ACADEMIA International Journal for Social Sciences
Volume 4, Issue 3, 2025 ISSN-L (Online): 3006-6638

Relationship of Spatial Scaling at Distance and Resilience in STEM Education at Secondary Level

Sidra Khushnood Iftikhar
PhD Scholar, Dept. of Science Education, AIOU, Islamabad

Attiya Rashid
PhD Scholar, Dept. of Education, Muslim Youth University, Islamabad

Sunnam Kausar
sanamsatti412@gmail.com
Lecturer, Department of Social Sciences University of Gujrat Rawalpindi Centre
Corresponding Author: *Sunnam Kausar sanamsatti412@gmail.com
Received: 12-05-2025 **Revised:** 25-06-2025 **Accepted:** 10-07-2025 **Published:** 03-08-2025

ABSTRACT

Spatial scaling is the ability to understand and manipulate the size and dimension in spatial representations and is considered as one of imperative skills to excel in STEM fields. This study explores how secondary students' proficiency in spatial scaling influences their academic resilience, which is the capacity to overcome challenges and helps them to maintain motivation in STEM subjects. The descriptive research design was used in which quantitative research method was followed. The participant of the study comprises of secondary and higher secondary students of science group were divided into two tiers primarily based on their spatial scaling scores. Spatial scaling was gauged online through a standardized research instrument and a short academic resilience scale in STEM was adapted, whereas 6-Point Likert Scale was used. Data analysis was done by using Pearson Correlation coefficient. Findings suggest a strong correlation between spatial scaling abilities and resilience, highlighting that students who excel in spatial tasks tend to exhibit greater perseverance and resilience in STEM education. This study signifies the integration of spatial thinking exercises to bolster resilience and overall performance in STEM subjects. It is recommended to foster spatial thinking development in curriculum to enhance educational outcomes and prepare students for future STEM careers.

Keywords: *Spatial Scaling, Spatial thinking, STEM, Resilience, Quantitative, Distance*

INTRODUCTION

Spatial scaling is amongst the cognitive abilities that are essential for success in disciplines that require manipulation and understanding of sizes, dimensions, and spatial relationships (Mohring, Frick, and Newcombe, 2018). Spatial scaling allows individuals to mentally visualize and transform objects of different sizes and scales (Frick, and Newcombe, 2012). Uttal, and Cohen, (2012) elaborated that, this is particularly important in engineering, architecture, and design, where professionals need to conceptualize and manipulate 3D models, sketches, and schematics particularly embedded in the academic streams such as mathematics, physics, and other scientific disciplines where understanding the relative scale of objects, forces, and phenomena is essential for accurate analysis and problem-solving. Now, spatial thinking is well recognized as crucial element for STEM related disciplines (Wai, Lubinski, and Benbow, 2009). Zhu, et al., (2023) presented that the ability to mentally rotate, resize, and reconfigure spatial representations is crucial for problem-solving and innovation in these fields and the skills developed through spatial scaling are directly applicable to solving practical, real-world problems in STEM fields.

Szubielska, et al., (2023) explains that it is directly linked to daily activities, such as whether it's designing efficient transportation systems, modeling the behavior of materials, or visualizing complex data, the ability to translate spatial concepts into tangible solutions is a hallmark of successful STEM professionals. Uttal, and Cohen, (2012) strongly emphasize that proficiency in spatial scaling is a strong predictor of success in STEM education and careers. Studies have shown that individuals with strong spatial abilities tend to excel in STEM-related subjects, perform better on standardized tests, and are more likely to pursue and thrive in STEM related fields (Gilligan, 2020). Margulieux, (2020) concluded that developing and nurturing spatial scaling skills can significantly enhance one's academic and professional opportunities in the STEM disciplines. Ishikawa and Newcombe, (2021) pointed out that by honing this ability, individuals can enhance their capacity to visualize, comprehend, and apply spatial concepts to solve complex problems, ultimately contributing to advancements in science, technology, engineering, and mathematics. Spatial training leads to durable and transferable benefits, improving performance not only in spatial domains but also in mathematics and the recent research indicates that students with higher spatial abilities are more likely to enter STEM professions as adults (Hall, McGill, Puttick, and Maltby, 2022). The relevant literature indicated that spatial thinking is missing building block in STEM (Gagnier, and Fisher, 2016) particularly in mathematics curricula (Gilligan-Lee, Hawes, and Mix, 2022). The aim of this study is to explore the relationship between spatial scaling which is amongst the essential components of spatial thinking and academic resilience among students of higher secondary related to STEM subjects.

LITERATURE REVIEW

In the literature, previous studies related to spatial scaling such as the seminal work of Liben, and Downs, (1994) elaborated that spatial information abstraction and understanding of geometric properties count heavily on basic spatial concepts which was also emphasized in the work of Piaget and Inhelder, (1948, 1956) in which the researchers proposed that spatial proximity of the object is the intrinsic properties internal to the figure or object under studied. The researchers further concluded that at early years between 4-7, the spatial conception is not so proficient as Piaget and Inhelder, (1956) concluded that it is not until after 7-8 years that the child’s spatial representation began to reflect on distance, shape, size and proximity or proportions but later Uttal, (2000) concluded that the child gradually develops the concept of spatial representation, however, they feel it difficult even at young age. Previously, Liben, and Yekel, (1996) found that preschoolers at the age of 4-5 have considerable difficulties understanding spatial concepts including spatial scaling. Afterwards, Huttenlocher, Newcombe, and Vasilyeva, (1999) studied the spatial scaling at young age and concluded that at early years it is very difficult for children to distinguish between spatial tasks but Huttenlocher, Vasilyeva, Newcombe, and Duffy, (2008) then concluded that it depends upon the task format as well as spatial scaling gradually develops. Later, Uttal, Meadow, Tipton, Hand, Alden, Warren, and Newcombe, (2013) endorsed similar findings while studying the disparate trainings outcome on spatial skills.

Spatial scaling is often viewed in the recent studies particularly as the abilities to convert distance information from one representation to another of a different size at disparate perspectives, and is considered as essential part of object orientation, positioning and projection on map, navigation, and other spatial tasks involving representational systems (Frick, and Newcombe, 2012) which all needs deep understanding and competencies of spatial thinking abilities. Vasilyeva, and Huttenlocher, (2004) performed many experiments and suggested that early scaling may involve a form of perceptual based reasoning whereby children mentally transform that may involve stretching or shrinking and change the projection of a layout in a way that preserves metric relations to develop their spatial scaling capabilities. Mohring, and Szubielska, (2023) concluded that spatial scaling offers the affordance of space at different scales that is scaling up as well as scaling down which means that spatial scaling abilities allows scale up or down in different projections or angles of the referent.

Spatial scaling abilities are the important component of spatial cognition as Gilligan, Hodgkiss, Thomas, and Farran, (2018) comprehend the spatial scaling as the ability to mentally manipulate and transform spatial information and associate it with success in aspects of mathematics (Gilligan, 2020). Spatial scaling has been identified as a significant predictor of success in STEM (science, technology, engineering, and mathematics) disciplines and studies have shown that enhancing spatial scaling skills can improve overall spatial cognition, which in turn supports better performance in scientific reasoning (Hodgkiss, Gilligan, Tolmie, Thomas, and Farran, 2018: Szubielska, Szewczyk, and Mohring, 2022). Studies show that spatial competencies predict strong learning outcomes in STEM subjects (Atit, et al., 2020: Gilligan, Flouri, and Farran, 2017: Young, Levine, and Mix, 2018). Spatial cognition encompasses a range of cognitive processes related to mental representations of physical environments (Buckley, and Seery, 2016) that help individuals to understand how people perceive distances and spatial relationships, similar as required in mental rotation abilities (Gilligan, 2020). Thus, both rely on similar cognitive frameworks as spatial scaling requires the mental rotation abilities to manipulate the stimulus for observing the projections, distance, size and proximity of the object.

The indicators of spatial ability consisted of spatial relationships, projective relationships, frame of reference, mental rotation, spatial representation, and distance/dimension conservation (Alimuddin, and Trisnowali, 2018) which is particularly related to spatial scaling concept that is not only important in academics but also it is recognized globally as standardized sought after skills and in demand at workplace (Yılmaz, 2009). However, researchers have discussed standardized measures to assess spatial thinking (Newcombe, 2010). It is not easy for all students to engage in activities requiring spatial skills and abilities because these tasks often demand significant effort. Students struggling to develop spatial abilities may become discouraged and abandon their attempts to reach learning objectives. Successfully overcoming these challenges not only relies on external support such as adequate facilities and infrastructure but also on the internal factor of resilience (Hidayati, and Wahyuni, 2020) because resilience is perceived as the persistence in doing cognitive tasks in recent studies (Kaur, and Singh, 2022). Therefore, the existence of ideas in line between spatial scaling and resilience has the following questions.

Problem Statement

While Spatial Scaling ability has been linked to STEM competencies, its relationship with resilience in STEM education at the secondary level remains unexplored. The lack of understanding of this relationship may hinder the development of effective interventions to support students' spatial thinking and resilience in STEM subjects, potentially leading to decreased academic achievement and interest in STEM fields. However, the empirical evidence linking spatial scaling abilities and resilience in STEM education is sparse, and the existing research does not adequately address how these variables interact at the secondary education level.

Rationale

The significance of this study lies in its potential contributions to both educational research and practice, particularly in the context of STEM (Science, Technology, Engineering, and Mathematics) education at the secondary level. This study bridges the gap in existing literature by examining the relationship between spatial scaling abilities and academic resilience. By highlighting the connection between these two constructs, it provides valuable insights into how spatial skills impact students' capacity to cope with and overcome challenges to promote sustainable academic growth. The findings suggest that integrating spatial thinking exercises into the STEM curriculum could enhance students' resilience and overall performance. Given the global emphasis on improving STEM education to prepare students for future careers, this study offers empirical evidence supporting the need to focus on spatial thinking as a critical component of STEM education.

Objectives

1. To examine the correlation between spatial scaling abilities and academic resilience among secondary students in STEM education.
2. To analyze the impact of varying levels of spatial scaling on the academic resilience of secondary students in STEM education.

Research Questions

1. What is the correlation between spatial scaling abilities and academic resilience among secondary students in STEM education?
2. How does the level of spatial scaling affect the academic resilience of secondary students in STEM education?
3. Does improving spatial scaling abilities enhance academic resilience in secondary STEM students?

RESEARCH METHODOLOGY

Research Design

This study utilized a non-experimental research design with quantitative descriptive approach with standardized measures to explore the relationship between spatial scaling abilities and academic resilience among secondary students in STEM education. The students of grades 812 with the combination of science subjects serve as the population of the study. The total number of students who volunteered to participate in the study was 241 at the initial stage. As the survey was conducted at a distance with the online tools, it was very likely to get the incomplete data. Therefore, the responses of the participants were rechecked, and the incomplete survey responses were scanned out from the data at the later stage.

Sample of the study

The students with the combination of science subjects, willing to participate in the research served as the sample of the study. The participants' selection criteria were limited to the science students of grades 8^{th}, 9^{th}, 10^{th}, 11^{th} and 12^{th} that comprised of secondary and higher secondary students from rural, semi urban and urban areas. Informed consent was taken from the participants of the study prior to participating in the study and data collection. There were 241 participants initially, however, the final sample comprised of 204 students after thorough scrutiny of the data.

Instrumentation

The first section of the instrument consisted of demographic information of the respondents. The second section consisted of spatial scaling measures. The third section was the measure of academic resilience in STEM. Spatial scaling was measured by a standardized test developed by Peters, Laeng, Latham, Jackson, Zaiyouna, and Richardson, (1995) which is a 24item test, and each item has two and only two matches (given at left side of the stimuli) of the given stimuli at the left side. The test was administered at a distance; therefore, the two matches were adjusted in the form of one pair along with the other alternative pair of choices. The participants have to identify one right pair and a score of 1 is given for the right choice and 0 score is given for wrong choice. In this way, the range of scores was 0-24. Whereas, for measuring academic resilience, a 9-items questionnaire developed by Ricketts, Engelhard, and Chang, (2015) was adapted and 6-point Likert scale was used with the indicators ranging as 1 = Strongly disagree; 2= Disagree; 3= Disagree somewhat; 4 = Agree somewhat; 5= Agree; 6= Strongly agree. Since the measure was standardized, it was considered valid and reliable, but given the socio-demographic considerations and change of modality for the administration of the tool, pilot testing was carried out before administering the test on a large scale. The pilot testing was carried out on 40 students who did not participate in the actual study. The internal consistency value dropped to 0.72 but it maintained a satisfactory level.

DATA ANALYSIS

The quantitative analysis of the data was done using SPSS-21 version, whereas descriptive analysis of frequencies and percentages was employed. The Pearson's Correlation value was measured using bivariate correlation model. Regression analysis was performed to identify the strength and direction of the relationship between two variables.

Table 1

Sample Distribution across grade levels

Grades	Frequency	Percentage
8th	26	12.7
9th	41	20.1
10th	46	22.5
11th	34	16.7
12th	57	27.9
Total	204	

Table 1 shows the distribution of participants across different grades from 8th to 12th. The total number of participants is 204.

Table 2

Descriptive Statistics of Variables of the Study

Descriptive Statistics	Spatial Scaling	Resilience
Mean	11.186	38.156
Median	10.00	36.00
Standard Deviation	4.321	7.676
Range	19.00	37.00
Sum	2282.00	7784.00
N	204	204

Table 2 shows that the average scores for spatial scaling and resilience among the participants were 11.186 and 38.156 respectively. The middle score for spatial scaling was 10.00, suggesting that half of the participants scored below 10.00 and half scored above. But the middle score for resilience was 36. The dispersion of the spatial scaling scores from the mean was 4.321 suggests moderate variability in scores and that for resilience score was 7.676 demonstrating higher variability in resilience scores compared to spatial scaling scores. The range which is the difference between lowest and highest scores for both spatial scaling and resilience was 19.00 and

37.00 respectively.

Table 3

Percentage Distribution regarding Spatial Scaling and Resilience towards STEM

Variables	Percentage Distribution	
	Low	**High**
Spatial Scaling	71.6	28.4
Resilience	52.5	47.5

Table 3 provide a detailed overview of the distribution of spatial scaling and resilience scores among secondary students. A significant majority (71.6%) of the participants fall into the low tier of spatial scaling abilities. This indicates that most secondary students in the sample have lower spatial scaling skills. Only 28.4% of the participants are in the high tier for spatial scaling, suggesting that a smaller portion of students exhibit higher spatial scaling abilities. However, the resilience scores were more evenly distributed compared to spatial scaling, with 52.5% of participants in the low tier and 47.5% in the high tier. This indicates a relatively balanced distribution of resilience levels among the students. This variability across grades can be shown by the following charts:

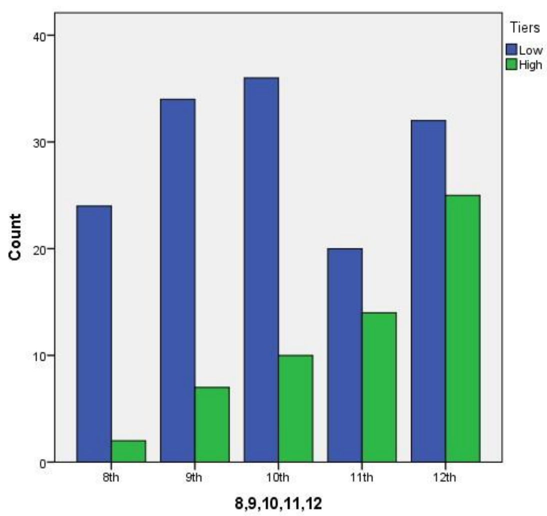

Fig 1. Frequency distribution across different grades for Spatial Scaling STEM

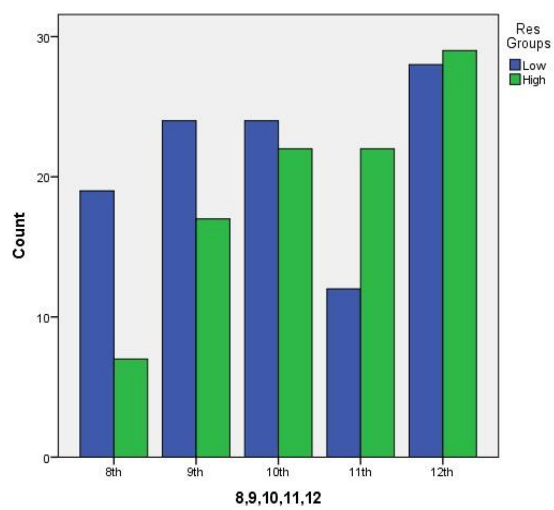

Fig 2. Frequency distribution across different grades for Resilience towards

The bar chart shown above in fig.1 visualizes the count of students with low and high spatial scaling across different grades. While the other bar chart in fig. 2 visualizes the count of students with low and high resilience scores at different grade levels. The chart in fig.1 shows that as students advance in grades, there is a general increase in spatial scaling abilities. Particularly in the 12th grade, there is a significant rise in students with high spatial scaling abilities.

Table 4

Relationship between Spatial Scaling and Resilience towards STEM

Variables		Resilience
Spatial Scaling	Pearson Correlation	0.731**
	Sig. (2 tailed)	0.000
	N	204

The correlation coefficient of r =0.731 which is significant at p< 0.01 indicates a strong positive relationship between resilience and spatial scaling. This means that as spatial scaling abilities increase, resilience also tends to increase among the students. The significance value (pvalue) is 0.000, which is also less than the standard threshold of 0.05. This indicates that the correlation between resilience and spatial scaling is statistically significant. Thus, there is a very low probability that this correlation is due to random chance.

Table 5

Impact of Spatial Scaling on learners' Resilience towards STEM

Regression Weights	Beta Coefficient	R Square	F value	t value	p value
Sp. Scaling —— Resilience	0.731	0.535	232.165	15.237	0.000

Table 5 shows that there is significant impact of spatial scaling on the learners' resilience towards STEM as P< 0.05 at F (1, 202=232.165), which indicates that the resilience towards STEM was significantly regressed over spatial scaling. Moreover, the beta coefficient indicates that for each one-unit increase in spatial scaling, resilience increases by 0.731 units. This positive value signifies a strong and direct relationship between spatial scaling and resilience. The R^2 value of 0.535 indicates that 53.5% of the variability in resilience can be explained by spatial scaling. This suggests that spatial scaling is a significant predictor of resilience, accounting for over half of the variation observed.

DISCUSSION ON FINDINGS

The study comprises diverse groups of students that varies in grade level. The sample distribution across grade levels in the study is well-balanced and adequately representative of secondary education. Diverse grade distribution allows for a comprehensive analysis of how spatial scaling abilities and academic resilience might differ or develop across different stages of secondary education. It also facilitates an examination of whether interventions or improvements in spatial scaling abilities have varying effects depending on the grade level. Studies indicate that spatial abilities, including spatial scaling, are critical for success in STEM education and tend to improve with age and education level (Uttal, Meadow, Tipton, Hand, Alden, Warren, and Newcombe, 2013). The gradual increase in frequency from 8th to 12th grade in the sample might reflect the natural development of these abilities over time. The mean and median scores in the study suggest that the average student has a moderate level of spatial scaling ability which was in line with the findings of Wai, Lubinski, and Benbow, (2009). Higher spatial ability scores are often associated with better performance in subjects like mathematics and science. Research suggests that cognitive skills like spatial scaling can influence a student's resilience by providing them with better problem-solving abilities and confidence in tackling academic challenges (Newcombe, 2010). The high percentage of students with low spatial scaling abilities (71.6%) is consistent with research indicating that spatial skills are often underdeveloped in secondary education. This can be due to a lack of emphasis on spatial reasoning in standard curricula (Uttal et al., 2013). The resilience scores of the study suggest that students generally exhibit a moderate to high level of resilience. The study of Martin and Marsh, (2006) has shown that academic resilience can vary significantly across different grade levels, with older students often developing greater resilience due to increased exposure to academic challenges. The findings of the study indicated strong positive correlation was in line with the study of Newcombe, (2010). These insights align with existing research, emphasizing the importance of spatial abilities in STEM success and the potential benefits of targeted educational interventions to enhance both spatial skills and resilience.

CONCLUSION

Based on the above findings, it was concluded that spatial scaling abilities play a critical role in enhancing academic resilience among secondary students in STEM education. The findings suggest that interventions aimed at improving spatial skills can significantly boost students' resilience, enabling them to better handle the challenges of STEM subjects. Given the strong correlation and significant impact demonstrated by the data, educational strategies focusing on spatial skills development could be highly effective in fostering both cognitive abilities and resilience, ultimately contributing to improved and sustainable academic outcomes in STEM education.

REFERENCES

Alimuddin, H., Trisnowali, A. (2018). Profil kemampuan spasial dalam menyelesaikan masalah geometri siswa yang memiliki kecerdasan logis. *Histogram: Jurnal Pendidikan Matematika, 2*(2), 169-182. http://dx.doi.org/10.31100/histogram.v2i2.238

Atit, K., Power, J. R., Veurink, N., Uttal, D. H., Sorby, S., Panther, G., ... & Carr, M. (2020). Examining the role of spatial skills and mathematics motivation on middle school mathematics achievement. *International Journal of STEM Education,* 7, 1-13. https://doi.org/10.1186/s40594-020-00234-3

Buckley, J., & Seery, N. (2016). Framing spatial cognition: establishing a research agenda. In *70th ASEE Engineering Design Graphics Division Midyear Conference.* ASEE. Frick, A., & Newcombe, N. S. (2012). Getting the big picture: Development of spatial scaling abilities. *Cognitive Development, 27*(3), 270-282. http://dx.doi.org/10.1016/j.cogdev.2012.05.004

Gagnier, K., & Fisher, K. (2016). Spatial thinking: A missing building block in STEM education. *Johns Hopkins Institute for Education Policy,* 01-05. http://jhir.library.jhu.edu/handle/1774.2/63010

Gilligan, K. A. (2020). Make space: the importance of spatial thinking for learning mathematics. *Frontiers for Young Minds, 8*(5). Doi: 10.3389/frym.2020.00050

Gilligan, K. A., Flouri, E., & Farran, E. K. (2017). The contribution of spatial ability to mathematics achievement in middle childhood. *Journal of experimental child psychology, 163*(1), 107-125.

Gilligan-Lee, K. A., Hawes, Z. C., & Mix, K. S. (2022). Spatial thinking as the missing piece in mathematics curricula. *npj Science of Learning, 7*(1), 10.https://doi.org/10.1038/s41539-022-00128-9

Gilligan, K. A., Hodgkiss, A., Thomas, M. S., & Farran, E. K. (2018). The use of discrimination scaling tasks: A novel perspective on the development of spatial scaling in children. *Cognitive Development, 47*(1), 133-145. https://doi.org/10.1016/j.cogdev.2018.04.001

Hall, S. S., McGill, R. M., Puttick, S., & Maltby, J. (2022). Resilience, science, technology, engineering, and mathematics (STEM), and anger: A linguistic inquiry into the psychological processes associated with resilience in secondary school STEM learning. *British Journal of Educational Psychology, 92*(3), 1215-1238. doi: 10.1111/bjep.12496

Hidayati, D. W., & Wahyuni, A. (2020). Correlation of Resilience and Spatial Ability in Distance Material. *Daya Matematis: Jurnal Inovasi Pendidikan Matematika, 8*(2), 149-153.

Hodgkiss, A., Gilligan, K. A., Tolmie, A. K., Thomas, M. S., & Farran, E. K. (2018). Spatial cognition and science achievement: The contribution of intrinsic and extrinsic spatial skills from 7 to 11 years. *British Journal of Educational Psychology, 88*(4), 675-697. https://doi.org/10.1111/bjep.12211

Huttenlocher, J., Newcombe, N., & Vasilyeva, M. (1999). Spatial scaling in young children. *Psychological Science, 10*(5), 393-398.

Huttenlocher, J., Vasilyeva, M., Newcombe, N., & Duffy, S. (2008). Developing symbolic capacity one step at a time. *Cognition, 106*(1), 1-12. Doi: 10.1016/j.cognition.2006.12.006

Ishikawa T., & Newcombe, N.S. (2021). Why spatial is special in education, learning, and everyday activities. *Cognitive Research: Principles and Implications. 6*(1):20. doi: 10.1186/s41235-021-00274-5

Kaur, J., & Singh, B. (2022). Cognitive Ability in Relation to Academic Resilience and Self-Regulation Of School Students in Punjab. DOI: 10.36106/paripex

Liben, L. S., & Downs, R. M. (1994). Fostering geographic literacy from early childhood: The contributions of interdisciplinary research. *Journal of Applied Developmental Psychology, 15*(4), 549-569. https://doi.org/10.1016/0193-3973(94)90022-1

Liben, L. S., & Yekel, C. A. (1996). Preschoolers' understanding of plan and oblique maps: The role of geometric and representational correspondence. *Child Development, 67*(6), 2780-2796. https://doi.org/10.1111/j.1467-8624.1996.tb01888.x

Margulieux, L. E. (2020). Spatial encoding strategy theory: The relationship between spatial skilland STEM achievement. *ACM Inroads, 11*(1), 65-75. https://doi.org/10.1145/3291279.3339414

Martin, A. J., & Marsh, H. W. (2006). Academic resilience and its psychological and educational correlates: A construct validity approach. *Psychology in the Schools, 43*(3), 267-281.DOI: 10.1002/pits.20149

Mohring, W., Frick, A., & Newcombe, N. S. (2018). Spatial scaling, proportional thinking, and numerical understanding in 5-to 7-year-old children. *Cognitive Development, 45*(1), 57-67. https://pdf.sciencedirectassets.com/272077/1-s2.0-S0885201417X00051

Mohring, W., & Szubielska, M. (2023). Scaling up= scaling down? Children's spatial scaling in different perceptual modalities and scaling directions. *Cognitive Research: Principles and Implications, 8*(1), 62. DOI: 10.1186/s41235-023-00517-7

Newcombe, N. S. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American educator, 34*(2), 29-43. https://www.researchgate.net/publication/285731029

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R., & Richardson, C. (1995). Are drawn Vandenberg and Kuse mental rotations test-different versions and factors that affect performance. *Brain and cognition, 28*(1), 39-58.

Piaget, J., & Inhelder, B. (1956). The child's conception of space (F. J. Langdon, & J. L. Lunzer, Trans.). London: Routledge and Kegan Paul. (Original work published 1948).

Piaget, J., & Inhelder, B. (1975). The origin of the idea of chance in children. New York: Norton.(Original work published in 1951)

Ricketts, S. N., Engelhard Jr, G., & Chang, M. L. (2015). Development and validation of a scale to measure academic resilience in mathematics. *European Journal of Psychological Assessment.* DOI: 10.1027/1015-5759/a000274

Szubielska, M., Szewczyk, M., Augustynowicz, P., Kedziora, W., & Mohring, W. (2023). Effects of scaling direction on adults' spatial scaling in different perceptual domains. *Scientific Reports, 13*(1), 14690. https://doi.org/10.1038/s41598-023-41533-3

Szubielska, M., Szewczyk, M., & Mohring, W. (2022). Adults' spatial scaling from memory: Comparing the visual and haptic domain. *Memory & Cognition, 50*(6), 1201-1214. https://doi.org/10.3758/s13421-022-01327-w

Uttal, D. H. (2000). Seeing the big picture: Map use and the development of spatial cognition.*Developmental Science, 3*(3), 247-264. https://doi.org/10.1111/1467-7687.00119

Uttal, D. H., & Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how?

In *Psychology of learning and motivation* (Vol. 57, pp. 147-181). Academic Press. https://doi.org/10.1016/B978-0-12-394293-7.00004-2

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N.S. (2013). The malleability of spatial skills: a meta-analysis of training studies. *Psychological bulletin, 139*(2), 352. DOI: 10.1037/a0028446

Vasilyeva, M., & Huttenlocher, J. (2004). Early development of scaling ability. *Developmental Psychology, 40*(5), 682. DOI: 10.1037/0012-1649.40.5.682

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of educational Psychology, 101*(4), 817-835. DOI: 10.1037/a0016127

Yılmaz, H. B. (2009). On the development and measurement of spatial ability. *International Electronic Journal of Elementary Education, 1*(2), 83-96.

Young, C. J., Levine, S. C., & Mix, K. S. (2018). The connection between spatial and mathematical ability across development. *Frontiers in psychology, 9*(1), 755. DOI: 10.3389/fpsyg.2018.00755

Zhu, C., Leung, C. O. Y., Lagoudaki, E., Velho, M., Segura-Caballero, N., Jolles, D., Duffy, G., Maresch, G., Pagkratidou, M., & Klapwijk, R. (2023). Fostering spatial ability development in and for authentic STEM learning. *Frontiers in Education* (Vol. 8, p. 1138607). Frontiers Media SA. https://doi.org/10.3389/feduc.2023.1138607