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Commognitive Analysis of 11th-Grade Students in Solving Inverse Matrix Problems: A Gender-Based Study

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Abstract

Research has shown that male students have good abilities in applying mathematical formulas appropriately and correctly, but they are less complete in explaining in detail the steps taken in solving problems, meanwhile, female students are systematically and completely structured and comprehensive manner. Commognitive analysis was important to understand how it influences student learning achievement so that educators can develop better learning strategies. This qualitative research with purposive sampling aims to analyze high school students' commognitive skills in solving contextual mathematics problems in terms of gender. All participants, 23 students of 11th-Grade grouped based on gender, male and female, and one student was chosen from each as the research subjects. Research data was taken from students' written tests and semi-structured interviews based on test results. The data analysis techniques included data reduction, data presentation, and drawing conclusions. The written test is used to determine students' commognitive skills using commognitive components, that are words use, visual mediators, narratives, and routines. The results show that female students demonstrate more detailed and structured completion steps than male. Further research can be carried out to further reveal the potential for commognitive conflict in other materials so that can help teachers how to choose teaching strategies.

Keywords: Commognitive Analysis; Commognitive; Gender; Problem Solving

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1. Introduction

The process of individual intellectual development is greatly influenced by learning mathematics (Sudarsana et al., 2019), for example using the developmental of technology in education can help students to finding clues in solving math-problems. However, there are differences between male and female students in solving problems given by teachers. This difference is often encountered by teachers when carrying out learning activities in the classroom. Mathematics learning activities in the classroom can help individuals to solve problems logically and analytically, as well as improve communication skills and develop critical thinking skills (Putut, Emanuel, Nusantara, & Rahardi, 2024; Putut, Emanuel, Nusantara, Rahman, & Rahardi, 2023). Learning mathematics effectively makes individuals increase their ability and confidence to solve more complicated problems (Hadinugrahaningsih, Rahmawati, & Ridwan, 2017; Sitorus & Masrayati, 2016). Learning mathematics is not just about memorizing formulas and calculating, but also requires understanding the concepts of the material and being skilled at solving problems using detailed procedures(Meilantifa & Emanuel, 2024; Putut, Emanuel, Maulina, & Soewardini, 2024). Understanding material concepts allows individuals to understand basic mathematical ideas, and individual skills based on procedures they know make it possible to apply them in solving problems(Erikson & Erikson, 2019; Guerra & Holgaard, 2016; Yazar Soyadı, 2015). A deep level of understanding of concepts and correct procedures using commognitive makes individuals more confident in applying them in everyday problems. The existence of differences in solving this problem makes this research interesting to do. This is intended to reduce the gap in the differences.

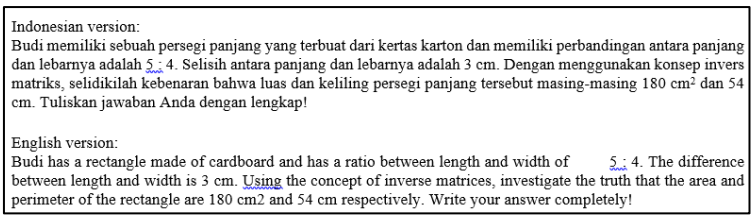
Good understanding of concepts can be seen from the use of routines and narratives expressed (Putut et al., 2023). Both of these things are part of individual cognition (Sternberg, 2014; Sternberg & Zhang, 2014). Commognitive is a combination of two things, namely communication and cognitive (Presmeg, 2016; Scott, Hargreaves, & Sfard, 2015; Sfard, 2008, 2020). Commognitive consists of four components, namely words use, visual mediators, narratives, and routines (Lu, Zhang, & Stephens, 2019; Swidan & Daher, 2019; Tabach & Nachlieli, 2016). Words use can be said to be special words or sentences used by individuals when solving mathematical problems (Heyd-Metzuyanim & Graven, 2016; Radford & Barwell, 2016). Words use (WU) has two types, namely colloquial and literate (Lu et al., 2019; Morgan & Sfard, 2016). Mathematical words that are commonly used in everyday life such as triangle, rectangle, matrix, determinant and inverse are colloquial WU (WU-1). Meanwhile, words used in the literate type (WU-2) are for example singular or the sentence "a function is a special relationship that maps each member of a domain to exactly one member of the codomain". Visual mediators (VM) are items that represent objects. VMs have three types, namely iconic, symbolic, and concrete. VM iconic (VM-1) is a symbol of mathematical objects such as triangles, circles, squares, and many more. VM symbolic (VM-2) can be variables or symbols in algebraic operations such as "→", "↔" and many more. Concrete VM (VM-3) is a real visual object such as a whiteboard, pencil box, ball, etc. that is used to represent objects. Narratives(N) are mathematical arguments expressed based on the steps taken to solve the problem, which can be in the form of definitions, theorems, lemmas and formulas (Park, 2017; Viirman, 2015). Routines(R) are repeated patterns that are carried out when solving problems, which are adjacent to WU, N, and VM (Barbieri, Rodrigues, Dyson, & Jordan, 2019; Mudaly & Mpofu, 2019; Toscano, Gavilán-Izquierdo, & Sánchez, 2019). Commognitive skills can help students in their activity to more understand about their study. With good commognitive skills by students, both male and female, in the components of words use, visual mediators, narratives, and routines, students will be able to solve problems correctly.

Based on the results of observations of students in several high schools and the results of interviews with teachers in Surabaya, students still experience difficulties or lack of understanding of matrix material, namely difficulty in concepts, difficulty translating non-routine question sentences into mathematical sentences, being less careful and thorough when solving contextual problems. These things were found when students completed non-routine contextual problems which caused students to experience errors in their work. This incident was also discovered by several previous researchers, including Emre-Akdoğan, Güçler, & Argün(2018) who said that students encountered difficulties in singular matrix material because they still did not understand the matrix and the necessary prerequisites, had difficulty in existing matrix concepts and did not understand the terms, and students still experienced difficulties when facing story type questions. According to Putut, Emanuel, Maulina, et al.(2024) one of the many elements that can influence students' talents in mathematics, especially mathematics subjects, is gender.

Male and female students learn mathematics in different ways due to variations in physiology and psychology which are undoubtedly influenced by gender. Gender inequality in educational attainment can occur in the classroom (Emre-Akdoğan et al., 2018). Gender differences are manifested in problem-solving approaches, with males often exhibiting a more rushed and less organized style, while females tend to be more methodical and deliberate in their reasoning. Gender stereotypes play a significant role in shaping attitudes toward mathematics, leading to differing levels of confidence and engagement in the subject. Females often face underrepresentation in advanced mathematics courses, which can further perpetuate gender stereotypes and impact performance (Ambrose & Fennema, 2001). Gender-sensitive teaching strategies can help bridge the gap in mathematics ability and foster a more equitable learning environment. This gender prejudice not only exists and is socialized through educational systems and processes in schools, but also through family-based education. Male students tend to solve problems based on their conceptual understanding but are less orderly and tend to be rushed. While female students are more orderly based on their conceptual understanding and are more careful. This claim is supported by Putut et al,(2023) that there are differences in abilities between boys and girls who are gifted from an early age. In this study, we analyzed the results of students' work, namely answers to problem solving using the commognitive component in terms of gender. This research also aims to describe students' commognitive skills in solving mathematics problems in terms of gender. Thus, the results of this research can contribute to the development of learning strategies based on the findings of this research so that they can help improve the quality of mathematics learning and overall student learning outcomes.

2. Method

This qualitative research used a descriptive approach to investigate conditions, events, occurrences or circumstances, the results of which are reports that are described in depth. In qualitative research, the researcher is the main instrument in the research (Cresswel, 2013; Kelly, 2014). Qualitative research is research that focuses on the natural conditions of objects. This research was carried out at the 11^{th} grade Natural Science Frateran Catholic High School in Surabaya, odd semester of the 2024/2025 academic year. A total of 23 students with details of 11 male students and 12 female students. The selection of potential research subjects was carried out based on the following criteria: 1). Has obtained the matrix inverse material. 2). Able to communicate his thoughts both orally and in writing. 3). Willing to be involved in research. The aim of this research is to explore and describe high school students' commognitive skills in solving mathematics problems in terms of gender. The stages in this research consisted of 3 stages, namely pre-research, research, post-research: 1). Pre-research stages include: (a). Carrying out preliminary studies to get an overview of the object, (b). Developing instruments and validating expert validators who are lecturers in mathematics education study programs. The instruments used in this research include contextual question sheets on inverse matrix material, observation sheets, and interview sheets, 2). Research stages include; (a). The researcher gave a question sheet, namely a contextual question about inverse matrices, to students to work on for 30 minutes as in **Figure 1** below. The instruments consist of contextual problem and questions of interview were validated by two expert validators in the field of mathematics education, especially commognitive. They recommended that the research question and questions of interview can be used in this research.


Indonesian version:
Budi memiliki sebuah persegi panjang yang terbuat dari kertas karton dan memiliki perbandingan antara panjang dan lebarnya adalah 5 : 4. Selisih antara panjang dan lebarnya adalah 3 cm. Dengan menggunakan konsep invers matriks, selidikilah kebenaran bahwa luas dan keliling persegi panjang tersebut masing-masing 180 cm^2 dan 54 cm. Tuliskan jawaban Anda dengan lengkap!

English version:
Budi has a rectangle made of cardboard and has a ratio between length and width of 5 : 4. The difference between length and width is 3 cm. Using the concept of inverse matrices, investigate the truth that the area and perimeter of the rectangle are 180 cm2 and 54 cm respectively. Write your answer completely!

Figure 1 Contextual Problems about Inverse Matrix

Researchers observed all activities carried out by students when completing questions and then collected student answer sheets. (b) The researchers chosed one subject from each group whose answers can be analyzed using commognitive components, namely words use, visual mediators, narratives, and routines based on the purposive sampling method. A description of each component is presented in Table 1 below

Table 1. Commognitive Components

Commognitive Components	Sub Components	Description	Code
Words Use	Colloquial	Using words or sentences in everyday life, both spoken and written	WU-1
	Literate	Using words or sentences, symbols, signs, numbers, which are mathematical in nature	WU-2
Visual Mediators	Iconic	Use pictures or illustrations of objects, tables in solving problems	VM-1
	Symbolic	Using symbols or variables in solving problems	VM-2
	Concrete	Using real objects to solve problems	VM-3
Narratives	Substantiation	Use justifications and reasons in solving problems	N-1
	Memorisation	Using formulas or rules in solving problems	N-2
Routines	Ritualized	Using steps or patterns that have been done before	R-1
	Exploratory	Use new ways to solve problems	R-2

(c) Researchers conducted semi-structured interviews with prospective subjects based on the previous steps, one student each representing their gender. 3). Post-research stages include; (a). Researchers analyzed the data obtained from student work and interviews using the commognitive component, (b). Checked the validity of the data in this research used the triangulation of method, namely the results of student work, observation results, and transcripts of interviews conducted. There are 3 data analysis techniques in this research, namely 1) Data reduction: (a) conducted a test on inverse matrix material on all students in one of the 11th Natural Science classes. (b) corrected the results of students' work and selecting two subjects consisting of one male student and one female student to solve mathematical problems, based on purposive sampling technique and commognitive's components, they were chosen to represent their group. (c). conducted interviews on selected subjects, the results of the interviews were used as triangulation of the results of students' work in solving mathematical problems on inverse matrix material, because of interviews used to dig deeper into the steps students take or to understand the way they thought while solved the problem (d). Analyzed and described selected research data based on problem solving indicators. 2). Data presentation was carried out by described the results of written answers and interviews from selected subjects. 3). Drawed conclusions, the final stage was to obtain a description of students' commognitive skills in solving contextual questions on inverse matrix material in terms of gender.

3. Results and Discussion

3.1. Results

The research subject was selected by one person representing the group based on gender. After obtaining two students for this study, the researcher conducted semi-structured interviews to obtain specific details of each student's responses. The process of solving questions for each subject, as determined by the commognitive component. The **Figure 2** below explains male students' commognitive skills in solving

problems, clarified in interview. Based on the commognitive review, S1 was able to solve the questions given well. Initially, S1 assumed that what was known in the problem was length and width, which are everyday words in mathematics (WU-1). S1 uses "x = length (cm), y = width (cm)". The next step taken by S1 was to write the statement in the problem into a mathematical sentence properly using mathematical symbols (VM-2) in an effort to find connections between existing information. Based on previous knowledge, S1 wrote a system of linear equations in two variables based on the information obtained. Then, using his understanding of matrices, namely inverse matrices, S1 solves the problem to find the answer to the question given (R1). Based on the results of the previous step, S1 draws conclusions by paying attention to the solutions that have been carried out (N1). S1 can carry out the steps to solve problems well based on the previous knowledge that has been obtained.

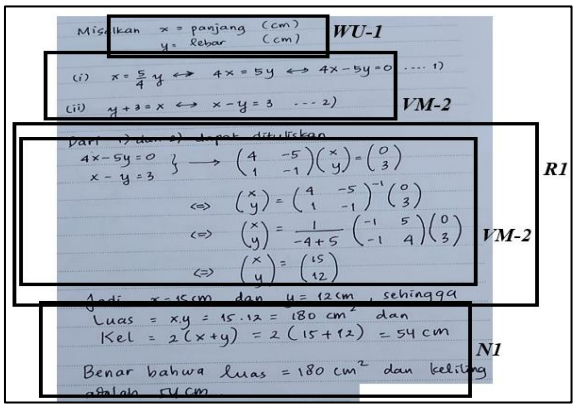


Figure 2 S1 work's result

In contrast to what was done by S1, in **Figure 3** below it can be seen that female students (S2) were more detailed and careful in carrying out the steps to solve the questions, clarified in interview. S2 is able to write examples of what is known in the problem well. The difference with S1 is that S2 defines length as "x" and width as "y" (WU-1). This is different from S1 who immediately chooses "x" and "y" to represent what is known in the question. S2 writes mathematical equations well as a continuation based on the previous steps and understands cause and effect relationships. Next, S2 uses symbols to write down what is known in the problem (VM-2). S2 uses symbols for variables as well as matrix symbols. Based on the knowledge he understands about matrices, namely determinants and inverses, S2 determines the inverse of the matrix resulting from the previous step (R1). The next step, S2 completes the questions to answer the question (R1). Based on the results obtained, S2 draws conclusions from the answers obtained correctly (N1). S2 is able to write symbols and symbols well, carry out completion steps correctly and in detail which differentiates it from S1, and draw conclusions correctly

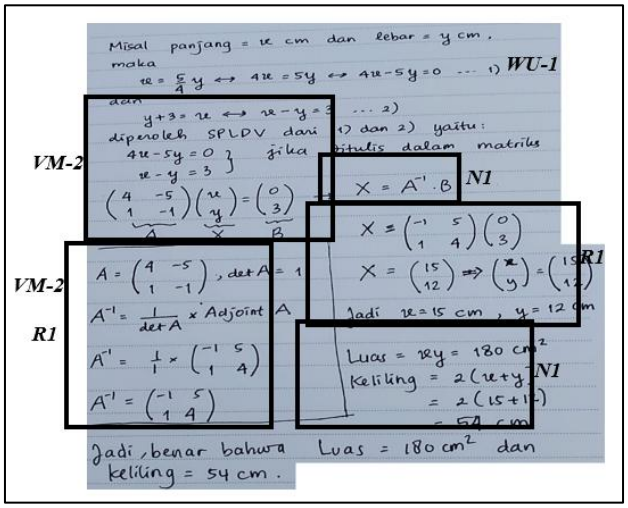


Figure 3. S2 work's result

3.2. Discussion

Male students are able to write what is given in the problem into mathematical symbols well, but female students are more careful in writing mathematical symbols. The male subject details the information that forms the problem briefly. This is in line with research conducted by Putut et al.(2023) which said that male students understood what was written but only wrote it briefly. Meanwhile, female students use the word use component to write down the information known from the question and what is asked accurately and carefully. The female subject wrote down the facts she learned from the questions in the order requested in a clear and concise manner. This is in line with research conducted by Erikson & Erikson(2019) that female students write more detailed information than male students. Male students use visual mediators when solving problems in symbolic form, but female students are more detailed and thorough. Writing mathematical symbols and markers, matrices, determinants and inverse matrices is done accurately by female students. This is done by female students to avoid missing out on existing information and also to avoid making mistakes in solving questions and is different from male students. This is in line with research conducted by Thoma & Nardi, (2018) who say that students incorrectly symbolize known data can cause errors in the next step. This was also expressed by Nachlieli & Heyd-Metzuyanim(2021) who said that female and male students were able to represent questions in their own way which they believed would solve the problem.

In the narratives component, male students were able to solve questions well using the inverse matrix formula. The male subject expressed the reason why this was written to solve the problem, namely based on the previous knowledge he had. This is in accordance with research conducted by Viirman & Nardi(2019) which said that male students were able to write down and state the mathematical formulas used in solving problems. This is different from female students who tend to be careful when solving questions. Furthermore, based on previous research by Lu, Tao, Xu, & Stephens(2020) that the mathematical representation of female students in solving problems is able to present appropriate formulas well, in detail and accurately with care. In the routines component, male and female students were able to use the previous knowledge they had acquired about inverse matrices well. However, female students are more complete and thorough in writing down the steps for solving questions based on conceptual and procedural understanding. Misu(2020) explain that subjects who find answers using conceptual understanding and procedural fluency are subjects who can find answers using routines involving the required mathematical objects. Based on the results of answers and interviews conducted with each subject, it was found that female students had better abilities in representing commognition than male students.

In media representation and popular culture where films, books, and media often depict scientists, engineers, and mathematicians as male figures. This indirectly instills the perception that mathematics is more "suitable" for boys. This is what causes parents and teachers, unknowingly, to have different expectations of boys' and girls' mathematical abilities. Higher expectations for boys in mathematics can encourage them to be more confident and take risks, while lower expectations for girls can hinder the development of their interests and confidence. So in the perception of female students, from an early age, there may be Internalization of negative stereotypes about their mathematical abilities. They may feel less confident or even anxious (math anxiety) when faced with math problems, even though they have good cognitive abilities. Female students' tendency to write down solution steps in a structured and detailed manner may also be related to gender constructions. Females may be taught to communicate their thinking explicitly and systematically, while males may be encouraged to seek quick and efficient answers, sometimes at the expense of detail. The stereotype that "males are more logical and intuitive" may subconsciously encourage them to skip steps.

This research found that female students had the ability to represent problem solving verbally and in writing better than male students. This is supported by research by Ioannou(2018) which states that students who are superior in answering questions in writing have good abilities in presenting answers orally. This research identified that male and female students were able to solve math problems well, but female students were able to present better results than male students. However, this research does not explain in detail the factors that influence the problem solving process, why female students are better than male students. These results are further supported by Umah & Vitantri (2019), who found that female students demonstrate more detailed answers and formal representations compared to male students. Their research revealed that female students typically present more comprehensive explanations with precise mathematical notation and structured representations, while male students, although capable of solving

problems correctly, often provide more condensed responses with less formal presentation. This research has limitations in the use of analytical techniques which may not be sensitive enough to detect significant differences between male and female students in solving questions seen from the perspective of the reasons for the cognitive problem solving process. The results obtained in this research can be used as a reference in the learning process related to solving mathematics problems in matrix material or other lecture material.

4. Conclusion

Based on the research results, it can be concluded that female students' commognitive skills are better than male students. Female students are more careful and detailed in writing mathematical symbols and symbols. Female students are more accurate in solving mathematical problems by writing down the steps in a structured and detailed manner. Female students are able to write in full the steps taken compared to male students who tend to be shorter and more concise. Drawing conclusions based on the completion steps taken by male and female students can be done properly and correctly. In this study, there was no commognitive conflict found within students. Male and female students approach mathematics problems differently, and these differences are likely influenced by gender constructions and stereotypes attached to mathematics. Although female students demonstrate advantages in rigor and solution structure, it is important not to interpret this as evidence of inherent cognitive superiority. Rather, these findings highlight how gender socialization and societal expectations can shape students' approaches and cognitive styles to mathematics. Notation for teachers when they should review the concept that is conducted to the learning materials. Based on the results of the study, it can be suggested to teachers to pay more attention to the selection of appropriate learning methods in carrying out learning activities in the classroom. This is intended to reduce the gap between male and female students in solving problems given by the teacher. Teachers should adjust the appropriate learning method based on the differences in their students' commognitive skills so as not to trigger commognitive conflicts or reduce the causes of commognitive conflicts.

Nevertheless, this study has several limitations. A key limitation lies in the limited number of research subjects—only one male and one female student were selected for in-depth analysis using purposive sampling. Although the selected subjects were considered representative of their respective groups, the small sample size limits the generalizability of the findings. The results may not comprehensively reflect the broader population of students with varying levels of mathematical ability, background knowledge, and cognitive approaches. Therefore, future research should involve a larger and more diverse sample to strengthen the validity and applicability of the conclusions drawn. Further research needs to explore in depth how gender stereotypes are internalized by students, how this affects their math confidence and anxiety, and how teaching strategies that consciously eliminate gender bias can help create more inclusive and empowering learning environments for all students, regardless of their gender. Understanding the role of gender stereotypes is key to addressing gender gaps in mathematics education and ensuring that all students have an equal opportunity to develop their full mathematical potential. That is possible to be done is how to prevent students from experiencing commognitive conflicts in solving problems when learning activities are carried out so that learning objectives can be achieved properly.It is recommended that further research be carried out on other mathematics topics and the possibility of how to reduce the effects of commognitive conflict in students.

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