Exploring Gender Differences in Spatial Reasoning: Analyzing Hyperbolic Problem-Solving Skills Among University Students

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Abstrak

Penelitian mengenai perbedaan penalaran spasial berdasarkan gender di tingkat universitas masih memerlukan konfirmasi lebih lanjut. Penelitian ini bertujuan mendeskripsikan perbedaan langkah-langkah penyelesaian soal hiperbola antara mahasiswa laki-laki dan perempuan. Menggunakan metode kualitatif, penelitian ini melibatkan 30 mahasiswa yang dipilih melalui rumus Slovin dari total populasi 480 mahasiswa. Instrumen penelitian meliputi tes soal hiperbola dan pedoman wawancara. Hasil penelitian menunjukkan adanya perbedaan signifikan pada aspek orientasi spasial, di mana mahasiswa perempuan menunjukkan keunggulan dalam langkah-langkah penyelesaian karena pemahaman konsep jarak yang lebih baik. Temuan ini menyimpulkan bahwa terdapat karakteristik unik pada penalaran spasial perempuan di tingkat pendidikan tinggi yang berbeda dari temuan umum di tingkat sekolah. Hasil penelitian ini memberikan kontribusi teoretis bagi pengembangan literatur penalaran spasial dalam pendidikan matematika.
Kata Kunci*: Gender; Hiperbola; Mahasiswa; Orientasi Spasial; Penalaran Spasial.*

Abstract

Research on gender-based differences in spatial reasoning at the university level requires further empirical confirmation. This study aims to describe the differences in procedural steps for solving hyperbola problems between male and female students. Employing a qualitative method, the study involved 30 students selected via Slovin's formula from a population of 480. Research instruments consisted of hyperbola problem-solving tasks supported by interview transcripts. The findings reveal distinct differences in spatial orientation, where female students demonstrated superior performance in solving steps due to a robust understanding of distance concepts. In conclusion, these results highlight unique spatial reasoning characteristics among female students in higher education, diverging from common findings at the school level. This research contributes to the theoretical development of spatial reasoning literature within mathematics education.
Keywords: Gender; Hyperbola; Spatial Orientation; Spatial Reasoning; University Students.

I. Introduction

Reasoning in mathematics is a systematic and logical thinking that relies on patterns and regularities and can be used to solve problems in new situations (Martin et al., 2023). PISA, a global assessment program established by the Organization for Economic Co-operation and Development, has tested students' reasoning ability to apply their knowledge, skills, and understanding in real world situations. It assesses students' ability to identify problems, formulate questions, collect and evaluate information, and come to conclusions or solutions supported by evidence or arguments (OECD, 2018). The average scores and distribution of students from each country that took the assessment show the results of PISA reasoning (OECD, 2018).

Reasoning depends on iconic mental representations of the spatial content of the premises, not on the steps in doing something (Ianì et al., 2023). Reasoning can be grouped into two types based on its strategy, namely spatial reasoning and verbal reasoning (Hardman & Macchi, 2005; Septia et al., 2018). In addition, empirical spatial reasoning and mathematical axiology are based on geometric thinking. From this statement, it can be concluded that there is a relationship between space and geometry, where space can be recognized from its geometric characteristics (Harris et al., 2021). Student in math education have studied spatial reasoning with a focus on the cognitive and psychological elements of math and philosophy (Bruce et al., 2017; Lowrie & Jorgensen, 2018). From the essence of the axiology of the philosophy of mathematics education, it is obtained that the results of research and studies on spatial reasoning provide significant benefits for the development of cognition and psychology as well as the factors that accompany the results of its formation. Furthermore, markers of spatial orientation, mental rotation, and spatial imagery are all part of the mental cognitive capacity known as spatial reasoning (Fujita et al., 2020; Lowrie & Jorgensen, 2018; Novak & Tassell, 2017).

While spatial imagery is crucial for working with geometric objects and is a key sign of spatial reasoning proficiency, mental rotation is a cognitive mental activity that, if rotated at a specific angle, reflects a 2D or 3D written item (Fowler et al., 2022). This is because there is a significant positive relationship between spatial visualization and the results of solving mathematical problems at the school level (Novak & Tassell, 2017; Vandenberg & Kuse, 1978). Spatial orientation is also useful in determining different directions of a particular object (Hegarty & Waller, 2004). To see how spatial reasoning is achieved, problem-solving steps are used. This is because strategic decisions require problem-solving skills that also function in evaluating solutions from interpreted results in real-world situations (OECD, 2021).

Problem-solving skills are an integral part of all subfields of mathematics learning (Kurnaz et al., 2023). Problem-solving often requires spatial reasoning processes in mentally performing imaginative spatial transformations such as changing shapes, cutting, and rearranging objects in new ways (Clement, 2008).

Problem-solving skills can be trained without using standard procedures because they are non-routine problem-solving (Bishara, 2016). These non-routine questions can be formed with a contextual approach in real-life situations that require high-level thinking with strategies and categorizations that involve creative thinking skills (Gözde, 2020; Kablan & Günen, 2021; Özreçberoğlu & Çağanağa, 2018; Yazgan & Sahin, 2018). Non-routine problem-solving is characterized as a high-level skill that must be acquired after students have learned basic mathematical concepts and skills with persistence in solving problems and the use of certain procedures in problem-solving (Panaoura, 2012; Schoenfeld, 2016). In addition, further attempts were made to investigate whether there are differences in feedback learning gains between multiple-choice and essay test items in the context of mathematical problem-solving (Attali, 2015; Attali & van der Kleij, 2017). As an essential component of mathematical problem-solving, problem-solving involves knowledge of mathematical relationships with knowledge of basic numerical skills and strategies (Lai et al., 2015), problem-solving can also be expressed using analytical-synthetic methods (Özreçberoğlu & Çağanağa, 2018; Szabo et al., 2020).

Courses that can be given non-routine questions are courses that have gender characteristics for university students who provide intellectual or innovative creative thinking contributions in a scientific discipline and can study mathematical principles and reasoning about mathematical methods (Anupan & Chimmalee, 2022; Tokarz et al., 2022; Wenzel, 1997). The students selected in this study were students who had a gender perspective. According to American psychologists, gender is a personality attribute that is influenced by the role of social construction that is categorized into four categories, namely masculine, feminine, androgyny, and undifferentiated (Bem, 1981). However, this study is only limited to the exploration of masculine and feminine. Gender experts have researched the feasibility of enforcing gender equality. Therefore, educational institutions must prioritize gender equality in the curriculum to ensure all students have equal access and representation (Sutherland, 2022). This is because textbooks and school culture do not fully reflect gender equality (Losioki & Mdee, 2023). Gender can be defined in certain ways, such as categories that consider the impact of changes based on social differences or norms used to assess those changes (Wolfram & Kienesberger, 2023). Therefore, an in-depth gender analysis is needed which aims to find the barriers and ultimately explain the best way to find solutions (Sebastian et al., 2022).

In the development of spatial reasoning theory reviewed based on gender differences, research results show that masculine men are superior in spatial reasoning indicators compared to feminine women (Harris et al., 2021; Linn & Petersen, 1985). Masculine students excel in solving hyperbola problems, which is associated with greater experience in learning mathematics at the secondary school level. The selection of hyperbola material is relevant because hyperbola is related to spatiality, which allows spatial characteristics to be explored with spatiality problems displayed through solving hyperbola problems from the contextual problem tasks given. It is hoped that the discovery of this new theory will be a modern reference in spatial reasoning theory regarding students and gender differences. This is consistent with the idea that the role of gender in spatial and mathematical performance has been extensively studied, with male advantages often found in spatial and mathematical tasks since adolescence (Lowrie et al., 2021). However, previous research remains limited to the school level, despite the existence of other essential elements important for the continuation of spatial reasoning theory at the university level. Therefore, research related to spatial reasoning at the university level is important to be carried out because it will contribute to creative and innovative thinking from gender characteristics in university students as a new perspective based on solving hyperbolic problems. This is in accordance with gender characteristics that can support the mathematical reasoning process (Anupan & Chimmalee, 2022; Tokarz et al., 2022). The purpose of this study is to describe the characteristics of the differences between problem-solving steps taken by masculine and feminine. Thus, this study is expected to provide significant benefits in the development of spatial reasoning theory, as a reference for relevant research in the future, and as a source of learning in higher education. In addition, this study can also contribute to the evaluation of mathematics education research.

II. METHOD

All students enrolled in the mathematics education study program who had completed the analytical geometry course at Universitas Negeri Medan and Institut Pendidikan Tapanuli Selatan made up the study's population. This is because the assignment that has been given is a hyperbola problem assignment, so students must have studied analytical geometry to complete the hyperbola problem assignment. Furthermore, the number of university student population is 480 people who have taken analytical geometry courses. Determination of sample size from the population using the Slovin formula.

$$n = \frac{N}{1+Ne^2} \quad (1)$$

Where n is the sample size, N is the population size and $e = 0{,}18$ is the margin of error (Tejada et al., 2012).

The size of the population sample was taken using the Slovin formula and the selection of two research subjects using the purposive sampling technique, meaning that the sample was selected based on the researcher's considerations to match the characteristics of the research subjects. This is the opinion of Dolores & Tongco (2007), who state that purposive sampling is a technique for deliberately selecting informants because of the qualities possessed by the informant. The purposive sampling technique, also known as judgment sampling, is the deliberate selection of informants based on the

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characteristics of the informants (Buljan, 2023). The sample in this study was also selected based on male and female gender. The instrument in this study was in the form of hyperbola problem assignments, which are in the form of descriptive questions with a non-routine contextual type as an instrument for measuring student's spatial reasoning. The following is the relationship between spatial reasoning indicators with hyperbolic material and the descriptors used in this study can be seen in Table 1.

Table 1.
Relationship between Spatial Reasoning Indicators, Hyperbolic Material and Descriptors

Spatial Reasoning Indicators	Hyperbola Material Indicator	Description
Spatial Visualization	Create horizontal and vertical hyperbola objects from pieces of the same hyperbola.	Students' ability to mentally manipulate two-dimensional and three-dimensional images.
Mental Rotation	Determines the horizontal and vertical rotation of a hyperbolic object based on a given angle.	Students' ability to rotate geometric shapes correctly.
Spatial Orientation	Determine the horizontal and vertical positions of hyperbola objects based on the focal points and vertices relative to similar hyperbolas.	The student's ability to place and orient himself in relation to objects, people, and his own body in a given space.

III. Result and Discussion

The hyperbola assignment test was given to a research sample of 30 mathematics education students, with the condition that they had taken the analytical geometry course. Information was obtained that the problem-solving scores of both genders were quite diverse. This was obtained from the results of the value analysis, which showed the lowest score of 70 and the highest score of 97. In detail, the lowest score for problem-solving in the masculine gender was 70 and the highest score was 96, while the lowest score for problem-solving in the feminine gender was 71 and the highest score was 97. Thus, it can be concluded that the achievement of problem-solving scores for both genders has the same range of values. Comparing problem-solving scores revealed that feminine students achieved the highest scores and masculine students the lowest.

The same range of values in both genders shows varying achievements because the achievement of the completion value of the hyperbole problem task in both genders is spread out and not accumulated in one value. Based on statistical calculations, the average achievement value of the hyperbole problem task for the masculine gender is 83.8, while the average achievement value of the hyperbole problem task for the feminine gender is 83.2. Thus, it can be concluded that there is a difference in the average values of the two genders. Overall, it is known that the average achievement value of the two genders is 83.5. The average value, standard deviation, minimum value, and maximum achievement value of the hyperbole problem task for both genders are presented in Table 2.

Table 2.
Statistical Description of Hyperbola Problem Task Achievement Descriptive Statistics

Statistics			
		Masculine Value	Feminine Value
N	Valid	15	15
	Missing	1	1
Mean		83.8000	83.2000
Median		85.0000	84.0000
Std. Deviation		7.20317	7.05286
Range		26.00	26.00
Minimum		70.00	71.00
Maximum		96.00	97.00

1) Problem-Solving of Masculine Subjects in Spatial Visualization

In the first step, namely understanding the problem of spatial visualization, it was found that masculine subjects could demonstrate the ability to understand the problem. This is indicated by the presence of symbolic and narrative forms that state what is known and what is asked. In expressing the symbol, the masculine subject describes three horizontal hyperbolic slices. The three horizontal hyperbolic slices still show the center point, focal point, abscissa axis, and Cartesian ordinate. In the case asked, the subject wrote a question, namely, manipulating the three pieces of the object to form a horizontal hyperbola. The following results from the masculine subject's understanding of the spatial visualization problem (see Figure 1 and 2).

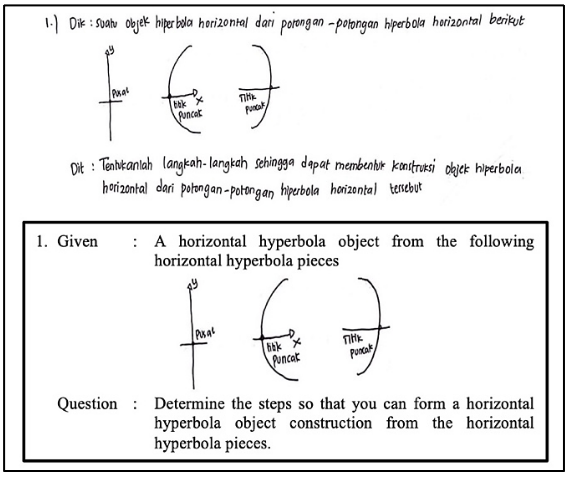

Figure 1. Understanding of spatial visualization problems of masculine.

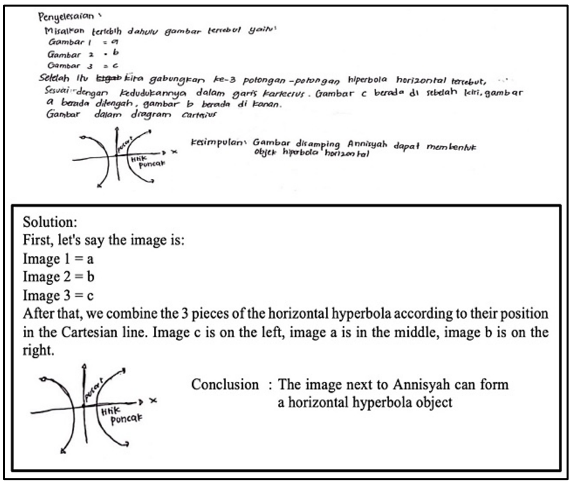

Figure 2. Solving the problem of spatial visualization of masculine.

2) Problem-Solving of Masculine Subjects in Mental Rotation

The first step is to understand the problem of mental rotation. It is known that masculine subjects are able to demonstrate the ability to understand problems, as indicated by the presence of symbolic forms and narratives that state things. what is known and what is asked. In stating the narrative, the masculine subject states that Alysa has a hyperbola and draws it. The description of the hyperbola is a vertical hyperbola complete with information on the center point, abscissa axis, and ordinate axis. In the case of what is asked, the masculine subject writes down what is asked to determine the rotation results of the known hyperbola rotation if rotated by 120°. The following are the results of the masculine subject's understanding of the problem of mental rotation (see Figure 3 and 4).

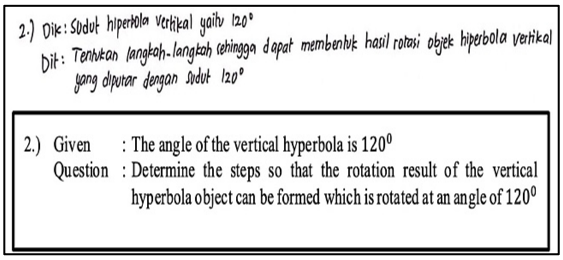

Figure 3. Understanding the problem of mental rotation of masculine.

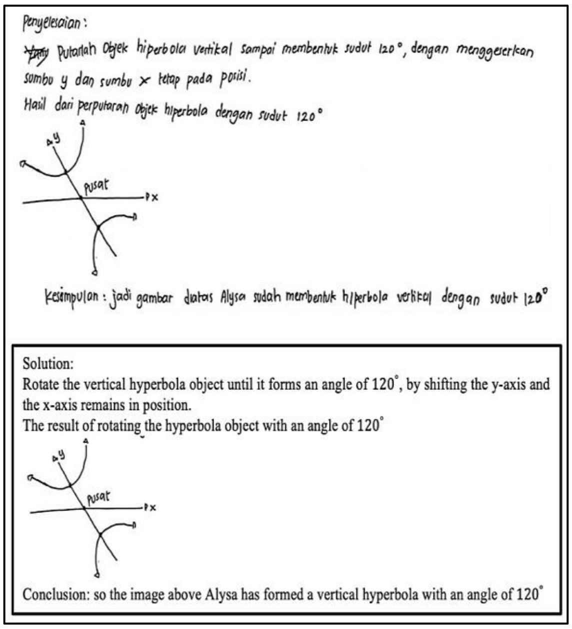

Figure 4.
Solving the problem of mental rotation of masculine.

3) Problem-Solving of Feminine Subjects in Spatial Visualization

In the first step, namely understanding the problem of spatial visualization, it is known that feminine students are able to demonstrate the ability to understand problems, as indicated by the existence of a narrative form that states what is known and what is asked. In stating the narrative, feminine students write the object of the horizontal hyperbola section in three object forms. The first object describes the intersection of the abscissa axis with the ordinate axis. The second object describes the intersection of the hyperbola on the positive abscissa axis. Finally, the third object describes the intersection of the hyperbola on the negative abscissa axis. In this case, feminine subjects also state what is asked about the construction of a horizontal hyperbola based on the intersection of the three objects. The following are the results of feminine subjects' understanding of spatial visualization problems.

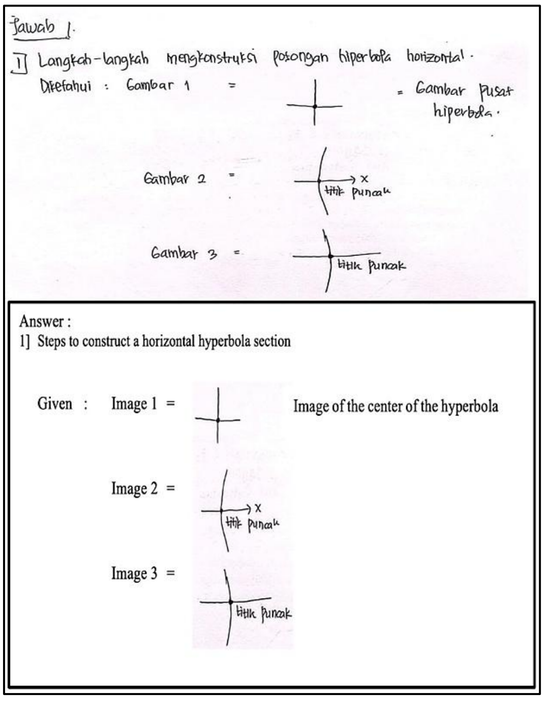

Figure 5. Understanding of spatial visualization problems of feminine.

Based on Figure 5, it is obtained that the feminine subject wrote down what is known based on the spatial visualization problem. In what is known, the subject wrote down an analogy based on the three horizontal hyperbola sections. The first section is illustrated in Figure 1, the second section is illustrated in Figure 2, and the third section is illustrated in Figure 3. The subject wrote this because it summarizes the idea of the problem so that they can write down what is known. While on the other hand, the feminine subject did not write down what was asked based on the spatial visualization problem. Meanwhile, in the second step, namely planning to solve the spatial visualization problem, it is known that there were no sufficient and necessary conditions to solve the problems given in planning the spatial visualization solution. In the third step, namely implementing spatial visualization problem solving, it is known that female students are able to demonstrate the ability to solve problems. The existence of systematic problem-solving solving problems indicates this. It is then known that the answer given is correct. This is contrary to the opinion of Buhaerahiain & Nasir (2022),which states that female students have difficulty in abstract spatial visualization. Hence, the subject needs teaching aids to help with the spatial visualization process. Based on the steps to understand the problem, the feminine student can combine several horizontal hyperbola cut objects. The results of combining several objects are directed to the horizontal hyperbola object. The feminine student can remember and master how to arrange horizontal hyperbola pieces. The following are the results of the feminine subject's solution to the spatial visualization problem (see Figure 6).

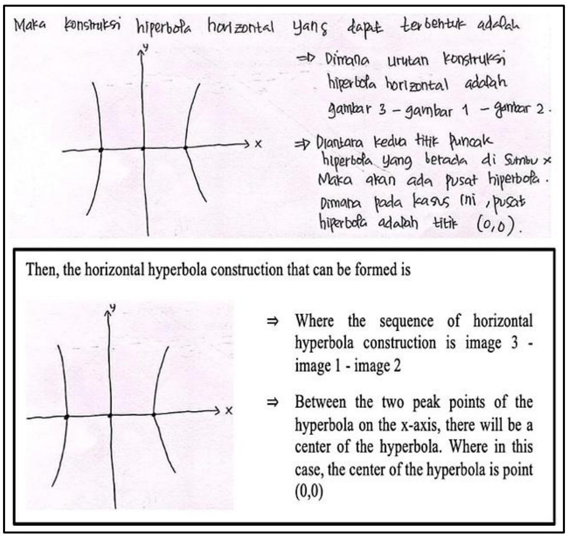

Figure 6. Solving the spatial visualization problem of feminine

4) Problem-Solving of Feminine Subjects in Mental Rotation

In the first step, namely understanding the question of mental rotation, it is known that students a feminine unable to demonstrate the ability to understand the question as indicated by not writing down what is known and what is being asked. In the statement, the student, a feminine, cannot describe a vertical hyperbola object complete with its attributes such as the center point, vertex point, focus point, abscissa axis, and ordinate axis of the hyperbola. The feminine also cannot describe hyperbole clearly and neatly, making it easier to remember and continue to the next step of the solution. In the questions asked, the feminine also did not write about the steps in forming the results of the vertical hyperbolic rotation 120°. The same thing happened in the second step, namely planning to solve the mental rotation problem; it is known that no sufficient and necessary conditions were found to solve the problem given in the problem-solving plan. mental rotation. In fact, at this stage, ideally, the subject can provide additional information in solving the mental rotation problem. In the third step, namely implementing the solution to the mental rotation problem, it is known that the subject, the feminine subject, has not been able to show the ability to solve the problem. Although there has been systematic problem-solving in solving the problem, the answer is wrong. In the first rotation, the feminine subject was able to solve it correctly with confidence, namely by rotating vertically hyperbola by 90°. However, in the second rotation, the resulting object has an incorrect value because the rotation is 30° does not match the rotation in the first round, so the solution result is wrong. This is supported by the opinion Kurt et al. (2023), which states that feminine subjects' beliefs about mental rotation have no influence on solving rotation problems. The following are the results of feminine subjects' solutions to mental rotation problems.

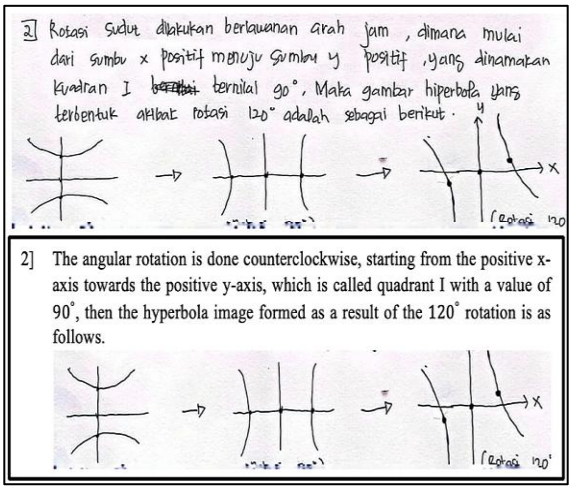

Figure 7. Diagram of steps for solving mental rotation problems by feminine.

IV. CONCLUSION

Both the chosen male and female subjects have distinct approaches to problem-solving, according to the examination of the phases involved in comprehending the issue, formulating a solution, and double-checking the outcome. While there is a little difference in the solution process for mental rotation ability, there is no difference in the results for spatial visualization ability. However, there is a difference in the end result for spatial orientation ability in the problem-solving implementation step. Psychological variables and the traits of both sexes contribute to the difference in the problem-solving process, with the female being more cautious. Overall, it can be said that the processes involved in applying hyperbolic problem solving, which include spatial orientation indications, are where the differences in solving hyperbolic issues emerge.The phases of comprehending the problem, formulating a solution, and verifying the outcome of the solution are distinct in the hyperbolic problem-solving process, but they share the same spatial thinking skills in terms of visualization and rotation. Disparities in spatial orientation skills indicate that women have a better final solution than men. Descriptive statistics of the average hyperbolic problem-solving achievement in both genders and the findings of unstructured interview transcripts from both subjects corroborate this. Because the variance values of masculine and feminine problem-solving are similar, there is statistically little difference between the average value of the hyperbolic problem-solving results in the two genders. This is evident from the phases involved in problem-solving, which include understanding the issue, planning the solution, carrying it out, and reviewing the outcome.

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