraduate students continue to experience difficulties in learning mathematics, particularly in topics that require in-depth analysis and complex problem-solving skills, such as linear programming (Mashuri, 2021). Linear programming is recognized as one of the most challenging subjects in mathematics education programs. Based on students' average course performance, only 34.4% were able to formulate mathematical models accurately. Moreover, as a branch of applied mathematics, linear programming requires students not only to master theoretical concepts but also to apply them to real-world contexts, particularly transportation and industrial optimization problems (Kartika, 2020a; Sari et al., 2017). These challenges may reduce students' self-confidence, learning motivation, and perseverance in solving linear programming problems, ultimately affecting their academic performance (Nihayah, 2020).

As a fundamental scientific discipline, mathematics plays a crucial role in developing the logical, critical, systematic, and analytical thinking skills required for problem solving in academic settings and everyday life. In mathematics learning, students are expected not only to obtain correct answers but also to understand the cognitive processes used to reach appropriate solutions. Yudha et al. (2024) argued that learning mathematics extends beyond performing calculations; students are also expected to understand mathematical concepts, think logically and critically, and develop effective problem-solving strategies. These abilities are closely associated with metacognition, which requires students to consciously plan strategies, monitor their progress, and evaluate the effectiveness of the approaches they use. Metacognitive activities vary among individuals, even among students with similar problem-solving abilities (Yudha et al., 2024), reflecting differences in their awareness and regulation of cognitive processes. When confronted with challenging mathematical problems, students also require mathematical resilience to persist, adapt, and recover throughout the problem-solving process.

One of the key factors influencing students' success in learning mathematics is metacognition, which is defined as the ability to monitor, regulate, and reflect on one's own thinking processes (Güner and Erbay, 2021; Lee et al., 2019). Students with well-developed metacognitive skills are better able to assess their understanding, recognize their cognitive strengths and limitations, and apply appropriate strategies to regulate their thinking during problem solving. Previous studies have consistently reported that students with higher levels of metacognitive ability tend to be more successful in solving complex mathematical problems (Akben, 2020; Suliani et al., 2024).

Classroom observations conducted during the linear programming course revealed that many students experienced difficulties in solving linear programming problems, particularly those involving the simplex method. The simplex method is widely used to solve industrial optimization problems by determining the maximum or minimum value of an objective function involving multiple decision variables (Prifti et al., 2020). Solving simplex problems requires lengthy, iterative computational procedures. Consequently, even minor computational errors in the initial stages may lead to incorrect final solutions. Such iterative calculations demand persistence, accuracy, and sustained effort, all of which are closely associated with mathematical resilience (Komalasari and Nuraida, 2024; Utami et al., 2024).

Mathematical resilience plays a crucial role in helping students cope with the challenges of learning mathematics (Arjun and Muntazhimah, 2023). It refers to students' ability to persist and recover from the difficulties, failures, and pressures encountered during mathematics learning (Herman and Fatimah, 2023; Lee and Johnston-Wilder, 2017). Students with high levels of mathematical resilience are more likely to manage mathematics anxiety, maintain motivation when faced with challenging problems, and remain confident in their ability to complete mathematical tasks effectively. Consequently, they are better equipped to develop appropriate solutions and achieve stronger academic performance (Herman and Fatimah, 2023). Although mathematical resilience has been widely investigated in relation to students' ability to cope with difficulties in learning mathematics, studies explicitly examining its relationship with metacognition among undergraduate mathematics education students, particularly at Universitas Muhammadiyah Banjarmasin, remain limited. Thus, the empirical relationship between these two constructs has not been adequately established.

Based on the preceding discussion, metacognition and mathematical resilience can be regarded as key determinants of students' ability to solve linear programming problems effectively. Nevertheless, empirical studies examining the relationship between these constructs, particularly in the context of linear programming, remain limited. Previous research has predominantly investigated cognitive and affective factors separately, with little attention to how metacognition and mathematical resilience interact to influence mathematical problem-solving performance. Therefore, this study investigated the relationship between metacognition and mathematical resilience among undergraduate students in the Mathematics Education Program at Universitas Muhammadiyah Banjarmasin while solving linear programming problems. By providing empirical evidence on the interaction between these constructs, the findings were expected to contribute to the development of more effective instructional approaches for enhancing students' competencies in applied mathematics, particularly linear programming.

METHOD

This study employed a mixed-methods approach with an explanatory sequential design, in which the quantitative findings were followed by qualitative exploration to provide a deeper understanding of students' metacognition and mathematical resilience in solving linear programming problems (Fetters et al., 2013). In the quantitative phase, Exploratory Factor Analysis (EFA) was conducted to examine the underlying factor structure of the metacognition and mathematical resilience instruments, following recommendations that factor extraction and interpretation be based on explicit psychometric criteria (Fabrigar et al., 1999; Watkins, 2018). The quantitative findings were subsequently explored qualitatively to obtain a more comprehensive understanding of how metacognition and mathematical resilience influenced students' linear programming problem-solving processes. The quantitative phase involved 35 undergraduate students. This sample size was consistent with Roscoe's (1982) recommendation that an appropriate sample size for behavioral research ranges from 30 to 500 participants. For the qualitative phase, participants were selected purposively to represent students with high, moderate, and low levels of mathematical resilience and to provide information-rich cases for explaining the quantitative patterns (Palinkas et al., 2015).

The research instruments consisted of mathematical resilience and metacognition questionnaires. Before data collection, both instruments underwent validity and reliability testing to ensure adequate psychometric properties and reliable measurement of the hypothesized constructs. Internal consistency was assessed using Cronbach's alpha, a coefficient commonly used to evaluate the reliability of multi-item scales (Tavakol and Dennick, 2011). The quantitative data were analyzed using descriptive statistics and Exploratory Factor Analysis (EFA) to examine the underlying factor structure and verify that the indicators of each variable appropriately represented their respective latent constructs. Correlation analysis was then conducted to examine the relationship between mathematical resilience and metacognition, followed by multiple linear regression analysis to determine the extent to which these variables influenced students' ability to solve linear programming problems.

In the qualitative phase, the study sought an in-depth understanding of students' experiences and problem-solving processes related to metacognition and mathematical resilience in solving linear programming problems. Data were collected through semi-structured, in-depth interviews with participants who were purposively selected based on the quantitative findings and represented high, moderate, and low levels of mathematical resilience. The interview questions focused on students' experiences in dealing with mathematical difficulties and the metacognitive strategies they used during problem solving. Students' written responses to linear programming problem-solving tasks were also analyzed to provide further insight into their cognitive processes. The data were examined through methodological triangulation by comparing findings from the interviews with students' written solutions, consistent with the use of multiple data sources to strengthen qualitative credibility (Carter et al., 2014). This triangulation enhanced the credibility and trustworthiness of the findings. Finally, the verified qualitative findings were presented descriptively to support the interpretation of the quantitative results and the study's conclusions.

As shown in Figure 1, the quantitative and qualitative findings were integrated to provide a comprehensive understanding of the research problem. Three integration strategies were employed. First, a connecting strategy was used, whereby the quantitative findings served as the basis for selecting participants for the qualitative phase. Second, an explaining strategy was applied, in which the qualitative findings were used to clarify and provide deeper insight into the quantitative results. Finally, a comparing strategy was employed to identify areas of convergence and divergence between the quantitative and qualitative findings. These procedures reflect integration through connecting and narrative explanation in mixed-methods research (Fetters et al., 2013).

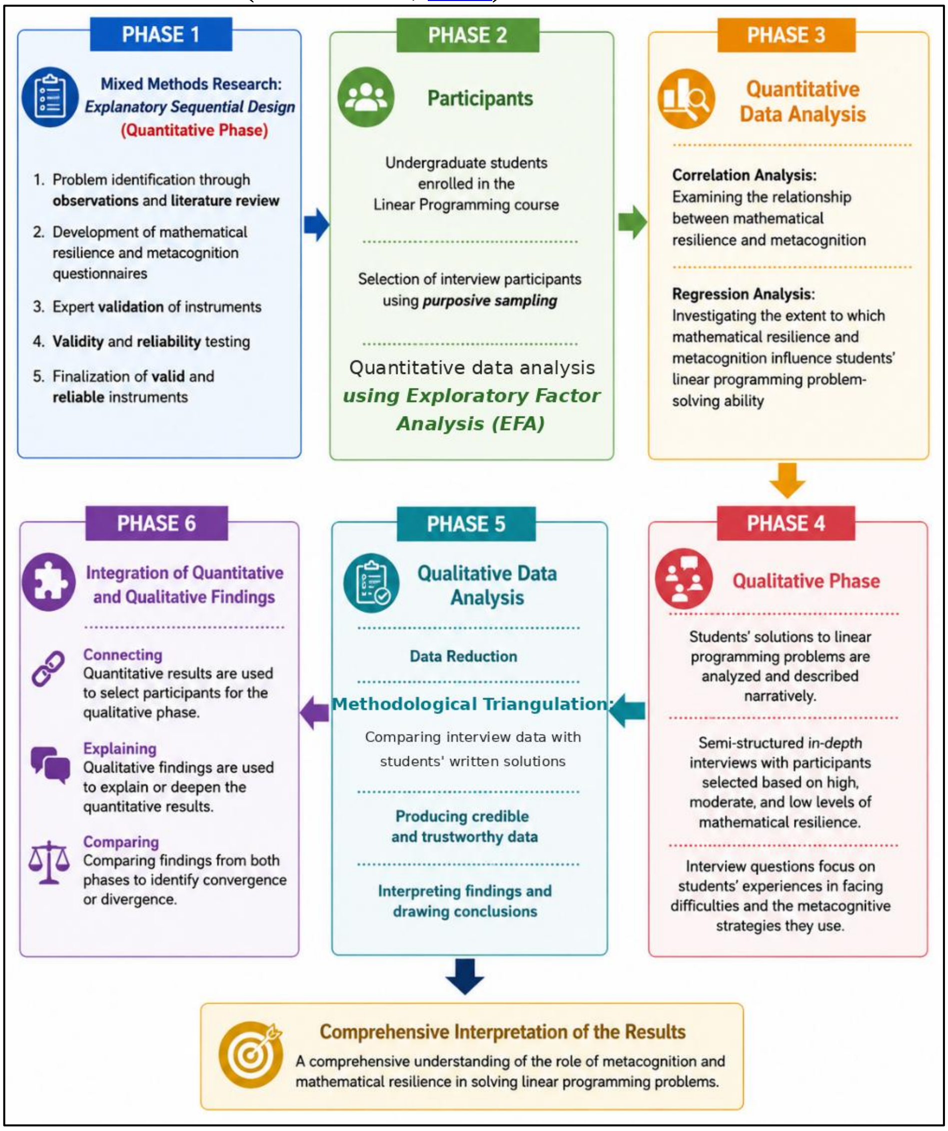


Figure 1. Research Flow Diagram

RESULTS AND DISCUSSION

The validity test was conducted by calculating the correlation between each questionnaire item's score and the total score at a significance level of 0.05. Each item was assessed by comparing its calculated correlation coefficient with the critical correlation value. An item was considered valid when the calculated coefficient exceeded the critical value and the correlation was positive. The critical value used in this study was 0.344, corresponding to 35 respondents at the 5% significance level. Table 1 presents the factor-analysis results for the metacognition and mathematical resilience questionnaires and indicates whether the data were suitable for subsequent factor extraction and construct validation.

Factor analysis was conducted to identify the underlying factors associated with students' metacognition and mathematical resilience in solving linear programming problems. As presented in Table 1, the Kaiser-Meyer-Olkin (KMO) values were 0.761 for mathematical resilience, 0.767 for metacognitive knowledge, 0.712 for metacognitive skills, and 0.676 for metacognitive experiences. Because all KMO values exceeded the minimum threshold of 0.50, the data were considered adequate for factor analysis. These results indicated sufficient sampling adequacy for further analysis.

Table 1 also presents the results of Bartlett's Test of Sphericity, which yielded $p < 0.001$. This result indicated that the indicators were significantly correlated and that the correlation matrix was appropriate for factor analysis. Therefore, the data met the assumptions required for factor extraction and construct validation.

Furthermore, the communalities of the observed variables reflected the proportion of variance in each indicator explained by the extracted factors. The communalities of all analyzed indicators exceeded the recommended threshold of 0.50, indicating that the extracted factors accounted for at least 50% of the variance in each observed variable. Consequently, the identified factors adequately represented the underlying constructs of metacognition and mathematical resilience involved in students' linear programming problem-solving processes.

Table 1. Exploratory Factor Analysis Results for the Metacognition and Mathematical Resilience Instruments

Construct	**Kaiser-Meyer-Olkin (KMO)**
Metacognitive Knowledge	0.767
Metacognitive Skills	0.712
Metacognitive Experiences	0.676
Mathematical Resilience	0.761

Bartlett's test: $p < 0.001$; communalities > 0.50

Factors with eigenvalues greater than 1.00 were retained in accordance with the Kaiser criterion. The analysis identified four factors for Metacognitive Knowledge, five factors for Metacognitive Skills, two factors for Metacognitive Experiences, and six factors for Mathematical Resilience in the context of solving linear programming problems. The reliability results for the metacognition and mathematical resilience questionnaires are presented in Table 2.

Table 2. Reliability Results for the Metacognition and Mathematical Resilience Questionnaires

Construct	Cronbach's Alpha	N of Items
Metacognitive Knowledge	0.902	15
Metacognitive Skills	0.913	18
Metacognitive Experiences	0.718	8
Mathematical Resilience	0.695	20

As presented in Table 2, all constructs achieved Cronbach's alpha coefficients greater than 0.60, indicating satisfactory internal consistency. After the validity and reliability assessments, the questionnaires demonstrated adequate psychometric properties for measuring the intended constructs. At the instrument level, the metacognition questionnaire yielded a Cronbach's alpha coefficient of 0.84, whereas the mathematical resilience questionnaire yielded a coefficient of 0.70. These findings indicated that the instruments reliably and consistently measured their respective constructs.

The findings indicated that metacognition and mathematical resilience were multidimensional constructs composed of several complementary factors. Students with higher levels of metacognitive awareness were better able to plan, monitor, and evaluate their problem-solving strategies effectively. They also demonstrated greater perseverance, were less likely to give up when encountering challenges, and were better able to recover from setbacks while solving mathematical problems, particularly linear programming problems. This multidimensional pattern is consistent with the view that metacognition comprises coordinated knowledge, monitoring, and control processes rather than a single undifferentiated ability (Veenman et al., 2006). Likewise, the multidimensional structure of mathematical resilience aligns with evidence that the construct includes students' perceived value of mathematics, willingness to struggle, and growth-oriented beliefs (Kooken et al., 2016). The acceptable internal consistency of the resilience instrument also accords with research conceptualizing academic resilience as cognitive-affective and behavioral responses to adversity (Cassidy, 2016).

After the quantitative phase, in which the metacognition and mathematical resilience questionnaires were evaluated through Exploratory Factor Analysis (EFA) and reliability testing, the study proceeded to the qualitative phase to obtain a deeper understanding of the findings. Participants were purposively selected from the quantitative sample based on scores representing high, moderate, and low levels of metacognition and mathematical resilience. This sampling strategy captured variation in students' experiences and provided a more comprehensive understanding of how they solved linear programming problems.

The qualitative findings were derived from analyses of students' responses to linear programming problem-solving tasks and semi-structured interviews. The selected participants represented high, moderate, and low levels of metacognition and mathematical resilience. Their responses were analyzed using indicators of metacognitive awareness during the problem-solving process. The findings for each category are presented in the following sections.

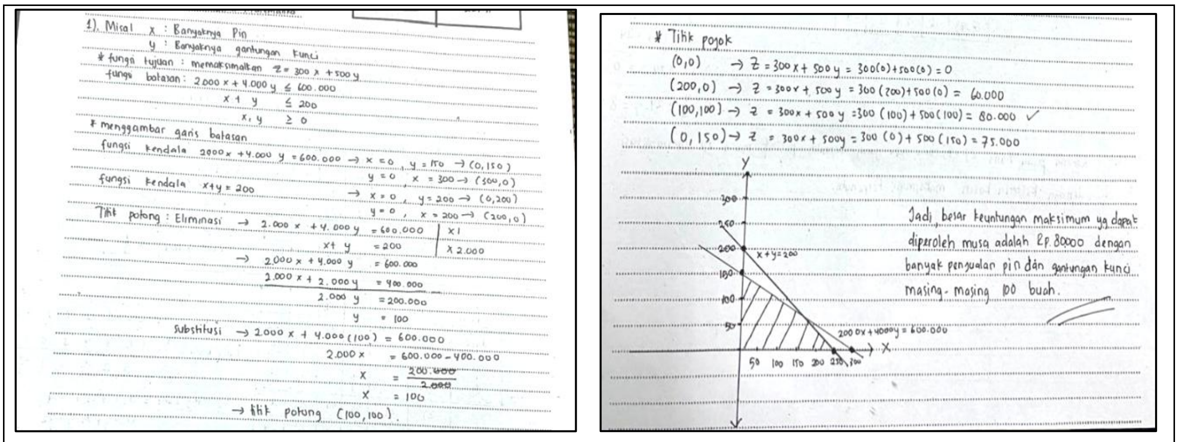
The problem presented to the participant reflected a real-life situation: determining the maximum profit obtainable from sales under specified constraints. The following section describes the metacognitive processes demonstrated by the participant in the high category while solving the linear programming problem.

Upon receiving the problem, the participant carefully read and examined the task before pausing briefly to understand its meaning and requirements. During this stage, the participant engaged in planning by identifying the given information, determining the quantities to be found, and clarifying the problem's objective. The participant quickly recognized the nature of the problem and proceeded systematically. The solution process began by defining the decision variables, with x and y representing the numbers of pins and keychains sold, respectively. The participant then formulated the objective function and constraints before completing the solution procedure logically and sequentially.

The participant demonstrated confidence in understanding the problem and continuously evaluated their comprehension throughout the problem-solving process. Figure

2 illustrates the participant's written solution. The interview results and task analysis revealed that high mathematical resilience positively influenced the participant's metacognitive awareness. During the planning stage, the participant clearly formulated the decision variables and objective function before beginning the solution. During the monitoring stage, the participant consciously reviewed each step by checking the consistency between the mathematical model and the contextual information provided in the problem.

During the evaluation stage, the participant engaged in critical reflection by reviewing the effectiveness of the selected strategy, identifying potential weaknesses in the solution process, and considering alternative approaches. These metacognitive behaviors were closely associated with the participant's mathematical resilience. The participant demonstrated persistence by revising the solution when an initial approach proved ineffective, remained determined when encountering difficulties, and recovered from errors by exploring alternative problem-solving strategies. These characteristics indicated a strong capacity to persevere and adapt when faced with challenging mathematical tasks, particularly linear programming problems. This finding supports prior evidence that explicit metacognitive training improves mathematical reasoning, transfer, and metacognitive awareness (Kramarski & Mevarech, 2003). Similarly, the IMPROVE framework has been shown to strengthen mathematical knowledge, reasoning, and metacognitive regulation through structured self-questioning (Mevarech & Fridkin, 2006).



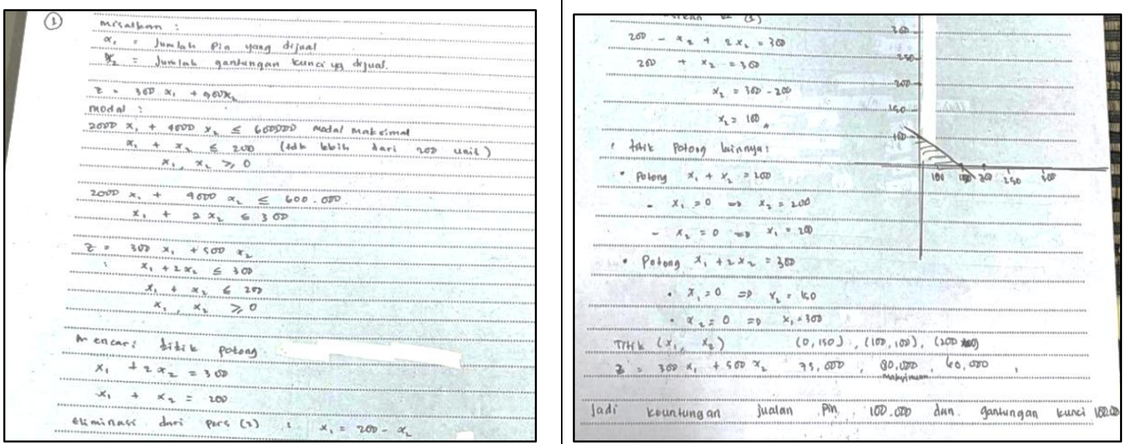
(a) (b)

Figure 2. Solution Produced by the Participant with High Mathematical Resilience

The findings from the interviews, task analysis, and classroom observations revealed that the participant with high mathematical resilience also demonstrated well-developed metacognitive skills. This pattern suggested a close relationship between metacognitive awareness and mathematical resilience. The participant's ability to deliberately plan, monitor, and evaluate each stage of the solution process increased self-efficacy, reduced anxiety, and fostered persistence when addressing linear programming problems. Komala et al. (2024) similarly reported that students demonstrated positive mathematical resilience when engaged in learning based on the Visual, Auditory, Read/Write, and Kinesthetic (VARK) approach. This resilience also contributed to the development of their metacognitive processes during mathematical problem solving. The participant's ability to revise and persist after initial difficulty also accords with findings that metacognitive instruction can produce sustained gains in regulation of cognition and mathematics achievement (Mevarech & Amrany, 2008). The observed connection among confidence, perceived difficulty, and strategic control is also consistent with evidence that metacognitive experiences integrate affective judgments with monitoring and control during learning (Efklides, 2006).

The participant with a moderate level of mathematical resilience generally demonstrated reasonable persistence when confronting mathematical problems but remained susceptible to emotional pressure and conceptual difficulties. Although the participant did not readily give up, they required more time to recover from challenges than the participant with high mathematical resilience. In solving the linear programming problem, the participant initially identified the problem and formulated a preliminary strategy by determining the known and required variables. Although the participant was somewhat inattentive during the planning stage and had difficulty formulating an effective initial strategy, they were still able to identify the problem's essential elements. Figure 3 presents the participant's written solution.

During the interview conducted to verify the participant's written solution, the participant experienced difficulty determining an appropriate problem-solving strategy. Nevertheless, with guidance and prompting from the researcher, the participant attempted to revisit and reconstruct the solution process by retracing the previously completed steps. The participant exhibited a moderate level of anxiety throughout the problem-solving process. Although the participant did not immediately abandon the task, the anxiety experienced during the initial stage adversely affected concentration, particularly during complex mathematical calculations. This pattern is consistent with evidence that mathematics anxiety consumes working-memory resources needed for complex problem solving (Ramirez et al., 2013). It also supports the interpretation that students' appraisal of difficulty can intensify anxiety and avoidance, indicating the need for interventions that reshape how mathematical challenges are interpreted (Ramirez et al., 2018).



(a) (b)

Figure 3. Solution Produced by the Participant with Moderate Mathematical Resilience

Analysis of the interview transcripts further revealed that the participant demonstrated a reasonably developed level of metacognitive awareness during the planning phase; however, weaknesses were evident in the monitoring and evaluation phases. The participant recognized errors made during the problem-solving process, particularly when attempting to understand and interpret the problem statement. Nevertheless, the participant experienced difficulty critically evaluating the obtained solution and comprehensively reflecting on its validity.

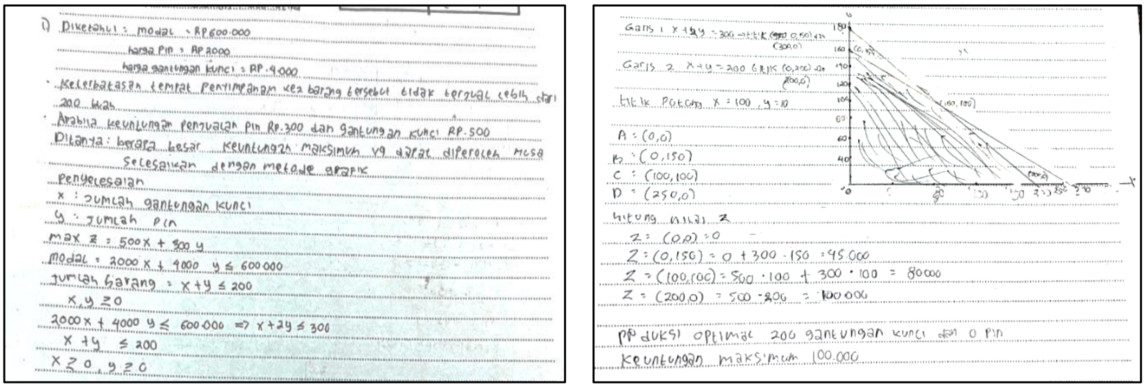
The participant with moderate mathematical resilience required structured guidance to strengthen self-regulation during problem solving. Such participants may benefit from instructional interventions grounded in self-regulated learning or metacognitive scaffolding. These interventions may reduce mathematics-related anxiety, strengthen self-monitoring and evaluation skills, and promote greater consistency in problem-solving performance. Thus, students with moderate mathematical resilience have considerable potential to develop stronger resilience when provided with appropriate pedagogical support. The potential benefits of structured metacognitive prompts are consistent with experimental evidence that explicit instruction in prediction, monitoring, and evaluation enhances mathematics problem solving (Desoete et al., 2003).

Analysis of the participant's written work and interview transcripts revealed several characteristics associated with low mathematical resilience. The participant correctly defined the decision variables, with x representing the number of keychains and y representing the number of pins. The objective function and constraints were also formulated accurately. These findings indicated an initial level of metacognitive awareness, particularly in understanding and interpreting the problem requirements. However, the participant's solution plan lacked coherence and systematic organization, as indicated by the placement of the constraint equations and the numerous revisions made throughout the solution process. These behaviors suggested uncertainty when encountering difficulties, limited access to alternative problem-solving strategies, and a tendency to become easily distracted. Figure 4 illustrates the participant's solution to the linear programming problem.

As shown in Figure 4, the participant attempted to construct the constraint graph and identify the feasible region. Nevertheless, the shading of the feasible region and the representation of the boundary lines lacked precision, and errors occurred when determining the intersection points. During the interview, the participant appeared confused and anxious, which hindered their ability to clearly explain the results. These findings suggested that emotional factors negatively influenced the participant's problem-solving performance.

The participant also failed to verify whether all corner points had been determined correctly and relied heavily on the initial calculations without further reflection. This pattern indicated weaknesses in metacognitive monitoring because the participant did not consistently review, verify, or adjust the solution process. Such characteristics are commonly associated with low mathematical resilience.

During the evaluation phase, the participant calculated the objective-function values at the corner points. However, the evaluation remained limited to numerical computations and lacked deeper reflection on the validity and reasonableness of the results. The participant identified the optimal solution without re-examining whether it consistently satisfied all constraints. This behavior reflected limitations in metacognitive evaluation, suggesting that the participant tended to accept the results without critically questioning their accuracy, consistency, or underlying mathematical rationale.



(a) (b)

Figure 4. Solution Produced by the Participant with Low Mathematical Resilience

The participant with low mathematical resilience experienced difficulty when confronted with problems involving multiple constraints. The participant demonstrated limited perseverance in exploring alternative solution strategies and relied primarily on routine computational procedures without considering other possible approaches. In addition, the participant lacked confidence in constructing and justifying mathematical arguments. From a metacognitive perspective, the participant did not effectively engage in metacognitive processes throughout problem solving. During the planning stage, although the participant identified the initial elements required to solve the problem, the plan lacked systematic organization and strategic direction. During the monitoring stage, the participant had difficulty identifying and correcting errors and often adhered to the initial procedure without critically examining its validity. During the evaluation stage, reflective thinking remained limited because the response focused largely on obtaining a numerical solution without interpreting or evaluating its meaning. Consequently, low mathematical resilience constrained the effective application of metacognitive processes in solving linear programming problems.

Analysis of the three selected participants revealed that awareness of planning, monitoring, and evaluating solution strategies contributed to greater self-confidence, enabling students to manage anxiety and maintain persistence when completing linear programming tasks. These findings indicated that students with higher levels of metacognitive awareness tended to demonstrate stronger mathematical resilience. Conversely, limited metacognitive awareness was associated with greater frustration, which could negatively affect students' mathematical resilience.

This qualitative analysis complemented the Exploratory Factor Analysis (EFA) findings by providing deeper insight into how metacognition and mathematical resilience were enacted while students solved linear programming problems. Whereas the quantitative findings established the structures of the two constructs, the qualitative evidence illustrated how they operated in practice through students' planning, monitoring, and evaluation activities. Integrating the quantitative and qualitative findings therefore provided a more comprehensive understanding of the learning processes underlying students' mathematical problem-solving performance.

CONCLUSION

The findings indicated that the metacognition and mathematical resilience inventory developed for solving linear programming problems comprised four constructs. The instrument demonstrated satisfactory psychometric properties, as evidenced by the validity, reliability, and model-adequacy results. Cronbach's alpha coefficients exceeded the acceptable threshold of 0.60, with overall coefficients of 0.84 for the metacognition instrument and 0.70 for the mathematical resilience instrument. These results indicated that the questionnaires consistently measured the intended constructs among undergraduate students solving linear programming problems.

The qualitative findings further revealed that students' awareness of planning, monitoring, and evaluating their problem-solving processes increased their confidence, reduced mathematics-related anxiety, and strengthened their perseverance when solving linear programming problems. Students with higher levels of metacognitive awareness generally exhibited stronger mathematical resilience. Conversely, lower levels of metacognitive awareness were associated with greater frustration, which could weaken students' mathematical resilience.

The validated questionnaires developed in this study may serve as reference instruments for future research on metacognition and mathematical resilience in mathematics education. The findings also provide empirical evidence to support the development of more effective instructional approaches for improving students' mathematical problem-solving abilities, particularly in linear programming.

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