e-ISSN: 2549-5070
p-ISSN: 2549-8231

Journal of Medives : Journal of Mathematics Education IKIP Veteran Semarang
Volume 8, No. 2, 2024, pp. 253-264
https://doi.org/10.31331/medivesveteran.v8i2.3160

Spatial Reasoning of Students With Mathematical Learning Difficulties

Alfin Khoiro Amalia[1], *Mohammad Faizal Amir[2]
[1, 2] Muhammadiyah University of Sidoarjo
*faizal.amir@umsida.ac.id

Received: *January 2024.* ***Accepted***: *April 2024.* ***Published***: *May 2024.*

ABSTRACT

Spatial reasoning is essential for solving two or three-dimensional oriented problems. Meanwhile, primary school students often experience mathematical learning difficulties (MLD) using spatial reasoning. The research analyzes the spatial reasoning of primary school students who experience MLD. The research method is qualitative, with the research subject being fifth-grade students at one of the primary schools in Sidoarjo. The research instruments used spatial reasoning tests and interview guidelines. The results stated differences in spatial reasoning in students' MLD types. Students who experience visual spatial type MLD have lower spatial reasoning skills because they cannot solve spatial orientation, mental rotation, and spatial visualization problems. Meanwhile, students who experience memory-type MLD have moderate spatial reasoning because they can solve spatial orientation and spatial visualization problems but cannot solve mental rotation problems. The researcher suggested that the subsequent research should intervene in the spatial reasoning of students who experience MLD.
Keywords: *geometry, mathematical learning difficulties, spatial reasoning.*

How to Cite: Amalia, A., & Amir, M. (2024). Spatial Reasoning of Students With Mathematical Learning Difficulties. *Journal Of Medives : Journal Of Mathematics Education IKIP Veteran Semarang*, *8*(2).

INTRODUCTION

Spatial reasoning plays a vital role in solving problems involving two-dimensional (2-D) or three-dimensional (3-D) in geometry learning (Fujita, Kondo, Kumakura, Kunimune, & Jones, 2020; Khine, 2017; Pavlovicova & SvecovA, 2015; Ramful, Lowrie, & Logan, 2017). In addition to geometry, spatial reasoning is also required in several domains, within the geometry domain (Fujita et al., 2020) or outside the geometry domain, such as algebra (Gunderson, Ramirez, Beilock, & Levine, 2012). In addition, spatial reasoning has been confirmed to predict students' mathematics achievement (Cheng & Mix, 2014; Clements, Germeroth, & Sovran, 2015; Gunderson et al., 2012).

The researchers mentioned that there is low or inadequate spatial reasoning among students in Indonesia (Dintarini, Jamil, & Ismail, 2022; Hasanah & Kumoro, 2021; Kusuma, Rochmad, & Isnarto, 2021; Lestari, Budiarto, & Lukito, 2021; Ma'rifatin, Amin, & Siswono, 2019; Musriroh, Hidayanto, & Rahardi, 2021). Students generally do not have experience solving problems based on spatial reasoning (Lowrie, Logan, & Hegarty, 2019). This low spatial reasoning is due to students' difficulties visualizing 2-D or 3-D objects (Dimitriu & Dimitriu, 2020). Students' spatial reasoning difficulties are also due to spatial reasoning rarely being taught explicitly in schools (Hawes, Moss, Caswell, Naqvi, & MacKinnon, 2017; Lowrie, Logan, & Ramful, 2017).

Student learning difficulties in mathematical learning are called mathematical learning difficulties (MLD) (Chinn, 2014; Hamukwaya & Haser, 2021). MLD is widely used to describe a wide range of mathematical difficulties. Students who experience MLD have impaired cognitive functioning (Bartelet, Ansari, Vaessen, & Blomert, 2014; Karagiannakis, Baccaglini-frank, & Papadatos, 2014; Yazdani et al., 2021), mathematical ability deficits (Zhang et al., 2019), and difficulties experienced by students in mathematical concepts and procedures as indicated by low achievement or low performance in mathematics (Beswick, 2008; Mazzocco, 2009).

Meanwhile, spatial reasoning and MLD have a relationship. This relationship can be seen from the students' spatial reasoning level, which affects math difficulties, especially for students who experience MLD (Yazdani et al., 2021). Spatial reasoning is one of the components of MLD assessment (Karagiannakis et al., 2014; Plerou & Vlamos, 2016). Spatial reasoning is significantly related to students who experience MLD (Donnelly, 2021; Levy, Turk-Browne, & Goldfarb, 2023; Yazdani et al., 2021).). In addition, spatial visualization is a deficit in the numerical system in MLD children (Levy et al., 2023). MLD students will experience limited spatial reasoning, especially visualization and mental rotation (Donnelly, 2021). Students with difficulty visualizing and analyzing geometry in rigid motion visualization, such as rotation, will be classified as visual-spatial type MLD (Thompson, Nuerk, Moeller, & Cohen Kadosh, 2013).

Several studies on spatial reasoning by reviewing MLD have been conducted. Research conducted by Yazdani et al. (2021) compares MLD students and typical development (TD). MLD students perform more difficult spatial reasoning tasks and take longer to complete mental rotation, spatial visualization, and spatial orientation tasks. Other researchers have suggested spatial deficits in MLD children (Murphy et al., 2007; Zhang et al., 2019) and numerical system deficits in spatial visualization (Levy, Turk-Browne, & Goldfarb, 2023). Empirical studies suggest that there is a comparison of working memory capacity between students with and without MLD who report deficits in visuospatial working memory but not verbal working memory in students with MLD (Szucs, Devine, Soltesz, Nobes, & Gabriel, 2013). In addition, students with MLD have difficulty solving mental rotation problems (Skagerlund & Träff, 2014). Impairments in the same cognitive skills, including language, spatial, and numeracy skills, were found to underlie MLD (Zhang & Rasanen, 2020).

Existing studies have not focused on revealing students' spatial reasoning based on the components by Ramful et al. (2017), namely spatial orientation, mental rotation, and spatial visualization. These components provide detailed information about spatial reasoning. It is expected that revealing spatial reasoning in terms of spatial orientation, mental rotation, and spatial visualization in students who experience MLD can provide information about the inhibition of spatial reasoning in MLD students. Therefore, this research can provide information and ideas about the weakness of spatial reasoning for MLD students. Hence, it is also expected that the study results have implications for providing appropriate advice so that the spatial reasoning of students who experience MLD can be further improved.

METHOD

The research involved 21 fifth-grade primary school students at Sekolah Dasar Negeri Lemahputro 1 in Sidoarjo, East Java, Indonesia. Determining research subjects was carried out purposively by categorizing students' MLD types into memory and visual-spatial. Memory-type MLD is a group of students who take a long time to solve problems. MLD of visual-spatial type is a group of students who struggle to imagine, remember, or think of a visual object in solving spatial reasoning problems. One student was selected to represent this study's MLD memory and visual-spatial types.

Data collection techniques used tests and semi-structured interviews. The tests consisted of a spatial reasoning test and MLD test. A spatial reasoning test is used to determine students' spatial reasoning. MLD test is used to categorize MLD students. Then, interviews were conducted to dig deeper into the spatial reasoning components, namely spatial orientation, mental rotation, and spatial visualization.

Spatial Reasoning Test

The spatial reasoning test consists of three problems (see Figure 1): spatial orientation, mental rotation, and spatial visualization, as adapted from Ramful et al. (2017). The first problem represents the spatial visualization component, which is about determining the shape of a space when viewed from different directions. The second problem represents the mental rotation component, which is about rotating a 3-D object, and the third problem represents the spatial orientation component, about imagining a net into a cube whose sides face each other.

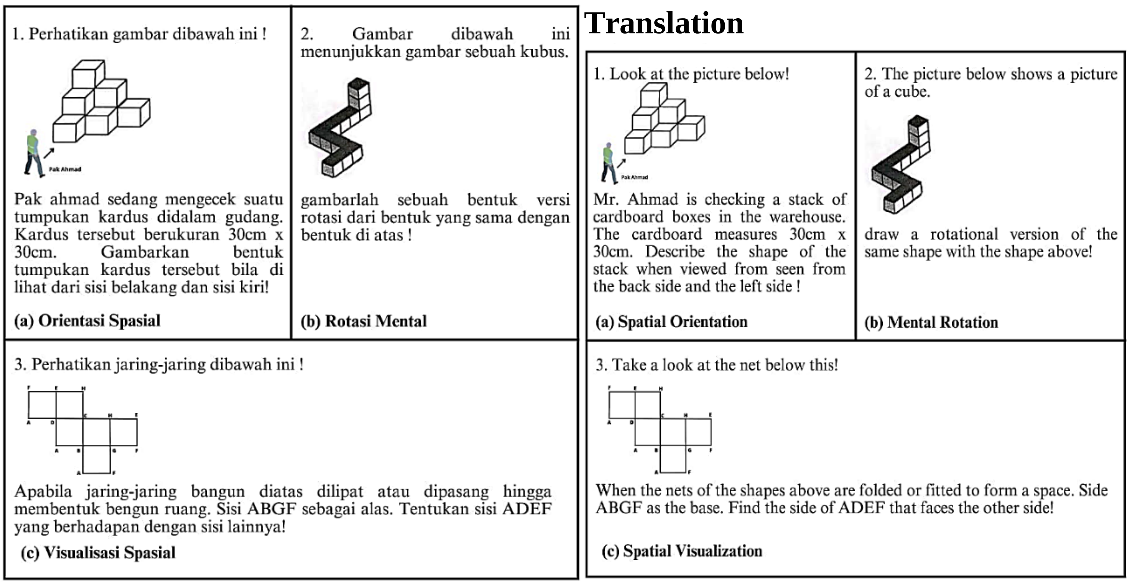


Figure 1. The Spatial Reasoning Test

MLD Test

The MLD test is an instrument to measure student learning difficulties in geometry properties. This test consists of 6 items: recognition and construction of net, manipulation of 3-D shape representation modes, structuring 3-D arrays of cubes, recognition of 3-D shape properties, calculation of the volume, and comparison of 3-D shape properties adapted from Pittalis and Christou (2010). The determination of students who experience MLD is focused on two types of MLD, according to Karagiannakis et al. (2014), namely memory and visual-spatial.

Data analysis used qualitative descriptive data techniques: data reduction, presentation, and conclusion drawing (Miles, Huberman, & Saldana, 2014). Data reduction is done by eliminating data not under students' spatial reasoning. Data presentation is done by displaying spatial reasoning activities on each type of students' MLD. The conclusion is drawn by classifying MLD students' problem-solving differences on each spatial reasoning component.

RESULTS AND DISCUSSION

This section describes the spatial reasoning of two students with MLD. VS is a student who experiences visual spatial type MLD, while ME is a student who experiences memory type MLD. Furthermore, the spatial reasoning of VS and ME is analyzed for the components of spatial orientation, mental rotation, and spatial visualization.

Visual-Spatial Type Students

Students with visual-spatial type MLD have difficulty understanding, imagining, remembering, or thinking in a visual form such as VS. VS cannot complete all three components of spatial reasoning: spatial orientation, mental rotation, and spatial visualization.

Spatial Orientation

VS illustrated a picture of a stack of cardboard cubes. The cubes are stacked in rows: the first row contains two cubes, the second row has two cubes, and the third row includes one cube. When viewed from the left and back, the sides of the cube are square. VS illustrates the side, as shown in Figure 2

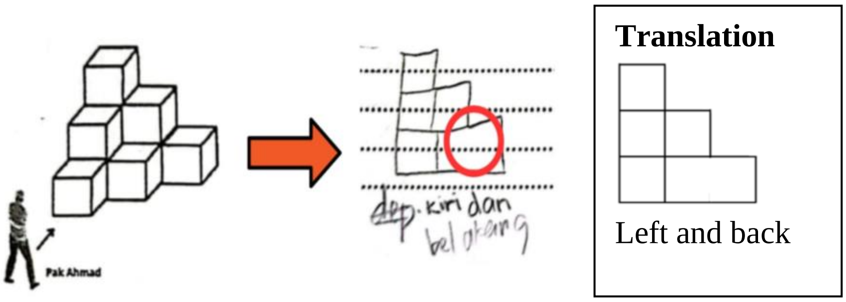


Figure 2. VS Looking at An Object from Different Perspectives

In solving spatial orientation problems, VS tends to have moderate imagination. VS admitted that he was confused about finding the OS answer, but VS almost correctly described an object from different perspectives (see Figure 2). VS said that he had never solved spatial orientation problems. VS skimmed and then identified the problem-solving information, such as drawing the side of the pile of cardboard seen from the front and right sides. VS drew the side of the pile of cardboard, but there were still sides that had not been drawn in solving spatial orientation problems.

Mental Rotation

VS had difficulty imagining an object viewed from one perspective, as would be seen if the object was rotated in space to a new orientation and viewed from a new perspective. VS had difficulty determining the changes that occur in a shape that is rotated several times, both in shape and position. VS showed the answer result that the student was still unable to do it after several times, as presented in Figure 3.

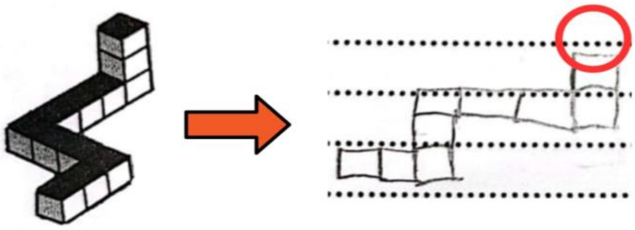


Figure 3. VS Drawing a Rotated 3-D Object

Spatial Visualization

VS drew a cube and knew that all the cubes were blocks. VS shaded the side AFGB in the problem provided but asked to draw it and still struggled. VS represented an edge with edges AB and E . However, VS left blank the point parallel to the corner point E. Side AFGB is the base side of the building. Then, the side facing the ADEF side is the DCBA side.

VS had difficulty imagining an object in Figure 4. VS solved the problem by guessing first and then checking the correctness. VS had trouble imagining how a cube's net could be formed into a cube. This difficulty resulted in VS not having a solid foundation to solve the problem because there was a visual image of how the sides of the cube faced each other. VS could not produce a mental image in his mind or describe the process VS went through clearly.

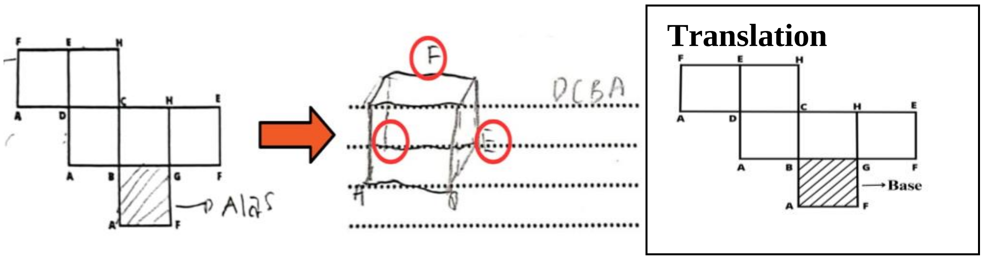


Figure 4. VS Visualizing A Net of A Spatial Structure

Memory Type Students

ME is a student who takes a long time to solve problems in each spatial reasoning component. However, ME can solve problems with spatial reasoning components, namely spatial orientation and spatial visualization, but cannot solve mental rotation problems compared to spatial visual type MLD students.

Spatial Orientation

Given a stack of cardboard boxes in the shape of a cube, the stack of cubes in 3-D is viewed from the left and back perspectives. Then, the side of the cube from the left and rear perspectives has the same image: a square with three levels. The first level has three squares, the second has two, and the third has one square, as shown in Figure 5.

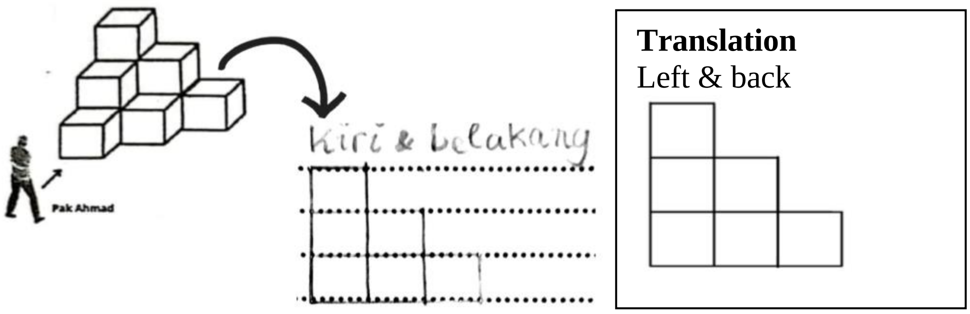


Figure 5. The Process of Observing The Position of The Stack of Cardboard Boxes

ME concludes that the correct answer can solve mental orientation problems even though solving them takes a long time. ME can observe the position of objects from different perspectives and the spatial relationship between objects. In this case, ME can remember where an object is concerning another object. For example, ME oriented a building. ME observes from the front side and draws as requested in the problem, while the right side imagines what the back side of the cardboard stack looks like and draws the left side.

Mental Rotation

ME had difficulty accepting new information and could not follow the instructions of the problem because He had not studied this material. ME rotated the object on the paper repeatedly and could not solve the problem correctly. ME had difficulty in understanding the given problem. In addition, ME had trouble determining the changes after being rotated several times, both in shape and position, as shown in Figure 6. The ability to solve problems regarding the rotation of spatial shapes was due to the difficulty in seeing the spatial shapes that had been manipulated.

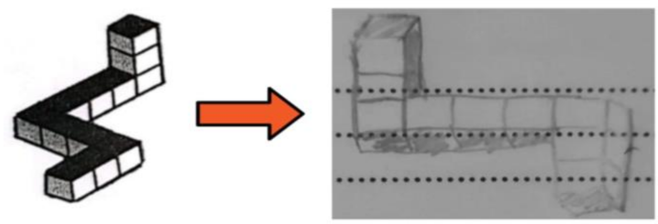


Figure 6. ME Solves The Problem of Mental Rotation

Spatial Vizualization

ME can manipulate the object by folding the net of the cube, then visualize the 3-D cube in her mind. ME assigns a letter to each cube side and determines the ABGF side as the base side and the DEHC side as the lid side. ME can transform 2-D shapes into 3-D shapes in spatial visualization problem-solving. Using the 3-D visualization obtained, ME can determine the side parallel to side AEDF and BHCG, as shown in Figure 7.

ME can explain in detail the process of what he has done in solving spatial reasoning. ME tried to explain the spatial visualization problem and was equipped with illustrations of problem-solving on a piece of paper when presenting to the interviewer. ME communicated her reasoning to the interviewer well and clearly. Besides that, ME did not experience any obstacles in solving the spatial visualization problem.

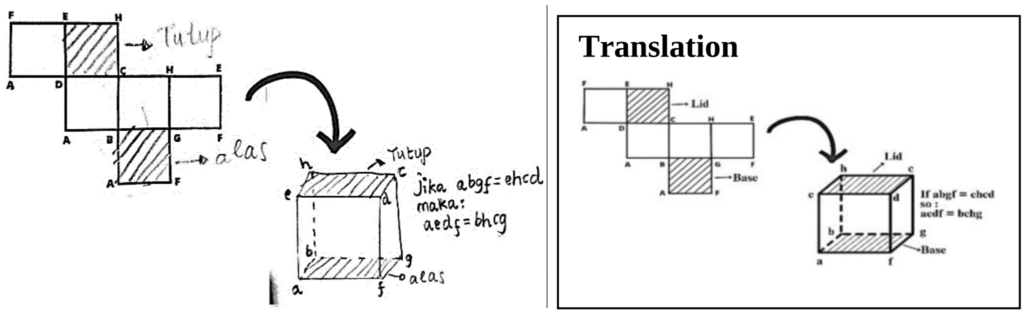


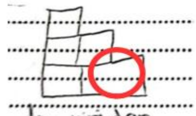
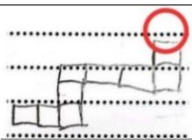
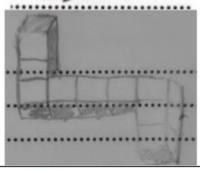
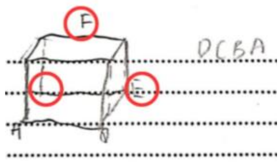
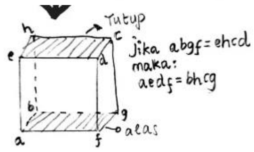
Figure 7. ME Visualize Cube Nets Into 3-D Objects

Based on the explanation above, memory-type MLD students make decisions that seem inconclusive. In addition, memory-type students have difficulty retaining the information needed to follow the instructions and solve the problem in the mental rotation problem. However, MEs could manipulate what had been done to solve the problem accurately. A visual object decreases performance on other spatial tasks, such as mental rotation.

DISCUSSION

The synthesis of MLD students' spatial reasoning classification is presented in Table 1. The problem-solving of MLD students consisted of incomplete objects in the first level, objects oriented perfectly, omitting one square in the figure, casting shadows of rotated objects, errors in giving sides at the base and manipulating the shape by folding the cube net into 3-D. In addition, spatial problem-solving and reasoning produced by MLD students of visual-spatial type and memory types are discussed in this section.

Table 1. Problem-solving of spatial reasoning component produced by MLD students

Spatial reasoning components	Example of spatial reasoning
Spatial Orientation	
Visual-spatial type: The cubes are stacked in rows: the first row contains two cubes, the second row has two cubes, and the third row includes one cube.	
Memory type: A stack of 3-D cubes is viewed from the left side and back. The sides of the cube are then drawn in a square shape with three levels. The first level has three squares, the second has two squares, and the third has one square.	
Mental Rotation	
Visual-spatial type: Draws a 2-D space after rotating, but one square is missing.	
Memory type: Identifies the position of an object that is rotated clockwise.	
Spatial Visualization	
Visual-spatial type: There was an error in giving the side at the base. Therefore, VS is not able to visualize the side facing AEDF.	
Memory type: 2-D building is manipulated by folding the cube's net and visualizing it in 3D. ME explains in detail and is equipped with illustrations of problem-solving	

Students who experience visual spatial type MLD will have difficulty understanding, imagining, remembering, or thinking in visual form. This is in line with Chinn (2014), who stated that MLD students of visual-spatial type will have difficulty interpreting spatial reasoning from the representation of mathematical objects and visualizing and analyzing an object in geometry. In addition, the relationship between spatial visual type MLD and spatial reasoning that we found is consistent with previous research, which showed that spatial visual type MLD students will have difficulty in visualizing and analyzing geometry in specific visualizations of rigid movements such as rotation (Thompson et al., 2013). MLD students have deficient working memory capacity in visuospatial working memory (Szucs et al., 2013).

MLD-type memory students have problems with working memory, namely, taking a long time to think about a problem regarding spatial reasoning but being able to solve the problem, except for mental rotation. Working memory selects verbal rather than spatial information as relevant (De Smedt, Taylor, Archibald, & Ansari, 2010). Working and semantic memory emphasize difficulties in understanding and learning numbers (Karagiannakis et al., 2014).

Spatial reasoning is rarely taught explicitly in schools, so researchers are finding methods to teach spatial concepts explicitly, including working with classroom teachers to create spatial interventions (Hawes et al., 2017; Lowrie et al., 2017). Researchers produced training programs to address low spatial reasoning. For example, Lowrie et al. (2017) defined three aspects of spatial reasoning: mental rotation, spatial orientation, perspective taking, and spatial visualization, including imagining complex spatial transformations, such as folding paper into three-dimensional shapes. Meanwhile, Lowrie et al. (2017) created and implemented a ten-week spatial reasoning intervention program for fifth and sixth-grade students. The program lasted twenty hours and focused on spatial visualization, spatial orientation, and mental rotation skills. Lowrie et al. (2018) implemented and evaluated a spatial training intervention program for fourth and third-grade students to extend the research to a broader age range.

CONCLUSION

The study results concluded that there are differences in students' spatial reasoning on the differences in students' MLD type. Not all MLD-type students have difficulty in solving spatial reasoning problems. MLD visual spatial type students have difficulty solving spatial orientation, mental rotation, and spatial visualization problems. Memory-type MLD students have difficulty in solving mental rotation problems. Visual-spatial-type MLD students have difficulty visualizing objects, while memory-type MLD students take a long time to receive information and make decisions or answers. However, these students can solve spatial reasoning problems, except in mental rotation. We suggest further research that leads to the availability of spatial intervention programs specifically for students with MLD.

ACKNOWLEDGMENT

The authors would like to thank Universitas Muhammadiyah Sidoarjo for allowing us to conduct research.

REFERENCE

Bartelet, D., Ansari, D., Vaessen, A., & Blomert, L. (2014). Cognitive subtypes of mathematics learning difficulties in primary education. *Research in Developmental Disabilities*, *35*(3), 657–670. https://doi.org/10.1016/j.ridd.2013.12.010

Beswick, K. (2008). Influencing teachers' beliefs about teaching mathematics for numeracy to students with mathematics learning difficulties. *Mathematics Teacher Education and Development*, *9*(2000), 3–20. Retrieved from http://ecite.utas.edu.au/55228/1/MTED_9_Beswick.pdf

Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, *15*(1), 2–11. https://doi.org/10.1080/15248372.2012.725186

Chinn, S. (2014). The routledge international handbook of dyscalculia and mathematical learning difficulties. In *The Routledge International Handbook of Dyscalculia and Mathematical Learning Difficulties*. https://doi.org/10.4324/9781315740713

Clements, D. H., Germeroth, C., & Sovran, B. (2015). *The Building Blocks of Mathematics for Infants* *and Toddlers: An Annotated Bibliography for Course Developers 2015*.

De Smedt, B., Taylor, J., Archibald, L., & Ansari, D. (2010). How is phonological processing related to individual differences in children's arithmetic skills? *Developmental Science*, *13*(3), 508–520. https://doi.org/10.1111/j.1467-7687.2009.00897.x

Dimitriu, D. G., & Dimitriu, D. C. (2020). A simple method to help students improve 3-D visualization skills. *ASEE Annual Conference and Exposition, Conference Proceedings*, *2020-June*.

Dintarini, M., Jamil, A. F., & Ismail, A. D. (2022). Secondary students' spatial thinking in solving the minimum competency assessment (MCA) on geometry. *Jurnal Elemen*, *8*(2), 544–555. https://doi.org/10.29408/jel.v8i2.5670

Donnelly, E. L. H. (2021). *Exploring the spatial-math link: The impact of tailored visual memory interventions for children with MLD*. Retrieved from https://prism.ucalgary.ca/handle/1880/112974%0Ahttps://prism.ucalgary.ca/bitstream/handle/1880/112974/ucalgary_2021_donnelly_emma.pdf?sequence=2&isAllowed=y

Fujita, T., Kondo, Y., Kumakura, H., Kunimune, S., & Jones, K. (2020). Spatial reasoning skills about 2D representations of 3D geometrical shapes in grades 4 to 9. *Mathematics Education Research Journal*, *32*(2), 235–255. https://doi.org/10.1007/s13394-020-00335-w

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: The role of the linear number line. *Developmental Psychology*, *48*(5), 1229–1241. https://doi.org/10.1037/a0027433

Hamukwaya, S. T., & Haser, Ç. (2021). "It does not mean that they cannot do mathematics": Beliefs about Mathematics Learning Difficulties. *International Electronic Journal of Mathematics Education*, *16*(1), em0622. https://doi.org/10.29333/iejme/9569

Hasanah, U., & Kumoro, D. T. (2021). Kemampuan spasial: Kajian pada siswa usia sekolah dasar. *Jurnal Pacu Pendidikan Dasar*, *1*(1), 27–34. Retrieved from https://unu-ntb.e-journal.id/pacu/article/view/68/19

Hawes, Z., Moss, J., Caswell, B., Naqvi, S., & MacKinnon, S. (2017). Enhancing children's spatial and numerical skills through a dynamic spatial approach to early geometry instruction: Effects of a 32-week intervention. *Cognition and Instruction*, *35*(3), 236–264. https://doi.org/10.1080/07370008.2017.1323902

Karagiannakis, G., Baccaglini-frank, A., & Papadatos, Y. (2014). Mathematical learning difficulties subtypes classification. *Frontiers in Human Neuroscience*, *8*(February), 1–5. https://doi.org/10.3389/fnhum.2014.00057

Khine, M. S. (2017). Visual-spatial ability in STEM education. In *Visual-spatial Ability in STEM Education*. https://doi.org/10.1007/978-3-319-44385-0

Kusuma, A. P., Rochmad, & Isnarto. (2021). Penerapan model accelerated learning cycle terhadap penalaran matematis ditinjau dari kemampuan spasial. *PRISMA, Prosiding Seminar Nasional Matematika*, *4*(1), 75–79. Retrieved from https://journal.unnes.ac.id/sju/index.php/prisma/article/view/44952

Lestari, D. D. P., Budiarto, M. T., & Lukito, A. (2021). Analisis kemampuan spatial visualization siswa sekolah dasar dalam pemecahan masalah geometri: Ditinjau dari kemampuan matematika tingkat tinggi. *ELSE (Elementary School Education Journal) : Jurnal Pendidikan Dan Pembelajaran Sekolah Dasar*, *5*(1), 55. https://doi.org/10.30651/else.v5i1.7371

Levy, S., Turk-Browne, N. B., & Goldfarb, L. (2023). Impaired visuo-spatial statistical learning with mathematical learning difficulties. *Visual Cognition*, (May). https://doi.org/10.1080/13506285.2023.2208887

Lowrie, T., Logan, T., & Hegarty, M. (2019). The influence of spatial visualization training on students' spatial reasoning and mathematics performance. *Journal of Cognition and Development*, *20*(5), 729–751. https://doi.org/10.1080/15248372.2019.1653298

Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Educational Psychology*, *87*(2), 170–186. https://doi.org/10.1111/bjep.12142

Ma'rifatin, S., Amin, S. M., & Siswono, T. Y. E. (2019). Students' mathematical ability and spatial reasoning in solving geometric problem. *Journal of Physics: Conference Series*, *1157*(4). https://doi.org/10.1088/1742-6596/1157/4/042062

Mazzocco, M. M. M. (2009). An introduction to the special issue: Pathways to mathematical learning difficulties and disabilities. *Developmental Disabilities Research Reviews*, *15*(1), 1–3. https://doi.org/10.1002/ddrr.52

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis*. SAGE Publications. Retrieved from https://books.google.co.id/books?id=3CNrUbTu6CsC

Murphy, M. M., Mazzocco, M. M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. *Journal of Learning Disabilities*, *40*(5), 458–478.

Musriroh, R. Z., Hidayanto, E., & Rahardi, R. (2021). Penalaran spasial matematis dimensi persepsi dan visualisasi kelas VIII dalam pemecahan masalah geometri. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *6*(11), 1774. https://doi.org/10.17977/jptpp.v6i11.15144

Pavlovicova, G., & SvecovA, V. (2015). The development of spatial skills through discovering in the geometrical education at primary school. *Procedia - Social and Behavioral Sciences*, *186*, 990–997. https://doi.org/10.1016/j.sbspro.2015.04.189

Pittalis, M., & Christou, C. (2010). Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies* *in Mathematics*, *75*(2), 191–212. https://doi.org/10.1007/s10649-010-9251-8

Plerou, A., & Vlamos, P. (2016). Algorithmic thinking and mathematical learning difficulties classification. *American Journal of Applied Psychology*, *5*(5), 22. https://doi.org/10.11648/j.ajap.20160505.11

Ramful, A., Lowrie, T., & Logan, T. (2017). Measurement of spatial ability: Construction and validation of the spatial reasoning instrument for middle school students. *Journal of Psychoeducational Assessment*, *35*(7), 709–727. https://doi.org/10.1177/0734282916659207

Skagerlund, K., & Träff, U. (2014). Development of magnitude processing in children with developmental dyscalculia: Space, time, and number. *Frontiers in Psychology*, *5*(JUN), 1–16. https://doi.org/10.3389/fpsyg.2014.00675

Szucs, D., Devine, A., Soltesz, F., Nobes, A., & Gabriel, F. (2013). Developmental dyscalculia is related to visuo-spatial memory and inhibition impairment. *Cortex*, *49*(10), 2674–2688. https://doi.org/10.1016/j.cortex.2013.06.007

Thompson, J. M., Nuerk, H. C., Moeller, K., & Cohen Kadosh, R. (2013). The link between mental rotation ability and basic numerical representations. *Acta Psychologica*, *144*(2), 324–331. https://doi.org/10.1016/j.actpsy.2013.05.009

Yazdani, S., Soluki, S., Arjmandnia, A. A., Fathabadi, J., Hassanzadeh, S., & Nejati, V. (2021). Spatial ability in children with Mathematics Learning Disorder (MLD) and its impact on executive functions. *Developmental Neuropsychology*, *46*(3), 232–248. https://doi.org/10.1080/87565641.2021.1913165

Zhang, Xiao, & Rasanen, P. (2020). Early cognitive precursors of children's mathematics learning disability and persistent low achievement: a 5-year longitudinal study. *Child Development*, *91*(1), 7–27. https://doi.org/10.1111/cdev.13123

Zhang, Xiaoxian, Fu, W., Xue, L., Zhao, J., & Wang, Z. (2019). Children with mathematical learning difficulties are sluggish in disengaging attention. *Frontiers in Psychology*, *10*(APR), 1–9. https://doi.org/10.3389/fpsyg.2019.00932