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Teachers' Conceptualisations of Spatial Ability & Implications for STEM

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Abstract

Spatial ability is a key component of STEM education, shaping how learners visualise, manipulate, and reason about objects and relationships. Despite its importance, little is known about how teachers conceptualise spatial ability and how these beliefs influence classroom practices. This study investigates Irish post-primary teachers' conceptualisations of spatial competency, using online card-sorting and spatial self-efficacy tasks. In the card-sorting task, participants classified everyday activities, such as parallel parking, assembling flat-pack furniture, and taking notes, as 'spatial', 'somewhat spatial', or 'not spatial'. The self-efficacy task assessed confidence in performing spatially demanding activities, including puzzles, map reading, and interpreting working drawings. Results indicate that disciplinary background strongly shaped conceptualisations: Engineering and Graphics teachers consistently rated multiple tasks as fully spatial, while Mathematics, Science, Technology, and Materials Technology Wood teachers applied more distributed classifications. Biology and Physical Education teachers used the full range of categories, suggesting flexible understanding. Across disciplines, subtle or traditionally gendered tasks were often under-recognised as spatial, reflecting implicit norms. These findings highlight that teachers' spatial epistemologies are influenced by disciplinary culture and task experience, potentially affecting which skills are emphasised and how students develop spatially. The study underscores the need to broaden teachers' conceptualisations of spatial ability and integrate its development intentionally across STEM curricula.

Key Words: Spatial Ability, Conceptualisations, STEM, Gender, Student Engagement

1 INTRODUCTION

This study seeks to explore the multifaceted nature of spatial ability as understood by practicing Irish second-level teachers engaged in science, technology, engineering and mathematics (STEM) education. While spatial ability is particularly prominent within Technology Education, the study intentionally adopts a broader STEM perspective in order to explore the nature and meanings of spatial ability across multiple disciplinary contexts, rather than limiting it to a single subject

domain. By capturing teachers' understandings of what they perceive spatial ability to be, the study develops a picture of how spatial self-concept relates to educational experiences and professional identity. Including teachers from across STEM disciplines also supports a broader exploration of how spatial ability is conceptualised across subject areas, providing a richer contextual lens for considering its role within Technology Education. Given that spatial ability is malleable (Sorby 2009; Uttal et al. 2013), and that it provides a foundational knowledge for learners' engagement with design, modelling, and technological problem-solving in technology education (Lin *et al.* 2025), deeper insight into this construct is essential for strengthening teaching and learning. This study therefore focuses on four research questions:

(i) How do teachers conceptualise spatial ability?
(ii) How do gender, age and disciplinary background affect these conceptualisations?
(iii) How do these conceptualisations relate to their own spatial self-efficacy?
(iv) Where are the conceptual gaps between cognitive science models of spatial ability and teacher's conceptualisations?

2 LITERATURE REVIEW

2.1 Teachers' Conceptualisations and Spatial Self-Efficacy

Teachers' conceptualisations of spatial ability shape how they interpret spatially demanding tasks, how they support students' spatial reasoning, and the extent to which they recognise spatial thinking as part of everyday learning. These conceptualisations are influenced by a combination of self-beliefs, affective responses, task interpretations, and professional experience (Gagnier *et al.* 2022). A central factor is spatial self-efficacy, defined as an individual's belief in their ability to successfully perform spatial tasks (Ramful *et al.* 2017). Teachers with higher spatial self-efficacy tend to conceptualise spatial ability as accessible and teachable, leading them to incorporate spatial tools, visual representations, and spatial reasoning activities more readily (Gagnier *et al.* 2022). In contrast, lower spatial self-efficacy may lead teachers to view spatial reasoning as specialised or inherently difficult, reducing their use of spatial pedagogy. Burte *et al.* (2020) demonstrated that teachers differentiate tasks according to whether spatial thinking is required, optional, or negligible for solution. Teachers who believe they possess strong spatial skills are more likely to view spatial ability as malleable and relevant across grade levels. Experience and exposure also play important roles. Gagnier *et al.* (2022) found that many teachers perceive spatial skills as more important for older students; however, teachers with more years of experience tend to view spatial thinking as important across all year levels, including the early years.

Teacher-led spatial interventions have shown that when teachers engage with structured spatial tasks, they begin to treat spatial reasoning as a routine component of mathematical thinking rather than an isolated skill (Lowrie & Logan 2023). Gender, disciplinary background, and previous experiences have also been associated with differences in spatial performance and spatial self-efficacy (Linn & Petersen 1985; Reilly *et al.* 2017). However, studies examining how teachers'

self-efficacy beliefs relate to their conceptualisations of spatial ability remain limited. Understanding this relationship is essential, as self-efficacy may guide how teachers notice, value, and respond to spatial thinking in students.

2.2 Cognitive Science Models of Spatial Ability

Contemporary research conceptualises spatial ability as a family of related but distinct cognitive processes rather than a single unified skill. One of the most influential models is the 2x2 classification scheme proposed by Uttal *et al.* (2013) and Newcombe & Shipley (2015), which characterises spatial thinking along two dimensions: whether the spatial information concerns properties of a single object, or relationships among multiple objects, and whether that information is static or changing over time. Table 1 illustrates this typology using an everyday example involving a coffee mug.

Table 1

Everyday example of the 2x2 classification scheme

Intrinsic Static	Recognising the shape and features of the mug from your current viewpoint without imagining any rotation or change.
Intrinsic Dynamic	Mentally transforming the mug, such as rotating it in your mind or imagining a cross-section to see its internal structure.
Extrinsic Static	Knowing where the mug is in relation to other objects on the desk, such as to the right of your laptop, without any movement or perspective change.
Extrinsic Dynamic	Appreciating the position of the mug relative to other objects when perspectives change, either by actually moving around the desk or by imagining yourself moving and shifting viewpoint.

These four categories highlight the diversity of spatial processes and underscore the fact that individuals often demonstrate different strengths across task types (Newcombe & Shipley, 2015). However, research shows that educators frequently conceptualise spatial ability more narrowly, often equating it primarily with mental rotation or visualisation (Hegarty & Waller 2005).

3 METHODOLOGY

In September 2025, an online survey was conducted for which ethical approval was obtained from the University of Limerick, School of Engineering Ethics Committee under the reference number 2025_07_02_S&E. The project explores how Irish post-primary STEM teachers perceive and define spatial ability. The sample included 35 teachers (20 male, 14 female, 1 non-binary) aged 21 to 54 , with a mean age of ≈ 35.1 and median age of ≈ 30. They taught subjects such as Science, Technology, Engineering, Mathematics, Materials Technology Wood (MTW), Construction

Studies, Design and Communication Graphics (DCG), Graphics, Biology, and Physical Education (PE). The survey comprised two core items along with demographic questions regarding age and subject area.

Firstly, a *card sorting* task, originally introduced by Hulin and Katz (1935), was employed in this study to investigate how participants naturally organise spatial tasks. In this method, individuals group cards containing terms, images, or scenarios in ways that make sense to them (Chen *et al.* 2020). They were not provided with any formal framework (e.g., 2 X 2 classification (Uttal *et al.* 2013)) to guide their decisions and instead relied on their own interpretations of what constitutes a spatial task. Following Miller's working memory framework (1956), which suggests individuals can effectively process around seven items at once, the study used seven cards to avoid cognitive overload. Each card described a scenario representing one of the four categories of spatial ability (Uttal *et al.* 2013; Newcombe & Shipley, 2015). For example, packing a suitcase neatly and assembling flat-pack furniture both involve *intrinsic* spatial processing, meaning the focus is on the relationships between parts of the same object or set of objects. However, 'packing a suitcase neatly' is *intrinsic static* because it mainly requires organising items based on their size and shape without mentally transforming them. In contrast, assembling flat-pack furniture is *intrinsic dynamic* because it requires mentally rotating and manipulating parts to understand how they fit together during construction.

- Choosing a photo to post online *(Intrinsic Static)*
- Packing a suitcase neatly *(Intrinsic Static)*
- Assembling flat-pack furniture *(Intrinsic Dynamic)*
- Taking notes during a lecture *(Intrinsic Dynamic)*
- Putting on makeup or moisturiser *(Intrinsic Dynamic)*
- Parallel parking a car *(Extrinsic Dynamic)*
- Navigating a crowded space *(Extrinsic Dynamic)*

Although all participants received the same scenarios, their order was randomised. Participants then sorted the cards into categories such as "very spatial," "somewhat spatial," and "not spatial," allowing the study to capture how individuals perceive the spatial demands of everyday activities and how they personally conceptualise spatial ability. The card-sorting task was not analysed using internal consistency statistics, as it is an exploratory categorisation method rather than a psychometric scale. Instead, its construct validity was supported by its grounding in the spatial ability framework proposed by Uttal *et al.* (2013) and Newcombe & Shipley (2015). Reliability was assessed through patterns of agreement in participants' sorting decisions. The *spatial self-efficacy scale*, adapted from the work of Arıkan & Çetin, (2024) (Cronbach's $\alpha = 0.77$) was used secondly, to assess participants' confidence in completing tasks involving spatial skills (e.g., puzzles, map reading, interpreting working drawings). Responses ranged from "I certainly cannot" to "I certainly can". The scale also aligns with the same spatial ability framework that informed the card-sorting task (Uttal *et al.* 2013) ensuring conceptual coherence across both measures. Items were randomised and presented without explicit reference to spatial ability. As an additional procedural control, the items were randomised individually for each participant, and no two items belonging to the same spatial category appeared consecutively. The items used in this task are listed in Table 2.

Table 2

The spatial self-efficacy scale adapted from Arıkan & Çetin (2024)

	Spatial Self-Efficacy Scale	I certainly cannot	I cannot	I can	I certainly can
Intrinsic Static	I can spot the difference between two photos of the same object.				
	I can distinguish between shapes such as triangle, square, hexagon, prism, cube, sphere and trapezoid.				
	I can classify objects according to their geometric shapes.				
	I can sort objects of similar sizes from large to small.				
Intrinsic Dynamic	I can make models out of paper, such as ships and aeroplanes.				
	I can mentally visualise a three-dimensional object rotated 90° to the right (e.g., a pyramid, pencil case, etc.).				
	I can mentally visualise how to assemble a toy divided into five parts.				
	When two holes are punched in different places on a symmetrically folded piece of paper, I can accurately predict where the holes will be located on the paper once it is opened.				
	I can accurately predict which surfaces will face each other when a cardboard box with surfaces numbered is folded.				
Extrinsic Static	I can read a map by looking at the legend.				
	I can calculate the difference between the local time of two different locations marked on a map.				
	I can draw a political map showing the borders of my country.				
Extrinsic Dynamic	When I sit in the front row of the classroom, I can mentally visualise how someone sitting in the back row sees the teacher's desk.				
	After a short walk in a building (e.g., a shopping centre, hospital etc.) that I am visiting for the first time, I can mentally visualise in detail what is located where in that building.				
	Once I have asked for an address, I can keep the location described to me in mind until I reach my destination.				
	I can get to a place that I am visiting for the first time by walking with the help of a navigation application on my phone.				

4 RESULTS & DISCUSSION

4.1 Data Analysis

Responses from the card-sorting task were converted into numerical scores (0 = NOT SPATIAL, 1 = SOMEWHAT SPATIAL, and 2 = IS SPATIAL), allowing mean scores (M) to be calculated. A mean of higher value indicated stronger perceived spatial demand. Activities were then ranked, and descriptive subgroup analyses were conducted for gender, age, and disciplinary backgrounds.

Spatial self-efficacy responses were scored on a 0 to 3 scale, with higher values indicating greater confidence (0 = I certainly cannot, 1 = I cannot, 2 = I can, 3 = I certainly can). Means (M), medians and standard deviations were computed for each of the 16 items.

4.2 Card Sorting

Participants showed clear and consistent differences in how they classified the spatial demands of the seven everyday activities. Tasks that required moving through space or manipulating physical objects were overwhelmingly viewed as spatial. In particular, *parallel parking a car* (M = 1.91) *assembling flat-pack furniture* (M = 1.83), *packing a suitcase neatly* (M = 1.80) and *navigating a crowded space* (M = 1.77) were each classified as "IS SPATIAL" by the majority of participants. In contrast, activities that centred on visual judgement or cognitive organisation rather than physical interaction were typically viewed as non-spatial. *Choosing a photo to post online* (M = 0.40) or *taking notes during a lecture* (M = 0.49) were most often classified as "NOT SPATIAL". One activity, *putting on makeup or moisturiser* (M = 1.09), consistently fell between these two extremes. Participants frequently placed it in the "SOMEWHAT SPATIAL" category, suggesting that while the task requires hand-face coordination and some awareness of spatial positioning, it does not demand substantial spatial planning or three-dimensional manipulation.

The median classification score across all activities was 1.77, closely aligning with the cluster of higher-scoring activities, reinforcing that participants' default interpretation of *spatial* emphasised bodily movement, object manipulation, and navigation in physical environments. At the same time, the substantial gap between the lowest (0.40) and highest (1.91) mean ratings demonstrates clear differentiation in how participants conceptualised spatial demands. The intermediate classification of makeup application further suggests that participants recognised gradations of spatial effort rather than treating spatiality as a binary distinction.

Overall, the pattern of responses demonstrates that participants intuitively organised the activities along a spatial continuum. 'Strong' spatial tasks involved physical movement or manual handling, whereas 'weak' tasks relied more on visual preference or symbolic processing, and 'intermediate' tasks sat between these poles. The median value provides additional support for this continuum, showing that most activities were judged to involve at least some spatial thinking, even if the nature and intensity of those demands varied.

4.3 Spatial Self-Efficacy

Spatial self-efficacy was generally moderate to high, with scores ranging from 1.89 to 2.86. The strongest self-efficacy appeared in sorting objects by size (M = 2.86), navigating with a phone application (M = 2.86) and identifying geometric shapes (M = 2.83). These reflect strong confidence in perceptual and everyday navigation skills. The lowest self-efficacy was observed in map-based analytical tasks, including calculating time differences between locations (M = 1.89), retaining multi-step directions (M = 1.94), calculating distances on maps (M = 2.06). These tasks require spatial computation and topographic reasoning, for which participants reported lower confidence.

Standard deviations (0.35 - 0.90) indicated moderate variability, with greater disagreement for items involving mental transformation and map interpretation. The median self-efficacy score across all items was 2.34, indicating that the typical response fell within the moderate confidence range. Overall, confidence was higher for perceptual and navigation tasks than for abstract map-based tasks.

4.4 Cross Task Alignment

A clear conceptual mismatch emerged between what teachers *classify* as spatial and what they feel *confident* performing. Teachers rated their highest self-efficacy in perceptual tasks (e.g., distinguishing shapes), yet they tended not to classify parallel perceptual tasks (e.g., choosing photos, note layout) as spatial. Conversely, they strongly classified embodied, movement-based tasks as spatial, despite these being largely absent from the self-efficacy measure. These observations are based on descriptive analyses only; no statistical correlations between the card-sorting and self-efficacy measures were conducted.

Overall, teachers appear to hold a narrow, action-centred conception of spatial ability, emphasising physical manipulation while under-recognising cognitive, analytic, and visual-spatial skills that research identifies as critical for STEM learning (Wai *et al.* 2009).

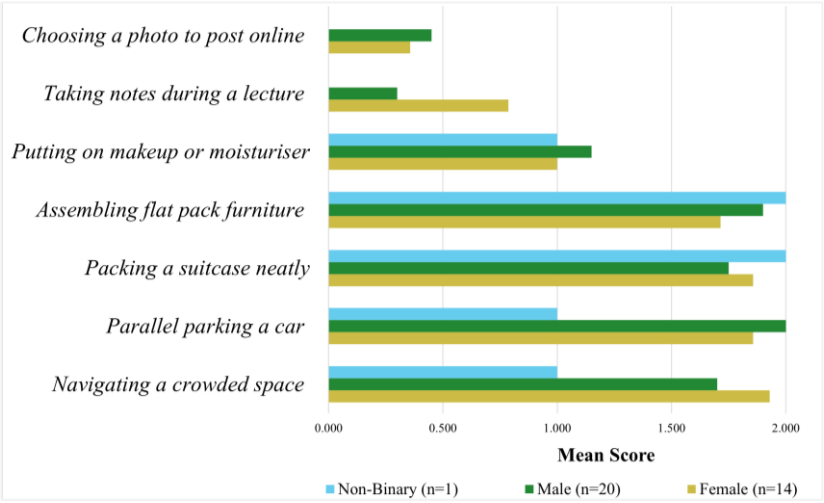
4.5 Gender, Age and Disciplinary Background

Patterns were broadly similar across genders, with all groups consistently classifying tasks involving physical movement or object manipulation as spatial, and perceptual or organisational tasks as non-spatial. Across the full sample (N = 35), parallel parking (M = 1.91), assembling flat-pack furniture (M = 1.83), packing a suitcase (M = 1.80), and navigating a crowded space (M = 1.77) were overwhelmingly rated as “IS SPATIAL”. In contrast, choosing a photo to post online (M = 0.40) and taking notes during a lecture (M = 0.49) were consistently classified as non-spatial. Modest gender-based differences reflected underlying conceptualisations of spatial ability. Male teachers (N = 20) rated object-based tasks most strongly, classifying parallel parking unanimously as spatial (M = 2.00) and assembling furniture highly (M = 1.90). Female teachers (N = 14) more readily identified socially embedded coordination tasks as spatial, with navigating a crowded space receiving their highest rating (M = 1.93) and showed greater recognition of

makeup/moisturiser application as spatial (M = 1.00). The non-binary participant's classifications aligned with these overall trends.

Figure 1

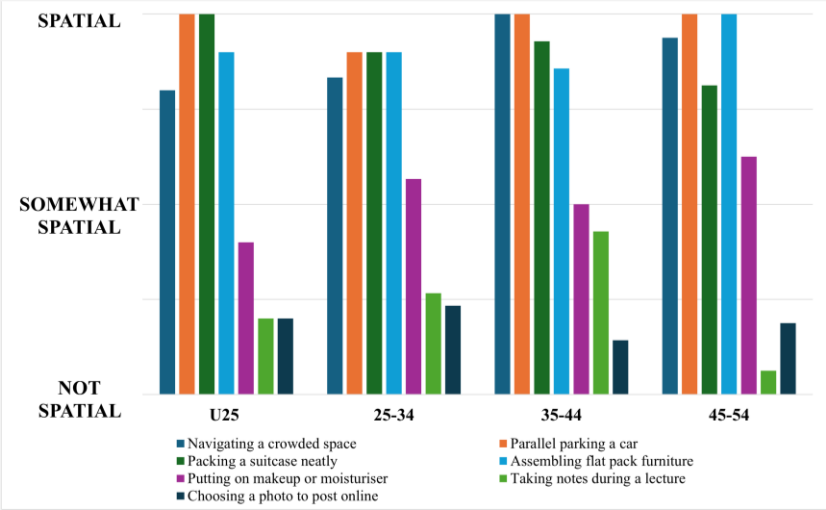
Card Sorting results organised by gender.



Descriptive analysis suggested potential age-related differences in spatial task ratings. Older teachers (35–54) made more categorical judgements, frequently assigning maximum spatial ratings to high-demand tasks (e.g. parallel parking, M = 2.00), whereas younger teachers (<25) relied more on the "SOMEWHAT SPATIAL" category, particularly for hybrid tasks.

Figure 2

Card Sorting results organised by age.

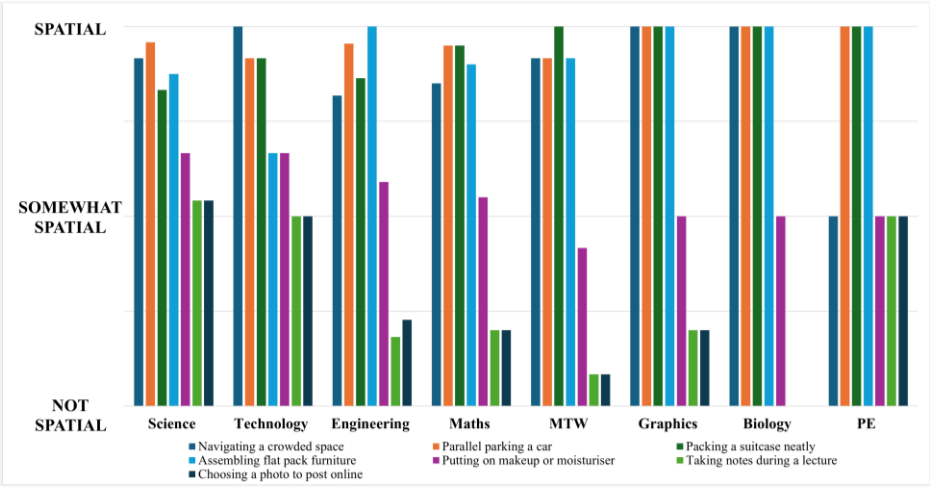


Disciplinary background exerted the most pronounced influence. Engineering and DCG/Graphics teachers rated multiple tasks as fully spatial (means frequently = 2.00), whereas mathematics, science, technology, and MTW teachers showed more distributed classifications. Biology and physical education teachers used the full range of categories, indicating more flexible spatial schemas.

However, given the relatively small sample size (N = 35), subgroup differences should be interpreted cautiously, as some variation may reflect sampling variability rather than meaningful differences.

Figure 3

Card Sorting results organised by discipline.



4.6 Perceived Gaps Between Research & Practice

A limitation of the card-sorting method used in this study is that categorising cards into only three groups may have constrained participants' ability to fully express the reasoning behind their choices. This approach offers limited insight into *why* teachers associated particular tasks with spatial ability, potentially oversimplifying complex conceptual understandings. Teachers in this study primarily associated spatial ability with overt physical movement and object manipulation. As a result, cognitive and analytic aspects of spatial reasoning received limited recognition. Tasks strongly linked to STEM achievement, such as visual comparison, map reasoning, and mental transformation, were rarely identified as spatial in the card-sorting task. These findings suggest a gap between research-based conceptualisations of abstract spatial skills and classroom recognition, highlighting the value of future interviews or qualitative methods to explore teachers' underlying reasoning and conceptual frameworks more deeply.

4.7 Implications for Practice

The results of this study suggest that teachers' understandings of spatial ability privilege physical manipulation and navigation, while abstract spatial processes such as visualisation, map reasoning, and diagram interpretation are less consistently recognised. Subtle differences related to gender, age, and disciplinary background further indicate that implicit norms shape which spatial skills are acknowledged in practice. These patterns have important implications for technology education. When abstract spatial demands are not explicitly identified, instruction

may place disproportionate emphasis on hands-on activities, limiting students' opportunities to develop representational and analytic spatial skills that are central to technological problem solving and STEM learning more broadly. Strengthening teacher education and curriculum design to broaden conceptions of spatial ability, and integrate perceptual, cognitive and representational spatial skills, can support more balanced learning opportunities and help ensure that diverse forms of spatial competence are recognised and valued.

5 CONCLUSION

This study shows that teachers tend to view spatial ability in terms of physical manipulation and navigation, while abstract skills such as map reasoning, diagram interpretation, and aspects of visualisation are less consistently recognised. Elements of mental rotation and other perceptual skills are generally acknowledged but not considered as central as embodied tasks. These conceptualisations, influenced by gender, age, and disciplinary background, create a mismatch between what teachers perceive as spatial and the skills they feel confident using. Including teachers from across STEM disciplines highlights how spatial ability is understood differently across subject areas, revealing diverse perspectives that can inform teaching practices. These differences have important implications for STEM education, as without recognition of abstract spatial skills, students may have limited opportunities to develop the full range of abilities critical for success. Enhancing teacher education and curriculum design by emphasising the multi-dimensional nature of spatial competency, integrating representational and abstract tasks, and using validated spatial activities that explicitly make students aware of the skills they are applying can help address these gaps. This approach fosters more diverse and effective learning experiences, supporting the development of spatial competency across all STEM disciplines.

6 DISCLOSURE STATEMENT

The title of this paper was generated with the assistance of ChatGPT. All other content is original and created without AI assistance.

7 REFERENCES

Arıkan, A. and Çetin, T. (2024) 'Psychometric properties of the spatial skills self-efficacy scale: A validity and reliability study', *Thinking Skills and Creativity*, 52, 101555, available: https://doi.org/10.1016/j.tsc.2024.101555.

Burte, H., Gardony, A.L., Hutton, A., and Taylor, H.A. (2020) 'Elementary teachers' attitudes and beliefs about spatial thinking and mathematics', *Cognitive Research: Principles and Implications*, 5(1), 17, available: https://doi.org/10.1186/s41235-020-00221-w.

Chen, D.A., Hoople, G.D., Ledwith, N., Burlingame, E., Bush, S.D., and Scott, G.E. (2020) 'Exploring Faculty and Student Frameworks for Engineering Knowledge Using an Online Card Sorting Platform.', *Int. J. Eng. Pedagog.*, 10(1), 62–81, available: https://www.academia.edu/download/88982070/6403.pdf [accessed 22 May 2025].

Gagnier, K.M., Holochwost, S.J., and Fisher, K.R. (2022) 'Spatial thinking in science, technology, engineering, and mathematics: Elementary teachers' beliefs, perceptions, and self-efficacy', *Journal of Research in Science Teaching*, 59(1), 95–126, available: https://doi.org/10.1002/tea.21722.

Hegarty, M. and Waller, D.A. (2005) 'Individual Differences in Spatial Abilities', in *The Cambridge Handbook of Visuospatial Thinking*, New York, NY, US: Cambridge University Press, 121–169, available: https://doi.org/10.1017/CBO9780511610448.005.

Hulin, W.S. and Katz, D. (1935) 'The Frois-Wittmann pictures of facial expression', *Journal of Experimental Psychology*, 18(4), 482–498, available: https://doi.org/10.1037/h0056770.

Lin, T.J., Buckley, J., Gumaelius, L., and Ampadu, E. (2025) 'The potential for spatial ability development through the Swedish technology and craft compulsory curricula', *International Journal of Technology and Design Education*, 35(4), 1409–1427, available: https://doi.org/10.1007/s10798-024-09958-7.

Linn, M.C. and Petersen, A.C. (1985) 'Emergence and characterization of sex differences in spatial ability: A meta-analysis', *Child Development*, 56(6), 1479–1498, available: https://doi.org/10.2307/1130467.

Lowrie, T. and Logan, T. (2023) 'Spatial Visualization Supports Students' Math: Mechanisms for Spatial Transfer', *Journal of Intelligence*, 11(6), 127, available: https://doi.org/10.3390/jintelligence11060127.

Miller, G.A. (1956) 'The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information[1]', *Psychological Review*, 63, 81–97.

Newcombe, N. and Shipley, T. (2015) 'Thinking About Spatial Thinking: New Typology, New Assessments', available: https://doi.org/10.1007/978-94-017-9297-4_10.

Ramful, A., Lowrie, T., and 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, available: https://doi.org/10.1177/0734282916659207.

Reilly, D., Neumann, D.L., and Andrews, G. (2017) 'Gender Differences in Spatial Ability: Implications for STEM Education and Approaches to Reducing the Gender Gap for Parents and Educators', in Khine, M.S., ed., *Visual-Spatial Ability in STEM Education: Transforming Research into Practice*, Cham: Springer International Publishing, 195–224, available: https://doi.org/10.1007/978-3-319-44385-0_10.

Uttal, D.H., Meadow, N.G., Tipton, E., Hand, L.L., Alden, A.R., Warren, C., and Newcombe, N.S. (2013) 'The Malleability of Spatial Skills: A Meta-Analysis of Training Studies', *Psychological Bulletin*, 139(2), 352–402, available: https://doi.org/10.1037/a0028446.

Wai, J., Lubinski, D., and 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, available: https://doi.org/10.1037/a0016127.