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Mathematical Communication of Vocational Students with Field Dependent and Independent Cognitive Styles in Solving Linear Programming Problems

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Abstract: This study aimed to investigate and compare the mathematical communication skills of vocational students with field-independent and field-dependent cognitive styles when solving linear programming problems. The goal was to investigate how these cognitive styles affect the effectiveness of mathematical communication, which includes understanding, planning, and expressing solutions. Data were obtained qualitatively from two vocational students: one with a field-independent cognitive style and the other with a field-dependent cognitive style. The data were analyzed using interactive analysis, which included codification, presentation, and conclusion. The findings revealed that students with a field-independent cognitive style had better mathematical communication skills than their field-dependent counterparts, particularly in understanding and planning solutions to linear programming problems. This study also discovered that both cognitive styles can effectively use different forms of mathematical communication, such as mathematical expressions, depictions, and text writing, particularly when answering questions. This study is unique in that it focuses on the role of cognitive styles in mathematical communication within the context of vocational education, thus providing insights into how educators can design more inclusive mathematics learning experiences that cater to different cognitive styles.

Keywords: mathematical communication; vocational students; field independent; field dependent; problem solving; linear programming

领域依赖型和独立认知型职业学生在解决线性规划问题时的数学交流

摘要：本研究的目的是調查和比較具有場獨立和場依賴認知風格的職業生解決線性程式設計問題時的數學溝通技巧。目的是研究這些認知風格如何影響數學溝通的有效性，其中包括理解、規劃和表達解法。研究人員從兩名職業學生身上取得定性資料，其中一名具有場獨立認知風格，另一名具有場依賴認知風格。資料分析採用互動式分析，包括資料編碼、呈現和結論。研究結果顯示，具有場域獨立認知風格的學生比具有場域依賴認知風格的學生有更好的數學溝通技巧，特別是在理解和規劃線性計畫問題的解決方案方面。研究也發現，兩種認知風格的學生都能有效地運用不同形式的數學溝通，例如數學表達、描繪和文字撰寫，尤其是在回答問題時。本研究的獨特之處在於它聚焦於認知風格在職業教育背景下的數學溝通中所扮演的角色，為教育者如何設計更具包容性的數學學習經驗以迎合不同的認知風格提供了啟示。

关键词：数学交流; 职业学生; 独立领域; 依赖领域; 问题解决; 线性规划

1. Introduction

The purpose of the introduction is to explain technology advances and job market demand shifts. Mathematical skills have become increasingly important in addressing challenges in a variety of professional fields. Mathematics education at the vocational level is important for students’ career development in various industries [1-2]. Mathematics plays an important role in many aspects of life, including vocational training [2-3]. Mathematical communication skills are an important aspect of learning mathematics. This ability encompasses the ability to explain, present, solve, and interpret mathematical problems [4-7]. The application of mathematics in vocational education contexts frequently has direct relevance in the workplace, and a solid understanding of mathematical communication skills is becoming increasingly important. Consequently, a solid foundation in vocational mathematics is required for students to succeed in their chosen industry. Furthermore, mathematical communication skills are essential, particularly when solving linear programming problems.

Linear programming is widely used in fields such as operations management, economics, computer science, and engineering to optimize outcomes under constraints [8-9]. It aids decision making by providing optimal solutions to complex problems, ranging from increasing profits in business operations to optimizing production processes to improve efficiency and profitability. Solving linear programming problems requires not only a strong understanding of mathematical concepts but also the ability to formulate problems mathematically, analyze them, and communicate solutions clearly and systematically. This skill necessitates a combination of mathematical knowledge and problem-solving abilities as well as the ability to effectively communicate results [10]. A solid understanding of linear programming is essential not only for learning mathematics but also for making real-world decisions. In the context of decision making, linear programming is useful in addressing complex problems with stochastic or fractional models, assisting in the optimization of decisions under uncertainty [11]. Understanding linear programming and being able to apply it in an applied mathematics context is an invaluable skill for vocational students. Students with a solid understanding of linear programming will be able to identify and solve problems in a variety of real-world contexts as well as make better decisions.

Many vocational students continue to struggle with a deep understanding of mathematical concepts and appropriately apply mathematical problem-solving [12-14]. A lack of adequate mathematical communication skills is one of the contributing factors [14-15]. Mathematical communication entails not only correctly explaining answers but also the ability to articulate logical and clear mathematical reasoning. Mathematical communication is an important skill that not only allows for the delivery of solutions, but also promotes a deeper understanding of mathematical concepts. Mathematical communication skills are critical for students because they allow them to develop the ability to convey mathematical ideas through language and symbols in order to solve problems effectively [16-18] and express mathematical ideas both orally and in writing, which aids in the organization of mathematical thinking [19-20]. These abilities allow students to organize and connect their mathematical thinking, communicate logical and clear mathematical ideas, and analyze and evaluate mathematical strategies used by others [21-22]. Mathematical communication skills are an important aspect of mathematics education, because they prepare students to solve problems competently and critically. This skill is also useful in the workplace, where a wide range of mathematical problems may arise, requiring individuals and teams to solve them thoroughly.

Cognitive style is one of several factors that influences students' ability to communicate mathematically. The cognitive style describes how people understand and process information [23-25]. The two most commonly discussed cognitive styles in literature are field-independent (FI) and field-dependent (FD). Students in the FI style can process information analytically and independently, demonstrating traits such as rigor and correctness in their approach. On the other hand, students with the FD style rely more on the context and structure provided by teachers or textbooks, which can lead to errors such as reading incomplete questions and rushing to complete tasks [26-28]. Cognitive style, whether field-independent or field-dependent, influences how students process information, use mathematical notation, and model mathematical problems [29-30]. Students with a field-independent cognitive style are better at processing information using mathematical notation and accurately modeling mathematical problems [29-30]. Furthermore, cognitive style influences students' mathematical reasoning ability, with field-dependent, field-intermediate, and field-independent cognitive styles having varying effects [31]. Understanding students' cognitive styles can assist educators in developing learning strategies tailored to their 'learning preferences, thereby improving the effectiveness of mathematical communication.

Several studies have examined the relationship between mathematical communication, problem-solving, and cognitive style [30, 32-35]. According to some studies, there is a positive relationship between mathematical communication skills and success in solving mathematical problems [17, 36]. Other studies have shown that cognitive styles influence students' mathematical communication strategies [37-39]. Cognitive style influences students' mathematical communication strategies and problem-solving approaches [6, 30, 34, 40-41]. Understanding students' cognitive styles can help educators tailor teaching methods to improve their mathematical communication and problem-solving abilities effectively. Although previous research has been conducted in this area, there have been few in-depth studies of vocational students.

The scarcity of research on students' mathematical communication profiles, particularly at the vocational level, highlights the need for more in-depth studies to better understand the dynamics of mathematical communication in the context of linear programs. With a better understanding of students' mathematical communication profiles, it is expected that more appropriate learning approaches can be developed, as well as valuable insights into the development of vocational mathematics curricula. As a result, this study contributes new insights and novelty to the literature by investigating the mathematical communication profile of vocational students and the factors that influence it, particularly in the context of linear program problem solving. The primary goal of this research was to investigate vocational students' mathematical communication profiles in solving linear program problems while considering their cognitive style. This study is highly relevant in the context of vocational mathematics education because it provides new insights into how to improve students' mathematical communication skills, which will improve learning effectiveness and students' preparation for the workplace. This study is expected to contribute significantly to the development of vocational mathematics curricula, teaching, and learning.

2. The Research Methods

2.1. Type and Approach

The purpose of this study was to investigate vocational students' mathematical communication in solving linear program problems based on their cognitive style, so the research design was a descriptive exploratory with a qualitative approach [42-43].

2.2. Research Subjects

Students from Class X at Nusantara Pharmacy Vocational High School in Palu participated in the study, which focused on their understanding of linear programming materials. The Group Embedded Figure Test (GEFT) was used to classify students' cognitive styles, specifically field-independent (FI) and field-dependent (FD). Students who scored between 0 and 9 were classified as having a field-dependent cognitive style, whereas those who scored between 10 and 18 were classified as field independent.

Each cognitive style was represented by one student chosen from two groups. Two main criteria guided The selection process. First, GEFT scores were used to identify the most representative members of each group. Specifically, the students with the highest score in the field-independent group and the lowest score in the field-dependent group were chosen. This method ensured that the chosen subjects strongly exhibited the characteristics of their respective cognitive styles. In addition to the GEFT scores, the selection committee also considered recommendations from students' math teachers. The teachers' recommendations were critical in identifying students who could effectively communicate their ideas and were eager to participate actively in the research. The ability to clearly articulate problem-solving processes is critical for the study's objectives. AR was chosen to represent the field-independent cognitive style based on these criteria as she had the highest GEFT score of 18. DA, who received the lowest score in the field-dependent group, was chosen to represent field-dependent cognitive style. This rigorous selection process ensured that the study accurately reflected the impact of cognitive style on students' mathematical communication.

2.3. Instrument

The instruments used in this study' were divided into two groups: main instruments and supporting instruments. The main instrument is the researcher who collects data. The supporting instruments included the Group Embedded Figure Test (GEFT) and linear program problem tests. GEFT is a twenty-five-item assessment test that assesses an individual's cognitive perceptual ability to detect simple shapes embedded in complex images [44], and was used to select the study's research subjects. GEFT comprises three parts. Part I is for practice (unassessed) and consists of seven GEFT questions, while Parts II and III each contain nine questions used to determine FI or FD cognitive styles. The GEFT has been widely used in several studies to assess field-independent (FI) and field-dependent (FD) cognitive styles [38, 45-49]. The linear problem-solving test contained two questions. The linear problem-solving test consisted of two questions. Before the questions were used, content validation was performed to ensure that the language was simple for students and that the questions were appropriate for mathematical communication indicators. The linear program problem is validated by mathematics teachers and education lecturers who already hold teaching certificates.

2.4. Data Analysis

Before analysis, mathematical communication data were validated using time triangulation, which involved assigning two equivalent problems at different times: S1 for problem 1 and S2 for problem 2. Each subject worked on the linear program problems twice at different times. The study's data analysis is qualitative and includes data condensation, data presentation, and conclusion drawing [50]. Data condensation entails sorting, filtering, and simplifying the data to make them more manageable. The researcher read the data several times, noting emerging patterns, themes, or categories and extracting pertinent information. The data are presented in a descriptive format. Drawing conclusions necessitated a thorough interpretation and analysis of the collected data to identify patterns, trends, and key findings. Data analysis activities are based on indicators of written or oral mathematical communication, such as mathematical expressions, drawings, and text writing [4, 51-53]. Mathematical expressions entail communicating mathematical concepts through symbols and language derived from events at hand. Drawing entails representing concrete objects, diagrams, graphs, tables, and drawings as mathematical concepts or vice versa. Writing a text entails expressing answers, developing mathematical models, and formulating problems in both oral and written languages. These communication indicators are associated with the stages of problem-solving, which include understanding the problem, developing a solution plan, implementing the solution, and drawing conclusions [54].

The research procedure is presented in Figure 1.

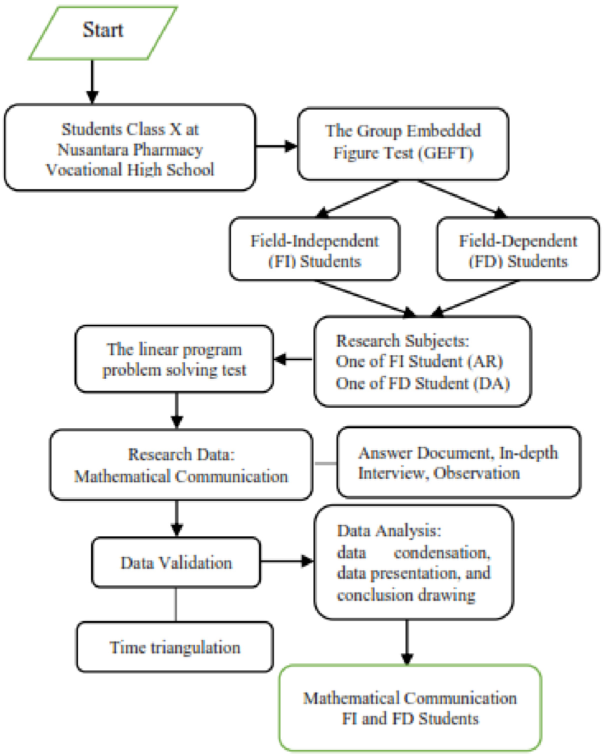

Figure 1. The research procedures (The authors' elaboration)

3. Results

The presentation of students' mathematical communication results in solving linear programming problems is based on a cognitive style, as detailed in Polya's solution stages.

3.1. Mathematical Communication of Field Independent Students (AR)

3.1.1. Mathematical Communication in Problem Understanding and Solution Planning

AR subjects' mathematical communication in understanding the given problem uses both written and oral communication in the form of text representations, such as those in the problem, and they understand the meaning of the question mark symbol. This is supported by the responses in Figure 2 and interviews with AR1 11 P to AR1 22 S.

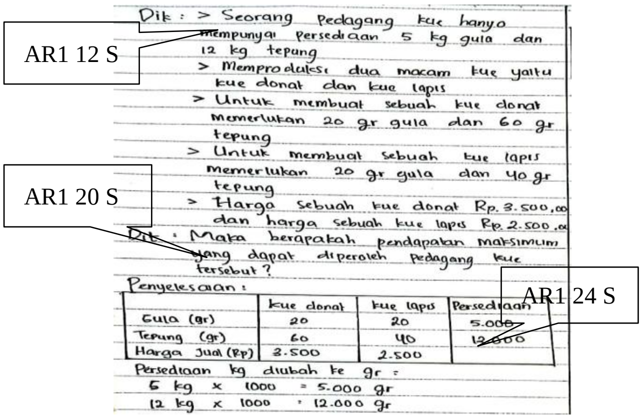

Figure 2. AR's written communication in understanding the problem (The authors' elaboration)

The interviews provided more detailed information regarding the results of the AR subjects' written responses. The following script includes excerpts from researcher interviews with AR subjects to help them understand the problem.

AR1 07 P: Do you understand the problem?

AR1 08 S: Yes

AR1 09 P: Do you understand this well?

AR1 10 S: It's okay.

AR1 11 P: If you understand, now try to express what information you get about the problem?

AR1 12 S: I obtained information that a cake trader only supplies 5 kg of sugar and 12 kg of flour. Producing two types of cakes: donut cakes and layer cakes. To make a donut cake, 20 g of sugar and 60 g of flour were required. To make a layer cake, 20 g of sugar and 40 g of flour were required. The price of donut cake is 3,500, and the price of layer cake is 2,500.

AR1 13 P: What do you think of the information you have received?

AR1 14 S: It is known.

AR1 15 P: Why do you know that information is known from the problem?

AR1 16 S: This is a statement sentence.

AR1 19 P: Ok. What is then asked from this question?

AR1 20 S: Maximum revenue obtained by the cake trader.

AR1 21 P: How do you know what is asked by the question?

AR1 22 S: There is a question mark (while pointing to the question).

According to Figure 2 and the interview results, AR's mathematical communication involves understanding problems orally and in writing using mathematical expressions, drawing, and writing text. The question mark symbol (?) to express mathematical expressions and interpret the problem' questions (AR1 22 S). While drawing a table (AR1 24 S) and writing the text, mention the information in the problem (AR1 12 S, AR1 20 S). Figure 3 depicts the AR subjects' written answers in developing a solution plan using mathematical terms, notations, and structures to present a mathematical idea.

Furthermore, the AR's written answers when developing a solution plan are represented in Figure 3.

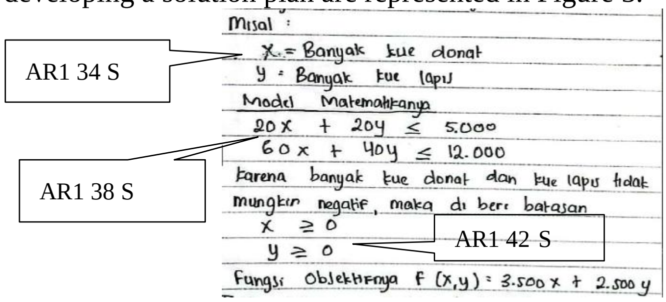

Figure 3. AR's written mathematical communication in developing a solution plan (The authors' elaboration)

The interviews provided more detailed information regarding the results of the AR subjects' written responses. An excerpt from the researcher's interview with the AR subject while preparing the plan is provided below.

AR1 23 P: What plan do you think is needed to solve this problem?

AR1 24 S: First, I compiled the known information from the problem in tabular form. Prior to that, I converted the inventory of 5 kg of sugar and 12 kg of flour to grams. I have changed it so that the units were the same, making it easier to calculate. The supply of kg is converted to gr: 5 kg multiplied by 1,000 equals 5,000 g, and 12 kg multiplied by 1,000 equals 12,000 g. The donut cake requires 20 g of sugar, whereas the layer cake requires 20 g of sugar, with a total supply of 5,000 g. The donut cake required 60 g of flour, whereas the layer cake required 40 g of flour, with a total of 12,000 g. The donut cake costs $3,500, while the layer cake costs $2,500 (as explained in the table).

AR1 25 P: Why did you write this in a table?

AR1 26 S: I wrote this in a table for easy reading and grouping, making it easier to progress to the next stage.

AR1 33P: What is your next step toward solving this problem?

AR1 34 S: The next step is memorization. I guess *x* is many donut cakes and *y* is many layer cakes.

AR1 35 P: Why do you think that?

AR1 36 S: The maximum income of a cake trader can be calculated by multiplying the number of donut cakes (x) and layer cake (y).

AR1 37P: What happens after you' memorize something?

AR1 38 S: Create a mathematical model based on a previously created table. In the sugar section, the donut cake requires 20 g, whereas the layer cake requires 20 g, with a total supply of only 5,000 g. In the flour section, the donut cake required 60 g, and the layer cake required 40 g, with a total of only 12,000 g. The mathematical model in the sugar section is 20x + 20y≤ 5.000, whereas that in the flour section is 60x + 40y ≤ 12.000. Because the number of donut cakes and layer cakes cannot be negative, constraints x ≥ 0 and y ≥ 0. are applied. I created the objective function *f(x,y) = 3.500x + 2.500y* based on their respective prices.

AR1 39 P: Why did you use the inequality notation '≤'? (Pointing to the answer).

AR1 40 S: The problem states that a trader has only 5 kg of sugar and 12 kg of flour in stock, resulting in an inequality of '≤'.

AR1 41 P: Ok. Why did you write x ≥ 0 and y ≥ 0 (pointing to the answer)?

AR1 42 S: Assuming x = many donut cakes and y = many layer cakes, the result cannot be negative; therefore, the constraints x ≥ 0 and $y \geq 0$.

AR1 43 P: So, you define the objective function *f(x,y) = 3.500x + 2.500y*. Why is this the case?

AR1 44 S: Because the question is how much money the cake trader can make with a donut cake price of 3.500 and a layer cake price of 2.500, the objective function is *f(x,y) = 3.500x + 2.500y*

Based on Figure 3, exposure and interview results (AR1 23 P to AR1 44 S), AR subjects used mathematical expressions, drawings, and text to create oral and written solution plans. Mathematical expressions were obtained by converting weight units from kilograms to grams and employing mathematical symbols in the form of variables and inequality signs (AR1 24 S, AR1 36 S, and AR1 42 S). Drawing and presenting a plan as a table. Writing a text involves developing mathematical models in the form of linear inequalities (AR1 38 S) and linear functions of two variables (AR1 44 S).

3.1.2. Mathematical Communication for Problem Solving and Conclusions

Figure 4 depicts the AR subject's written answers to problems by interpreting mathematical ideas orally and in writing, using graphs, tables, and algebra. Based on Figure 4, the interviews yielded more detailed information about the outcomes of the AR subjects' written responses. An excerpt from the researcher's interview with the AR subject to solve this problem is presented below.

AR1 45 P: What is the next step you will take to solve this problem?

AR1 46 S: Create a line equation table to determine the intersection point of the line with the X and Y axes of each line equation. (1) Intersection of the line 20x + 20y = 5.000 with the X (y = 0) and Y axes (x = 0). Substituting x = 0 into equation 20x + 20y = 5.000 yields 20 (0) + 20y = 5.000, resulting in y = 5.000/20. Crossing 0s above and below yields y = 5.000/20 = 250. Substituting y = 0 into the equation 20x + 20y = 5.000 yields x = 5.000/20 = 250. Line 20x + 20y = 5.000 intersects the X-axis and Y-axis at (0,250) and (250, 0), respectively. Analog, the line 60x + 40y = 12.000, intersects the X-axis and Y-axis at $(0{,}300)$ and $(200{,}0)$.

AR1 47 P: What is the next step after determining the intersection points of each line with the X- and Y-axes?

AR1 48 S: Creating a graph. Each obtained point was inserted into the X- and Y-axes. Line 20x + 20y = 5.000 intersects the X and Y axes at (0,250) and (250.0). The line 60x + 40y = 12.000 then intersects with the X- and Y-axes at (0.300) and (200.0). Therefore, if (0.300), x = 0, and y = 300, I create point 300 on the Y-axis. Then, (200.0); x = 200 and y = 0, I create a point 200 on the X-axis and draw a line connecting the two points.

AR1 55 P: After that, what did you do?

AR1 56 S: The inequalities 20x + 20y ≤ 5.000 and 60x + 40y ≤ 12.000 were used to determine the shaded area at (0,0). (1) 20x + 20y ≤ 5.000; $20(0) + 20(0) = 0 + 0 = 0 \leq 5.000$ (satisfied), indicating that the shaded area is below the line. (2) 60x + 40y ≤ 12.000; 60(0) + 40(0) = 0 + 0 = 0 ≤ 12.000 is satisfied), and the shaded one is below the line.

AR1 57 P: Why is the shaded area below this line?

AR1 58 S: Because, for the test point (0,0), the shaded area containing (0,0) is below the line.

AR1 59 P: Why did you write $x \geq 0$ (shaded on the right) and $y \geq 0$ (shaded on the top), pointing to the answer?

AR1 60 S: x ≥ 0 is bounded by the line x = 0, where. As previously explained, x = 0 (same as the Y-axis) means that what is shaded is to the right of the Y-axis, whereas y ≥ 0 is bounded by the line y = 0, (same as the X-axis) means that what is shaded is above the X-axis.

AR1: 61 P: What do you do after that?

AR1 62 S: The area of the solution set can be calculated by looking at the shaded area four times. Subsequently, determining the DHP corner points yields O(0,0), B(200.0), C(100.150), and D (0.250).

AR1 63 P: Ok. What comes next?

AR1 64 S: To calculate the maximum value, each corner point was substituted into the objective function *f(x,y) = 3.500x + 2.500y*.

AR1 65 P: Explain how you got the highest value

AR1 66 S: Points O(0,0), B(200,0), C(100,150), and D(0,250) substitution to *f(x,y) = 3.500x + 2.500y* such that yields 0, 700.000, 725.000, and 625.000, respectively. The highest value is 725,000.

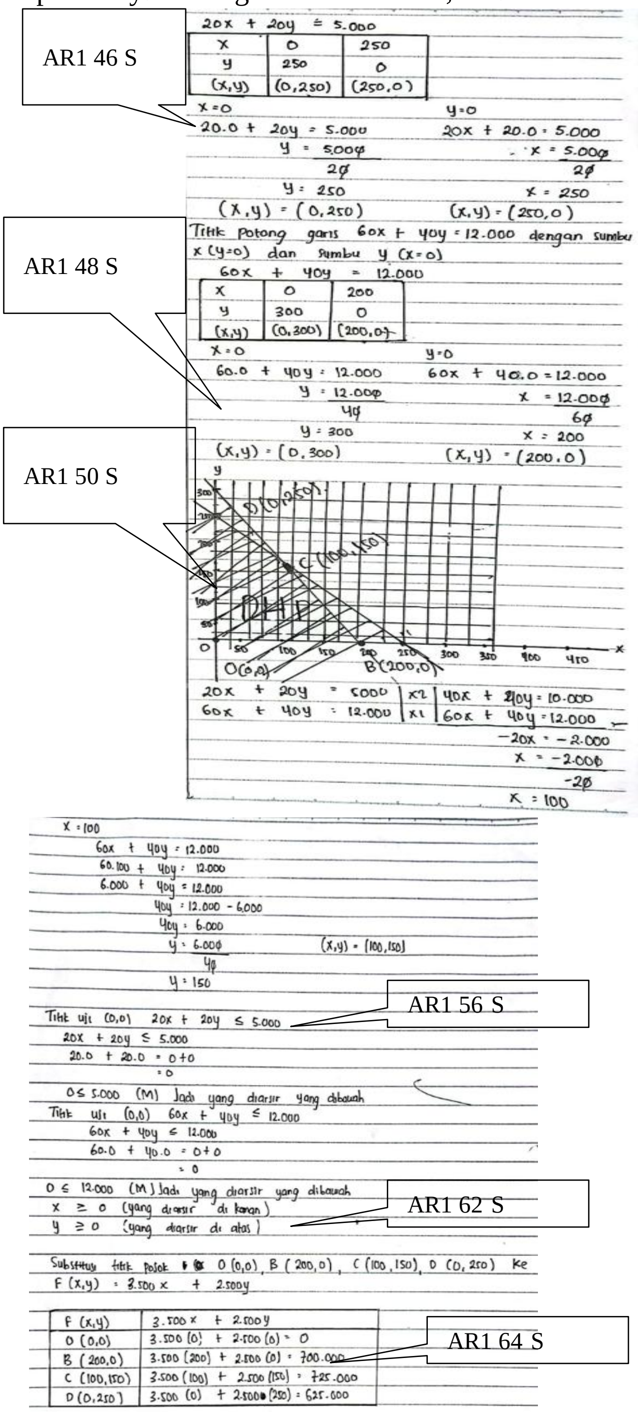

Figure 4. AR's written mathematical communication when solving problems (The authors' elaboration)

According to the responses and interview results, AR's mathematical communication in problem solving is performed in writing and orally using mathematical expressions, drawings, and writing text. Mathematical expressions use memorization with x and y variables (AR1 34 S and AR1 36 S), the intersection point of the line with the X-axis and Y-axis of each line equation (AR1 46 S), test points (AR1 56 S to AR1 60 S), and determining the area of the solution set by looking at the shaded area four times so that the points surrounding the solution set area (DHP corner points) are visible (AR1 62 S). Furthermore, according to Figure 4, AR mathematical communication involves drawing and creating tables (AR1 46 S) and graphs (AR1 48 S). Writing text by creating mathematical models in the form of linear inequalities (AR1 38 S, AR1 40 S, and AR1 42 S) and expressing answers (AR1 50 S and AR1 66 S).

Figure 5 depicts the AR subject's written response to summarizing the results.

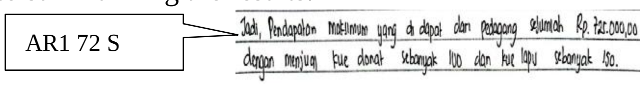

Figure 5. AR's written mathematical communication in summarizing answers (The authors' elaboration)

The interviews provided more detailed information regarding the results of the AR subjects' written responses. The following script includes an excerpt from the researcher's interview with the AR subject that summarizes the answer.

AR1 67: Are you certain of your answer?

AR1 68 S: Already.

AR1: 69 P: Are you certain?

AR1 70 S: Yes.

AR1 71 P: How do you determine your answer to the question?

AR172S: The trader can earn a maximum of Rp725,000 by selling 100 donut cakes and 150 layer cakes.

Based on the exposure of AR subjects' answers and interview results, it was discovered that AR's mathematical communication in concluding the results of the answers orally and in writing included writing text, formulating answers (AR1 72 S), and writing conclusions on the answer sheet (Figure 5).

3.2. Mathematical Communication for Field Dependent Students (DA)

3.2.1. Mathematical Communication for Understanding the Problem and Developing a Solution Plan

Figure 6 depicts a table containing the written responses of the DA subject' to understanding the problem.

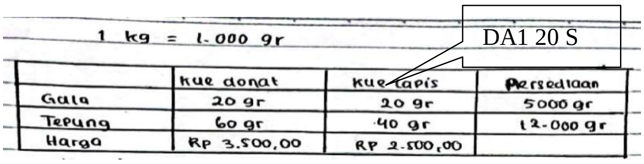

Figure 6. The DA's written mathematical communication to understand this problem (The authors' elaboration)

Interviews were used to obtain more detailed information about the outcomes of the 'written responses of subjects with DA. The following excerpts were obtained from the researchers' interview with subject DA to better understand the problem.

DA1 07 P: Do you solve this problem?

DA1 08 S: I did.

DA1 09 P: Do you understand this completely?

DA1 10 S: Yes

DA1 11 P: If you already understand, try to express what information is found in the problem

DA1 12 S: A cake trader has only 5 kg of sugar and 12 kg of flour in the hand. The trader makes two types of cakes: donut cakes and layer cakes. Donut cakes require 20 g sugar and 60 g flour, whereas layer cakes require 20 g sugar and 40 g flour. The price of a donut cake is 3.500, that of a layer cake is 2.500, and the cake merchant asks what the maximum revenue is.

DA1 13: Why do you believe the information is known and ask the question?

DA1 14 S: Because the information is a statement sentence, specifically the sentence "a cake trader only has a supply of 5 kg of sugar and 12 kg of flour up to 2,500" and a question sentence because the sentence ends with a "?".

DA1 15 P: Is there anything else you can add to this question?

DA1 16 S: No; that is, all.

DA1 17 P: So, are you certain that you have all the information in the problem?

DA1 18 S: I did

DA1 19: Why did not' you write down on the answer sheet what you know and what you a're asking about the problem? Do you believe that it is necessary to write down the known questions?

DA1 20 S: This is already under question. I do not believe that this is necessary because the information is already in question. I wrote down the information from the question, but I did so in the format of a table. Previously, I adjusted the supply of 5 kg of sugar and 12 kg of flour to g. One kg equals 1000 grams, so 5 kg equals 5000 grams, and 12 kg equals 12,000 grams. To simplify the calculation, the units were changed to be identical. Sugar supply: The donut cake requires 20 g, the layer cake requires 20 g, and the inventory is 5,000 g. The donut cake requires 60 g of flour, the layer cake requires 40 g, and the inventory is 12,000 g. The donut cake costs 3,500, whereas the layer cake costs 2,500 (see the table in Figure 5).

DA1 21 P: Why did you write it in a table format?

DA1 22 S: I wrote it down in a table so that I could easily create the mathematical model later.

Based on the exposure of the results of the written answers and the results of the DA subject interview, the DA's mathematical communication was obtained by understanding the problem in writing and drawing by creating a table. While speaking, write the text by mentioning information in the problem (DA1 12 S to DA1 14 S) and mathematical expressions by interpreting the question mark symbol (?) as the question regarding the problem.

Furthermore, the DA subjects' written responses to the problem use mathematical terms, notations, and structures to present a mathematical idea, as illustrated in Figure 7.

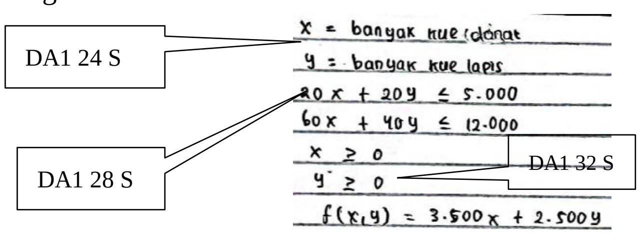

Figure 7. The DA's written mathematical communication to understand the problem (The authors' elaboration)

The interviews provided more detailed information about the results of the 'written responses of the DA subject. The following excerpts were obtained from the researcher's interview with subject DA to better understand the problem.

DA1 23 P: What is your next step in solving this problem?

DA1 24 S: I memorized. For example, x represents many donut cakes and y represents many layer cakes.

DA1 25 P: Why did you generalize this?

DA1 26 S: To calculate the maximum income for the cake trader, I use x as the number of donut cakes and y as the number of layer cakes.

DA1 27 P: What is the next step after memorization?

DA1 28 S: I created a mathematical model by examining the table from left to right. The donut cake required 20 g of sugar, whereas the layer cake required 20 g. With a sugar supply of only 5,000 g, the mathematical equation is $20x + 20y \leq 5.000$ Furthermore, in the flour ingredient section, the donut cake requires 60 g and the layer cake requires 40 g, with a flour supply of only 12,000 g, so the mathematical model is $60x + 40y \leq 12.000$. Constraints $x \geq 0$ and $y \geq 0$, as well as the objective function $f(x,y)$

= *3.500x + 2.500y*, were created by analyzing the cake prices.

DA1 29 P: Why did you use the inequality notation '≤'? (Pointing to the answer).

DA1 30 S: It is stated that 5 kg of sugar and 12 kg flour were supplied. The inequality sign '≤' indicates that the quantity does not exceed 5 or 12 kg.

DA1 31 P: Okay. Why do you write x ≥ 0 and y ≥ 0? (pointing to the answer)

DA1 32 S: Because *x* is the number of donut cakes and *y* is the number of layer cakes, the result was not negative.

DA1 33 P: You wrote *f(x,y) = 3.500x + 2.500y*. Why is that?

DA1 34 S: The objective function for the cake trader is *f(x,y) = 3.500x + 2.500y*, where x and y are the prices of the donut and layer cake, respectively.

Based on the exposure of the results of the written answers and the results of the DA subject interview, the DA's mathematical communication was obtained by developing a solution plan orally and in writing, using mathematical expressions and writing text. Mathematical expressions were formed using mathematical symbols, variables, and inequality signs (DA1 24 S, DA1 28 S, and DA1 32 S). When writing text in the form of mathematical models, consider linear inequalities (DA1 28 S) and linear functions of the two variables (DA1 34 S).

3.2.2. Mathematical Communication for Problem Solving and Conclusions

Figure 8 depicts the' written answers of DA subjects to S1 problems, which involve interpreting mathematical ideas using graphs, tables, and algebra.

The interviews provided more detailed information about the results of the 'written responses of the DA subject. The following excerpts were obtained from the researcher's interviews with the subject DA to solve the problem.

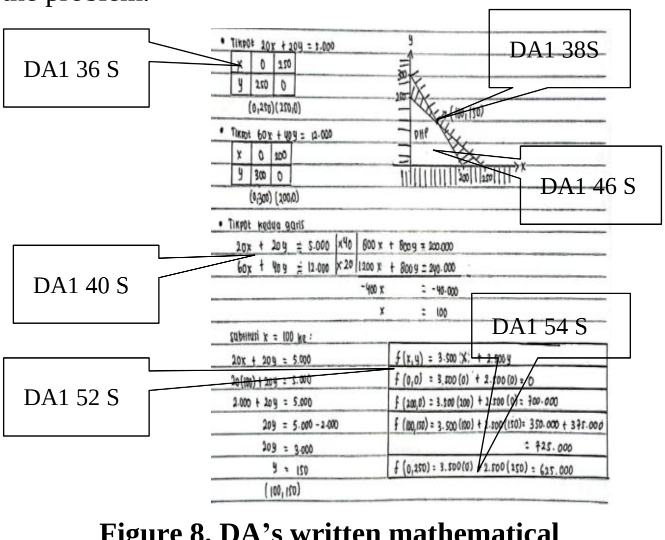

Figure 8. DA's written mathematical communication when solving problems (The authors' elaboration)

DA1 35 P: What is your next step toward solving this problem?

DA1 36 S: I created a table with the line' equation to determine the point at which the line intersects the X and Y axes. (1) Intersection points of line 20x + 20y = 5.000. Substituting x = 0 into the equation 20x + 20y = 5,000 yields 20 (0) + 20y = 5,000 and y = 5,000/20, indicating that y = 250. Substituting y = 0. into equation 20x + 20y = 5,000 yields 20x + 20(0and x = 5,000/20, indicating $x = 250$. The lines intersect at (0.250) and (250.0). (2) The intersection of the line 60x + 40y = 12,000. Substituting x = 0 into the equation 60x + 40y = 12,000 yields 60(0) + 40y = 12,000 and y = 12,000/40, indicating y = 300. Substituting y = 0 into the equation 60x + 40y = 12,000 yields 60x + 40(0) = 12,000 and x = 12,000/60, indicating that x = 200. The lines intersect at (0.300) and (200.0).

DA1 37 P: What is the next step after determining the intersection point of each line with the X- and Y-axes?

DA1 38 S: I created a graph. For the first, line 20x + 20y = 5.000 intersects at (0.250); 250 is on the Y-axis and (250.0); 250 is on the X-axis, and I draw a line through these two points. For the second, the line 60x + 40y = 12,000 intersects at (0.300), which is on the Y-axis, and (200.0), which is on the X-axis, so I draw a line through these two points.

DA1: 39 P: What else did you do?

DA1 40 S: Determine the intersection of lines 20x + 20y = 5,000 and 60x + 40y = 12,000.

DA1 45 P: What did you do thereafter?

DA1 46 S: Shaded to identify the completion set region (DHP). The inequality '≤' (20x + 20y ≤ 5.000) is shaded below the line, but I have shaded the opposite. 60x + 40y = 12,000, the inequality sign '≤' is shaded below the line, whereas I shaded the opposite. x ≥ 0 is shaded on the right, but the opposite is shaded on the left. y ≥ 0 is shaded above; however, I have shaded the opposite.

DA1 49 P: Can you explain why you are shading the opposite (not the area of inequality)?

DA1 50 S: Looking at the unshaded area helps me see the solution set more easily.

DA1 51 P: What did you do thereafter?

DA1 52 S: After determining the DHP corner points, we got (0,0); (200,0); (100,150); and (0,250), indicating the answer.

DA1 53 P: Okay. What is next?

DA1 54 S: Substitute each corner point into the objective function $f(x, y) = 3.500x + 2.500y$ to determine the maximum value.

DA1 55 P: Explain how the maximum value was obtained.

DA1 56 S: Substituting points (0,0) to *3.500x + 2.500y* yields 0; (200,0) to *3.500x + 2.500y* yields

700.000; (100,150) to *3.500x + 2.500y* yields 350.000 + 375.000 = 725.000, and (0.250) to *3.500x + 2.500y* yields 625.000. The maximum value was 725,000.

Based on the results of the written answers and interviews, DA subjects' mathematical communication when solving problems in writing and orally through mathematical expressions, drawing, and writing text. Mathematical expressions employ mathematical symbols, X and Y axes, variables, and inequality signs (DA1 36 S and DA1 46 S). Drawing with tables and graphs (DA1 36 S and DA1 38 S) while solving mathematical models in the form of linear inequality systems, linear equations, or functions as text writing activities (DA1 36 S and DA1 54 S).

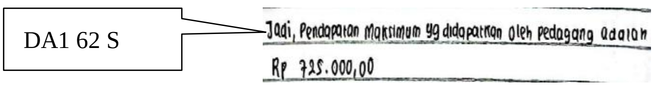

Figure 9. The DA's written mathematical communication for concluding the answer (The authors' elaboration)

The interviews provided more detailed information about the results of the 'written responses of the DA subject. The following excerpt from the researcher's interview with the DA subject concludes the answer.

DA1 61 P: How do you answer this question?

DA1 62 S: The trader can earn a maximum IDR of 725,000.00.

DA1 63 P: How many donut and layer cakes should the trader sell to maximize revenue?

DA1 64 S: Substituting the point (100,150) into the objective function yields a maximum value of 725,000, resulting in 100 donut cakes and 150 layer cakes.

Based on the exposure to written answers and interviews, mathematical communication of DA subjects in concluding the results of oral and written answers by writing text, formulating answers (AD1 62 S and AD1 64 S), and writing conclusions on the answer sheet (Figure 9).

4. Discussion

4.1. Mathematical Communication When Understanding the Problem and Developing a Solution Plan

The findings revealed that vocational students with a field-independent cognitive style used mathematical expressions, drawings, and writing coherent texts to understand problems. Students with field-dependent cognitive styles communicate mathematically using mathematical expressions, writing texts orally, and drawing in writing. These findings indicate that students with a field-independent cognitive style perform better than field-dependent students in understanding linear program problems through oral and written communication that includes mathematical expressions, drawing, and writing coherent texts [30, 34, 40, 55-56]. Students with a field-independent cognitive style can process information more structurally and independently of context, allowing them to use various forms of mathematical communication more effectively [30, 40, 57]. Students with a field-dependent cognitive style appear to be more adept at using mathematical expressions, writing text orally, and drawing in writing [30, 58-59]. Students with a field-dependent cognitive style are more aware of the relationship between information and the larger context [60-62], so they are better at using mathematical communication that is more context-related verbally and visually.

In general, students with a field-independent cognitive style outperformed those with a field-dependent cognitive style, in terms of understanding mathematical concepts. Field-independent students excel in mathematical critical thinking skills such as inference, assumption, deduction, and interpretation [63, 64]. They are skilled at processing information using mathematical notation and accurately modeling mathematical problems [29, 65]. Furthermore, students with a field-independent cognitive style perform better in mathematical problem-solving, learning achievement, and mathematical appreciation [66]. These findings suggest that vocational students with a field-independent cognitive style are more effective in using various forms of mathematical communication, such as mathematical expressions, drawings, and writing coherent texts, when developing a solution plan for a given problem [34, 40]. Students with a field-independent cognitive style are better than field-dependent in creating a solution plan for mathematical problems [30, 67]; exhibit strong creative thinking processes when tackling mathematical challenges; demonstrate a deep understanding of the problem and the ability to design effective solutions by modifying existing knowledge [23, 38]; and have a positive attitude toward the use of various modes of communication, such as oral and written expressions, drawings, and coherent mathematical texts [23]. This suggests that students with a field-independent cognitive style can process information independently of the context and use mathematical communication more effectively to understand and plan solutions.

This finding implies that teachers should consider students' cognitive styles when developing learning strategies. They can use various forms of mathematical communication to help students with field-independent cognitive styles to understand, whereas students with field-dependent cognitive styles may benefit from more contextual approaches. Understanding cognitive style can help shape how vocational students communicate mathematically, emphasizing the importance of considering individual differences when designing educational approaches and support systems.

4.2. Mathematical Communication When Problem-Solving and Concluding Answers

The findings revealed that vocational students with field-independent and field-dependent cognitive styles solved problems through oral and written communication using mathematical expressions, drawings, and writing coherent text. To emphasize the answer, they used mathematical communication by writing the text. The findings of this study' show that vocational students with field-independent and field-dependent cognitive styles solve problems by using a variety of mathematical communication methods. They used oral and written communication as well as mathematical expressions, drawing, and writing coherent texts to convey solutions [68-70]. Oral and written communication, as well as mathematical expression, drawing, and writing texts, are important tools for conveying mathematical concepts, both in practical situations and in summarizing written responses. They frequently discussed and presented their ideas orally, and wrote down the steps to the solution. Regarding answering questions, both cognitive styles preferred to use mathematical communication in the form of coherent written text. They wrote the answer's conclusion in a clear and structured manner to emphasize and clarify the final outcome of problem-solving.

Although there are differences in their preferences for mathematical communication forms, both field-independent and field-dependent students use various forms of communication to solve problems and reach appropriate conclusions. This study confirms the importance of facilitating both cognitive styles by providing opportunities for students to explore various forms of mathematical communication, whether oral, written, symbolic, visual, or contextual, based on individual characteristics and preferences. This demonstrates that mathematical communication skills are not solely dependent on a particular cognitive style but can be developed by all students, regardless of their cognitive style. Mathematical communication skills are essential for students because they require the ability to express mathematical ideas clearly through various modes of communication, including oral, written, and visual communication [71-72]. These skills include organizing and connecting mathematical thinking, effectively communicating logical ideas to others, analyzing peers' strategies, and accurately using mathematical language. Students must develop these skills to communicate accurate and comprehensive solutions to mathematical problems [17].

These findings contradict previous research, which found that students with field-independent and field-dependent cognitive styles performed differently in mathematical communication strategies, with field-independent students outperforming field-dependent students [30, 34, 55]. Field-independent students demonstrate superior mathematical communication skills, expressing ideas logically and systematically in a variety of formats, including oral, written, and visual representations [30, 48]. By contrast, field-dependent students struggle with proper communication and frequently fail to meet communication indicators [55]. In this study, the teacher's strategy for teaching linear program problem solving, which did not distinguish cognitive styles in the learning process, influenced the similarity of mathematical communication between the two cognitive styles. Both independent and dependent cognitive styles can effectively use various forms of mathematical communication to solve linear programming problems.

This finding implies that a mathematics learning approach should facilitate the overall development of students' mathematical communication skills. As part of the learning process, teachers must encourage students to use mathematical expressions and draw and write coherent texts. By allowing students to practice and develop mathematical communication skills, they can improve their understanding of mathematical concepts and their problem-solving abilities. Teachers can help students succeed in a variety of settings, including workplaces.

5. Conclusion

The current study found that cognitive style had a significant impact on vocational students' mathematical communication skills, particularly when dealing with linear programming problems. The main findings show that students with a field-independent cognitive style perform better in problem comprehension and solution planning than their field-dependent counterparts do. Field-independent students, in particular, demonstrated greater proficiency in problem solving and articulating final answers by using mathematical expressions, drawing diagrams, and writing coherent texts.

Compared with previous research, these findings are consistent with existing studies that highlight the impact of cognitive styles on problem-solving strategies. However, this study broadens conversation by focusing on mathematical communication, which has received less attention in terms of cognitive styles in vocational education. The findings show that, while cognitive style influences mathematical communication skills, these abilities are not limited to specific cognitive types and can be developed across a wide range of students.

The findings of this study have significant implications in vocational mathematics education. Including cognitive-style awareness in teaching practices can improve the effectiveness of mathematical communication instruction. Educators should be able to identify students' cognitive styles and adapt their teaching methods accordingly. To foster these skills, a multimodal approach to learning is recommended, which includes multiple forms of communication such as text, visual aids, and mathematical symbols.

Future research should examine how different learning environments such as the use of technology and peer interaction affect the development of mathematical communication skills. Longitudinal studies could also provide insight into how these skills evolve over time and across educational contexts. The 'findings of this study provide a foundation for developing more inclusive and effective educational strategies to address vocational students' diverse cognitive styles.

Declarations

Author Contributions

Conceptualization, D.I. and R.L.; methodology, S.; software, B.; validation, D.I., R.L. and S.; formal analysis, B.; investigation, D.I., R.L., S. and B.; resources, D.I.; data curation, D.I.; writing—original draft preparation, R.L.; writing—review and editing, D.I.; visualization, S.; supervision, D.I.; project administration, D.I.; funding acquisition, R.L. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

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

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Muhammadiyah Malang, Indonesia.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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