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# Analysis of spatial reasoning ability in solving geometric transformation problems

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**Abstract**: Spatial reasoning ability significantly affects mathematics learning in the area of geometric transformations. However, students' spatial reasoning ability is still underdeveloped. This study focused on analyzing students' spatial reasoning ability while working on problems involving geometric transformations. Data were collected through a spatial reasoning ability test and personal interviews. The subjects were six grade XI students. The research design applied was descriptive qualitative. It was found that students with high spatial reasoning ability could mentally analyze and understand rotation patterns, envision objects moving in a clockwise direction, determine dilation and reflection of an object about a specific axis, and comprehend spatial changes and the position of objects and shapes in space. Students with moderate spatial reasoning ability could understand the rotation patterns and mentally picture the objects moving clockwise; however, they could not grasp the concept of object transformations correctly. Low spatial reasoning ability could not grasp the problem and visualize the rotation of the objects, resulting in an inability to determine the transformation of the object position. This also prevented the students from solving the transformation concept. This study has been able to identify specific aspects that need to be addressed in the geometric transformation topic. This research can help inform the design of more effective and innovative learning strategies.

**Keywords**: Spatial Reasoning; Geometric Transformation; Problem Solving

## Analisis kemampuan penalaran spasial dalam penyelesaian soal transformasi geometri

**Abstrak:** Kemampuan penalaran spasial secara signifikan memengaruhi pembelajaran matematika di bidang transformasi geometri. Namun, kemampuan penalaran spasial siswa masih kurang berkembang. Penelitian ini berfokus pada analisis kemampuan penalaran spasial siswa saat mengerjakan soal-soal yang melibatkan transformasi geometri. Data dikumpulkan melalui tes kemampuan penalaran spasial dan wawancara pribadi. Subjek penelitian adalah enam siswa kelas XI. Desain penelitian yang diterapkan adalah deskriptif kualitatif. Ditemukan bahwa siswa dengan kemampuan penalaran spasial tinggi dapat menganalisis dan memahami pola rotasi secara mental, membayangkan objek bergerak searah jarum jam, menentukan dilatasi dan refleksi suatu objek terhadap sumbu tertentu, serta memahami perubahan spasial dan posisi objek dan bentuk dalam ruang. Siswa dengan kemampuan penalaran spasial sedang dapat memahami pola rotasi dan membayangkan objek bergerak searah jarum jam secara mental; namun, mereka tidak dapat memahami konsep transformasi objek dengan benar. Kemampuan penalaran spasial rendah tidak dapat memahami soal dan memvisualisasikan rotasi objek, sehingga mengakibatkan ketidakmampuan untuk menentukan transformasi posisi objek. Hal ini juga menghambat siswa dalam menyelesaikan konsep transformasi. Penelitian ini telah berhasil mengidentifikasi aspek-aspek spesifik yang perlu dibahas dalam topik transformasi geometri. Penelitian ini dapat membantu menginformasikan perancangan strategi pembelajaran yang lebih efektif dan inovatif.

**Kata Kunci**: Penalaran Spasial; Transformasi Geometri; Pemecahan Masalah

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## INTRODUCTION

Learning math is an important part of education. Learning math can help you develop better numeracy skills, as well as enhance your reasoning, logical thinking, critical thinking, and problem-solving skills that are necessary to confront the challenges of the 21st century (Bahbah et al., 2023; Ningsih & Hidayati, 2022; Ulandari et al., 2019). Learning math helps students identify and understand ideas, process information, and show and talk about their results in different ways, such as verbally, symbolically, or visually. These skills assist students in cultivating numeracy skills, which are fundamental competencies (Alkhateeb, 2018; Astuti, 2017; Mainali, 2020). We should integrate math with other subjects and useful habits in daily life. Mathematics cultivates learning competencies that enable individuals to understand phenomena, make informed decisions, and analyze and resolve problems in both professional and personal contexts (Astuti, 2025; Popescu, 2021; Rani et al., 2023). Consequently, mathematics education should not be confined to the acquisition of cognitive skills; it must also include the cultivation of a positivistic perspective, an innovative mindset, and a flexible adaptability to the rapid advancements in science, technology, and global transformations.

Geometry is an important part of learning math. This area of study encompasses a comprehensive understanding of form, spatial dimensions, and the interrelations among objects, which are applicable in daily life (Astuti et al., 2016; Jablonski & Ludwig, 2023; Novita et al., 2018). Understanding basic geometric ideas helps students improve their spatial and visual thinking skills and their ability to solve problems in a more organized and systematic way (Cheng & Mix, 2014; Novita et al., 2018). In secondary school, students perceive geometric transformations to be a difficult subject. This includes studying translations, rotations, reflections, and dilations. Students must employ abstract and advanced visual representations to comprehend the motion and spatial alterations of an object within the coordinate plane and space for each concept constituting a geometric transformation (Dahal et al., 2022; Evidiasari et al., 2019). Students encounter difficulties in this subject due to inadequate spatial reasoning skills and a significant disconnect between abstract concepts and their practical application (Riastuti et al., 2017; Suciati et al., 2023). Conceptual teaching of geometric transformations is essential to enable students to solve more complex problems.

According to N.c.t.m (2012), spatial reasoning ability is one competency of students in geometry learning. This ability is vital in sustaining students' problem-solving thinking when they encounter geometric challenges that involve comprehension of shapes, positions, and the relation of various objects in a given space. Hence, to help students formulate better mental representations in problem solving, advancing spatial reasoning is crucial in acquiring the understanding of the core concepts in geometry (Battista et al., 2018; Fujita et al., 2022). While solving geometry learning problems, students need to develop their spatial reasoning skills (Maghfiroh & Qothrunnada, 2024; Mega & Meiliasasi, 2024). In addition, the ability to perform mental rotation, spatial orientation, and spatial visualization, which are all constituent parts of spatial reasoning, aids not only in the successful completion of numerous geometry-related tasks but also in the overall achievement in school (Harris, 2023; Lowrie & Logan, 2018; Ramful et al., 2017). These three dimensions enable students to construct thinking, interpret abstract materials, and relate mathematics to various phenomena in the world. Thus, the development of spatial reasoning is not only a requirement in geometry learning but also an important strategy to prepare students to face academic and daily life challenges that require higher-order thinking skills.

Skills in spatial reasoning contribute to the development of geometry in mathematics. Spatial reasoning is the capacity to comprehend, understand, interpret, and manipulate objects in space. Additionally, it may envisage the visual relationship created between these objects (Alkouri, 2022; Lavicza et al., 2023). Spatial reasoning involves not just shape and size but also the ability to visualize, rotate, and connect representations of objects. Learning about geometry takes a lot of problem-solving techniques that apply spatial reasoning to help students find an answer. Students need to master spatial reasoning to deepen their understanding of geometric concepts and to improve their problem-solving skills (Herawati & Hariyani, 2024; Kurt et al., 2023). Spatial reasoning is a visual and manipulative thinking skill that is a cognitive skill that contributes substantially to the building of students' conceptual knowledge in geometry. Therefore, in the mathematics learning process, students must possess and develop this ability into a crucial competency.

Spatial reasoning ability can be mapped into three main constructs: mental rotation, spatial orientation, and spatial visualization (Ramful et al., 2017). First, mental rotation refers to an individual's ability to mentally rotate a two-dimensional or three-dimensional object representation in their mind's eye, either clockwise or counterclockwise, to accurately complete a task or problem. Second, spatial orientation is the ability to recognize the position of an object. Moreover, the competence also involves recognizing the object's direction concerning oneself and other objects around it. The third spatial visualization is the capability to envisage changes in the shape, position, or configuration of an object after its manipulation. Manipulation in this sense refers to such physical actions as translation, rotation, etc. The subject must evaluate the altered position of the object from various perspectives. These three constructs serve as the foundation for the growth of students' spatial reasoning skills in geometry learning. Thus, understanding mental rotation, spatial orientation, and spatial visualization is important not only to support success in solving geometry problems but also to develop higher-order thinking skills in the context of mathematics learning in general.

In geometry learning, geometric transformations are often a challenge for students. Translation, rotation, reflection, and dilation are components of geometric transformations. Understanding and applying these transformation concepts are highly dependent on spatial reasoning skills, as each transformation requires the ability to visualize the movement and changes in position of objects in space (Šćepanović, 2019; Shriki & Patkin, 2021). Therefore, students with strong spatial reasoning skills tend to find it easier to solve geometry problems than those with poor spatial reasoning skills. Several previous studies have shown a strong correlation between students' success in solving geometry problems and their spatial reasoning abilities. While the majority of students with low spatial intelligence have difficulty, especially in completing geometric transformations, the majority of students with high spatial intelligence have no difficulty in completing geometry questions (Juliana et al., 2022;

Maghfiroh & Qothrunnada, 2024; Rustanuarsi, 2023). This confirms that mastery of spatial reasoning is a cognitive factor that contributes significantly to students' understanding and success in geometry learning.

Observations of high school students indicate that their learning outcomes in geometric transformations are still low. This evidence indicates that students experience difficulties in understanding and working on problems involving various types of geometric transformations. Students still experience difficulties in understanding and working on problems involving various types of geometric transformations. The low average scores of students in geometry indicate the presence of conceptual learning barriers that may require further analysis, as well as obstacles affecting their understanding of the material's concepts. In this regard, a study reported that 22% of 54 high school students in Indonesia were in the low category in solving assigned geometry problems. Furthermore, students' misconceptions about geometric concepts will lead to low overall conceptual mastery and understanding (Budiarto & Artiono, 2019). Furthermore, students were found to be categorized into three levels in solving geometry problems and their spatial abilities: Level 0, Level 1, and Level 2. These categories further indicate the presence of ontogenic, didactic, and epistemological learning barriers in solving geometry problems with their spatial abilities (Juliana et al., 2022). For students, spatial reasoning is critical, considering its contribution to the understanding of the depth of geometric concepts and the dynamics of mathematical problem-solving. Several studies have found that students' spatial abilities are still low. However, there has been no research that specifically and in detail identifies students' spatial abilities in solving transformation geometry problems. Therefore, the novelty of this study is to identify students' spatial abilities specifically based on high, medium, and low mathematical abilities.

The research problem is formulated as follows: How are high school students' spatial reasoning abilities in solving geometric transformation problems? This study aims to identify high school students' spatial reasoning abilities in solving geometric transformation problems. We hope this analysis can provide an accurate assessment of students' abilities and clarify the challenges they face in understanding the concept of transformation. Therefore, the results of this study are expected to be very useful in formulating an efficient and flexible learning approach. This will improve problem-solving competence and students' understanding of geometric concepts.

## METHOD

The type of research used is qualitative research with a descriptive approach. Qualitative research is a research method used to understand phenomena in depth, conducted by observing objects in their natural state, involving the researcher as a key instrument (Cresswell & Cresswell, 2023). Qualitative research procedures produce descriptive data in the form of written or spoken words from people and observable behavior; the approach is directed at the setting and individuals holistically (Baxter & Jack, 2008; Bogdan & Biklen). Research that aims to describe a variable, symptom, or condition, rather than to test a specific hypothesis or determine the source and impact of a treatment, is known as descriptive research (Kothari & Garg, 2008).

The subjects of this study were grade XI high school students in Purworejo Regency. Sampling was purposively conducted based on considerations (Cresswell & Cresswell, 2023; Nyimbili & Nyimbili, 2024) and snowball sampling, which is the selection of subjects that starts from a small number and eventually increases (Cantone & Tomaselli, 2022). Using a purposive technique, potential subjects were selected based on their mathematics learning outcomes. In this case, potential subjects were divided into three categories: those with high, medium, and low mathematics learning outcomes. Then, potential subjects were given a spatial reasoning ability test. Furthermore, in-depth interviews were conducted to obtain comprehensive information and data on each potential subject until data saturation was reached. The selection of research subjects was carried out using the snowball technique. The spatial reasoning ability test, consisting of three main constructs: mental rotation, spatial orientation, and spatial visualization, was the research instrument used. The materials used included rotation, dilation, translation, and reflection. Before use, the instrument was validated by a mathematics education lecturer. The instrument validation results indicated that the instrument was valid. The data analysis approach in this study includes data collection, data reduction, data presentation, and conclusion (Miles et al., 2014).

## RESULTS AND DISCUSSION

Based on the data analysis, subjects were categorized into high spatial reasoning ability (ST), medium spatial reasoning ability (SS), and low spatial reasoning ability (SR). Interviews were then conducted to obtain in-depth information related to the answers to the spatial reasoning ability test for solving geometric transformation problems.

a. High Spatial Reasoning Ability

The test results of subject ST in solving geometric transformation problems are presented in Figure 1.

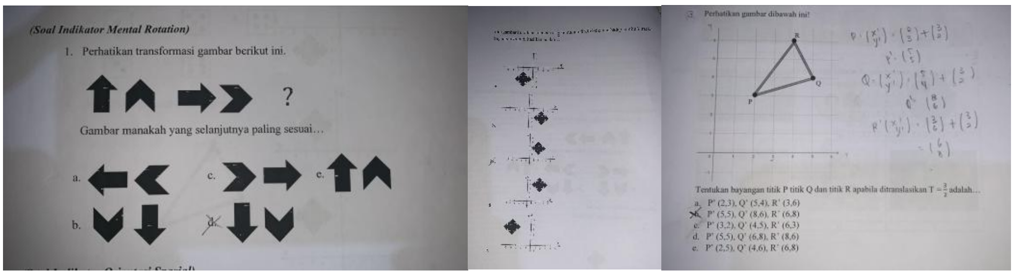


Figure 1. ST Subject Test Results

Test results indicate that individuals with high spatial reasoning abilities (ST) demonstrate skills in solving problems involving geometric transformations. Spatial reasoning involves all three components: mental rotation, spatial orientation, and visualization. For mental rotation, ST subjects can accurately identify transformations and images of rotated objects, even complex ones. Such problems might include arrow transformations, where the subject correctly identifies and rotates the image. For spatial orientation, ST subjects can accurately define problems involving dilations and reflections of geometric objects about an axis. For spatial visualization, the repositioning and shaping of objects in space, as well as the results of point transformations in coordinates, are understood spatially and conceptually by SRM subjects. In this case, the subject correctly handles transformation concepts such as translation. The following is the result of an interview with ST subjects.

*P : Apa alasanmu memilih gambar di pilihan D?*
*S1 : Karena pada gambar pertama ke atas dan gambar kedua ke kanan maka setelah saya amati, saya berpikir gambar selanjutnya ke bawah seperti arah jarum jam.*
*P : Apakah kamu mengalami kesulitan saat mengerjakan soal no. 1?*
*S1 : Tidak*
*P : Apa yang ditanyakan dari soal no. 2?*
*S1 : Bayangan yang dihasilkan dari refleksi terhadap sb-y.*
*P : Menurutmu, gambar mana yang paling sesuai?*
*S1 : Yang C*
*P : Mengapa kamu memilih jawaban tersebut? Bagaimana cara menghitungnya?*
*S1 : Saya menghitungnya dengan cara titik koordinatnya didilatasikan* $k = \frac{1}{2}$, *kemudian direfleksikan ke sb-y. Sehingga saya memilih C karena hasil perhitungan saya tepat di pilihan C.*
*P : Apakah kamu mengalami kesulitan saat mengerjakan soal no. 2?*
*S1 : Tidak*

Figure 2. Interview with Subject ST

Based on further confirmation through interviews, ST students have demonstrated an understanding of the concept of geometric transformations, specifically rotation, reflection, translation, and dilation, as evidenced in the questions, and can provide alternative solutions to the transformation concept, accompanied by appropriate explanations in their answers.

b. Medium Spatial Reasoning Ability

The test results of subject SS in solving geometric transformation problems are presented in Figure 3.

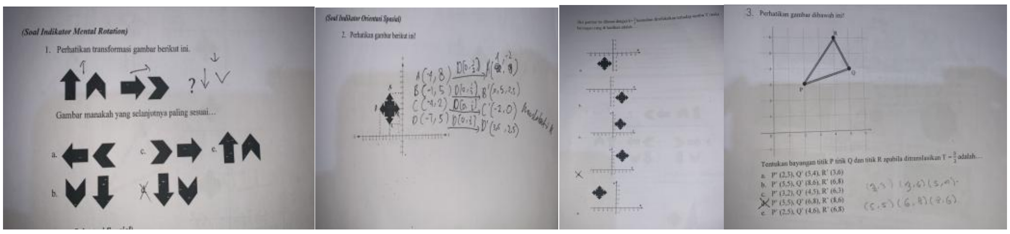

Figure 3. SS Subject Test Results

Subjects with moderate spatial reasoning (SS) abilities in mental rotation can rotate images clockwise and identify object rotation transformations well. Subjects can understand complex rotation patterns, such as in questions with arrow direction transformations, to produce accurate answers without errors. In questions on spatial orientation and spatial visualization, SS subjects are unable to identify the concept of transformation in objects wholly and correctly, resulting in errors in the solution process. The following is the result of an interview with SS subjects.

*P : Apa yang ditanyakan pada soal no. 2?*
*S2 : Hasil bayangan yang dihasilkan dari refleksi terhadap sb-y*
*P : Penandaan gambar mana yang paling sesuai?*
*S2 : gambar yang 8*
*P : Kenapa kamu memilih gambar tersebut dan bagaimana kamu menghitungnya?*
*S2 : Karena itu dilatasi* $\frac{1}{2}$ *maka dilaikan dengan* $\frac{1}{2}$*. Lalu itu kan* $(-1,3)$ *jadi* $(0,3)$. $(2,3)$ *lalu direfleksikan ke sb-y jadi posisinya pindah ke bawah.*
*P : Apakah kamu mengalami kesulitan saat mengerjakan soal no. 2?*
*S2 : Sedikit karena dari hasil perhitungan saya tidak menemukan yang pas tetapi pilihan yang paling mendekati itu 8.*

Figure 4. Interview with Subject SS

Based on further confirmation results, it was found that subject SS had a better understanding of more complex rotation patterns, for example, in problems involving arrow direction transformations, which allowed him to produce accurate answers without errors. However, in the aspects of spatial orientation and spatial visualization, subject SS was not yet able to identify the concept of object transformation correctly and comprehensively. This limitation resulted in errors in the process of solving problems that require a higher spatial representation.

c. Low Spatial Reasoning Ability

The test results of subject SR in solving geometric transformation problems are presented in Figure 5.

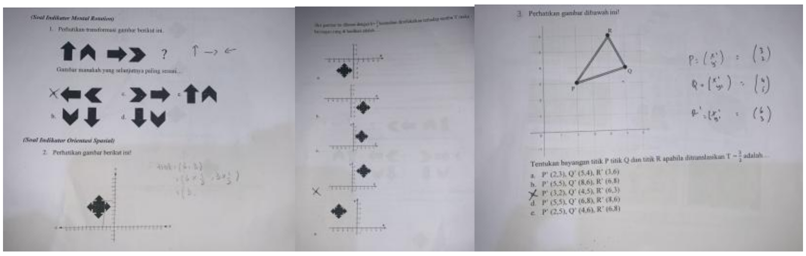

Figure 5. SR Subject Test Results

Individuals with low spatial reasoning (SR) ability often struggle to understand problems in problem-solving accurately. In mental rotation problems, subjects often struggle to visualize the rotation of objects in their minds, frequently unable to determine the exact transformation of an object's direction or position. Subjects require concrete visual aids to understand the rotation pattern. People often struggle to orient objects in space, particularly in spatial orientation problems. Misunderstanding the measures can lead to errors in determining the results in processes of dilation and reflection around the axes. In spatial visualization problems, SR subjects are very limited in visualizing changes in the position, shape, or size of objects in space. Therefore, guidance and clear stages are needed to understand the relationships between elements in geometry. With these limitations, subjects require extensive practice, guidance, and visual aids to understand and solve geometry problems involving translation. The following is the result of an interview with an SR subject.

*P : Apa yang ditanyakan pada soal no. 3?*
*S3 : Menentukan bayangan dari titik P, Q, R setelah ditranslasikan*
*P : menurutmu pilihan mana yang paling sesuai?*
*S3 : Yang C*
*P : Bagaimana cara kamu mengerjakannya?*
*S3 : Hanya kira-kira saja. Setelah ditranslasikan, titik P, Q, R akan sesuai sama dengan yang C*
*P : Apakah kamu mengalami kesulitan saat mengerjakan soal no. 3?*
*S3 : Iya, saya tidak paham translasi itu apa.*

Figure 6. SR student interview

Further confirmation reveals that subject SR was unable to comprehend the problem presented to them. Subject SR struggled to find which way the transformation goes. Subject SR also found it challenging to determine the position. As a result, subject SR made mistakes in geometric transformation problems.

Based on the results of the spatial reasoning ability test in this study, students were categorized into high, medium, and low spatial reasoning abilities. Spatial reasoning ability is divided into three levels: high (spatial), medium (fuzzy), and low (plane) (Amro & Dawoud, 2024; Mega & Meiliasasi, 2024). In this study, students with high spatial reasoning ability (ST) demonstrated good abilities in solving geometric transformation problems, achieving indicators in the three aspects of mental rotation, spatial orientation, and spatial visualization. According to previous research findings, students with strong spatial reasoning skills engage in exploratory, analogical, abstract, synthetic, and idea recycling thinking processes. Students with high spatial reasoning abilities also have a high level of imagination (Aje et al., 2025; Tanjung et al., 2021). Therefore, a student with higher spatial thinking skills will be able to solve problems on geometric transformation competently, as long as they also possess a high level of creativity. Research results support this, showing that the higher a student's spatial reasoning ability, the easier it is for them to learn geometry (Maghfiroh & Qothrunnada, 2024; Mega & Meiliasasi, 2024).

Students with moderate spatial reasoning ability (SS) can understand the concept of transformation well, where the mental rotation aspect is resolved with correct understanding and solution. In understanding the concept of transformation in spatial orientation and spatial visualization problems, students generally perform well; however, they often encounter difficulties when solving these problems. Students can determine the coordinate points in the presented problems and identify alternative solutions for the concepts of translation and dilation; however, in the process, they tend to be less precise in providing explanations. SS students still struggle with understanding the concept of transformation. Actually, students understand how a shape is transformed and can think analogically and abstractly about the shapes presented in the problem; however, they are less precise and incomplete in the process of solving the transformation concept. Students with moderate spatial reasoning ability (SS) exhibit exploratory thinking processes, analogical thinking, semi-abstract thinking, and recycling of ideas, and possess moderate imagination (Lakin et al., 2024; Tanjung et al., 2021).

Students with low spatial reasoning (SR) weaknesses can recognize the geometric shapes and the actions of transformations, but the principles of the transformations: translation, rotation, reflection, and dilation are inaccessible to them. Consequently, students with low spatial (SR) reasoning problems are still visualizing and identifying transformations; problem-solving and reasoning are still inaccessible to them. This is because the students do not understand the aim of the given questions, and the geometric transformations content seems especially difficult, leading to poor performance. Not all questions were answered correctly, but students with low spatial reasoning (SR) problems did provide an answer to the 3rd question, considering the coordinates of the quadrilateral. Problem solving involving high cognitive transformations and problem solving focusing on semi-abstract concepts was still a problem for them, leading to difficulty in completing the geometric transformations (Ikhsan et al., 2024; Masamah & Farabi, 2024; Tanjung et al., 2021).

Students exhibit varying abilities in solving problems involving geometric transformations. This is due to the intellectual differences and abilities of each individual. Geometry, particularly transformations, relies heavily on spatial reasoning, which geometry educators should strive to evaluate and understand based on each student's individual abilities. This will then allow them to identify optimal learning alternatives and strategies for each student.

## CONCLUSION

Students who acquire high spatial reasoning skills (ST) perform well in solving geometric transformation problems involving mental rotation, spatial orientation, and spatial visualization accurately and adequately. These students understand the rotation pattern of imagining objects clockwise, determine the results of dilation and reflection of an object on a given axis, and understand the changes in position and shape of the objects in space. Moderately able students (SS) understand the rotation pattern of imagining objects clockwise but fail to fully and accurately grasp the concept of transformation in an object, which results in errors in the solution process. These students can solve the mental rotation, but students with spatial orientation and spatial visualization have difficulty applying the concept of transformation. Students with weak spatial reasoning (SR) often have problems rationally solving the problems posed to them because they cannot visualize the rotation of the objects in their minds. Consequently, they cannot accurately determine the transformation of an object's direction and position, and the concept of transformation cannot be grasped. These students predominantly perform poorly on problems related to mental rotation, spatial orientation, and spatial visualization. The results of this study can be used as a reference for future researchers, suggesting that more effective methods and techniques should be used in teaching geometry and spatial concepts to students to reduce the level of misconceptions experienced by students.

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