A Systematic Review of Spatial Visualization Research Using The Purdue Spatial Visualization Tests: Visualization of Views

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Abstract

Spatial ability is essential across science, technology, engineering, mathematics, and medicine (STEMM) disciplines. The Purdue Spatial Visualization Tests: Visualization of Views (PSVT:V) is designed to distinctly measure an individual's ability to mentally visualize three-dimensional objects from multiple perspectives. Since its creation, the test has been frequently employed in engineering and educational contexts. However, little research has clarified how it compares to other spatial measurements or how differing interventions influence its outcomes. A structured review was conducted of 59 empirical studies published between 1976 and 2025 that employed the PSVT:V to measure the specific spatial visualization skill. The findings revealed strong convergence between PSVT:V scores and other spatial assessments, such as the Perspective Taking Ability Test, even though each targets specific subskills and cognitive processes. Instructional approaches that incorporated integrated curriculum-based training, digital visualization tools, physical modeling activities, or hybrid methods consistently improved the PSVT:V scores. However, the retention and long-term sustainability of these gains were rarely evaluated. Few studies included longitudinal follow-ups, leaving gaps in understanding the durability of spatial skill development beyond immediate post-instructional testing.

1. Introduction

"It is generally agreed that spatial ability is an important component of intellectual ability, yet its nature remains to be clarified" [1]. Nearly four decades later, this observation remains a strikingly familiar theme in the fields of science, technology, engineering, mathematics, and medicine (STEMM) and research. More broadly, spatial ability relates to an individual's ability to interact with and interpret their environment [2]. More closely, spatial ability encompasses a range of distinct but interrelated domains and sub-skills that comprise a significant component of our intellect, with many of these abilities being crucially involved in essential skills required for STEMM-related learning and performance.

Indeed, spatial ability is rather an umbrella term than a singular construct and can thus be further categorized into several unique but related processes, including spatial perception, mental rotation, and spatial visualization. All are particularly relevant, with prior spatial ability research typically focusing on and magnifying one sub-domain. Although these domains are all integral, spatial visualization, which was defined by McGee [3] as involving "the ability to mentally rotate, manipulate, and twist two- and three-dimensional stimulus objects" (p.188), can be emphasized explicitly for its involvement in skills, such as diagram interpretation, solving complex spatial problems, and designing structures in the engineering field. Uttal et al. [4] also stated that spatial visualization is the specific ability to imagine and mentally transform spatial information, as it involves the ability to mentally manipulate and transform spatial representations, which is also critical for tasks, such as interpreting orthographic projections and technical diagrams [5]. For example, when assembling a new furniture piece, one must mentally integrate two-dimensional (2D) directions and images into three-dimensional (3D) mental models. These connections help the builder to visualize and understand how parts fit together or predict the final image from a new angle.

Research on these unique cognitive processes has led to the development of several separate psychometric tools, each targeting specific domains of spatial ability to not only support educational interventions but also to identify interconnections with other spatial skills. Among these, the Purdue Spatial Visualization Tests: Visualization of Views (PSVT:V) [6] emerged as a specifically designed assessment to measure a spatial visualization skill from different perspectives. Despite the amount of time passed since its creation and frequent use, there has been little systematic analysis of how the PSVT:V is used across studies, how it compares to other psychometric spatial assessments, and the kinds of demographic factors that shape not only PSVT:V scores but total success outcomes in academics and beyond. This systematic review aims to address the identified gaps in information and connections between spatial visualization and the PSVT:V.

1.1 Purpose of the Study

The purpose of this systematic review is to synthesize and evaluate the body of research that has specifically employed the PSVT:V. By systematically examining studies across educational, psychological, and engineering contexts, this work aims to clarify how the PSVT:V has been used to measure spatial visualization ability as well as the instructional approaches associated with its use. Instructional approaches refer to structured pedagogical methods implemented within educational or professional learning contexts to influence spatial visualization outcomes. This review also aims to identify patterns and or gaps in reporting, as well as provide direction for future research. Two overarching research questions guided this review:

1. What patterns of convergence or divergence are observed between the PSVT:V and other measures of spatial skills?
2. Which types of instructional approaches produce the most substantial improvements in PSVT:V scores?

2. Theoretical Framework

Throughout the literature, many researchers have originated concepts, such as “spatial visualization,” “visuospatial ability,” and “visualization” with varying levels of precision, even if there are also implied nuance differences. Although researchers often note that these terms can be used interchangeably [2], spatial visualization is most frequently treated as a distinct and measurable subskill within broader models of spatial ability, warranting the need for exploration in both research and instructional contexts.

There are also, however, further distinctions in the categorization of spatial visualization and its sub-domains within broader models of spatial ability across the literature. McGee [3] originally proposed a two-component model of spatial ability that included a distinction between spatial visualization and spatial orientation. This two-factor model is also noted in Uygan and Kurtuluş [7], for example, where researchers emphasized that spatial orientation involves imagining one's own bodily movement in space, while spatial visualization requires complex, multistep mental operations. This particular distinction reinforces the notion that spatial visualization operates as a standalone cognitive skill, central to many other spatial reasoning domains [2]. While some other models, such as Linn and Petersen's [1] three-factor framework, differentiate between spatial visualization, mental rotation, and spatial perception. Even with differing classification systems, with some either viewing spatial visualization as one component among many or others as a coequal cognitive dimension, it can be noted that spatial visualization appears as a unique core skill with a need for complex transformations, making it deviate from the more perspective or rapid based processes based in mental rotation or orientation [3], [7], [8]. This difference must be acknowledged as imperative for researchers involved in refining measurements and findings, even as the conversation continues about the exact organization of spatial ability and its related domains.

At its core, spatial visualization can be further defined as an individual's ability to mentally visualize and interpret how a 3D object appears from various vantage points, such as the front, side, top, or other oblique angles. For example, this includes imagining what the back or side of an object would look like based on its front view. Spatial visualization encompasses other skills, such as reconfiguring, folding, unfolding, or visualizing the structural changes of an object without physical manipulation [2], [3], [9]. Many scholars agree that spatial visualization is a distinct domain of spatial ability, requiring skills such as mental manipulation, imagery, and transformational thought [2], [3], [10].

Table 1 summarizes some of the core spatial abilities commonly assessed in the literature, including spatial visualization, mental rotation, and perspective taking. The original Purdue Spatial Visualization Test (PSVT) was originally developed in 1976 as a three-part battery consisting of three sub-assessments, including the Visualization of Views (PSVT:V), Visualization of Rotations (PSVT:R), and Visualization of Developments (PSVT:D), which were collectively designed to assess multiple dimensions of spatial visualization. Because the larger PSVT battery spans across these several spatial constructs, clarifying how the PSVT:V relates to these broader dimensions is thus particularly important for interpreting its role relative to other spatial assessments. Definitions were synthesized from foundational theoretical and review literature to provide a stable conceptual framework. Although spatial abilities are often discussed as a unified construct, prior work consistently emphasizes distinctions between object-based and viewpoint-based transformations, which are central to interpreting PSVT:V outcomes in this review.

Table 1. Definitions of Spatial Skills Relevant to the Present Review

Spatial Skill	Synthesized Definition	Type of Cognitive Transformation	Measures	Key Theoretical Sources
Perspective-Taking / Viewpoint-Based	The ability to mentally imagine how a fixed object or spatial environment would appear when the observer changes position or viewpoint, without manipulation of the object itself. This ability relies on egocentric transformations, where the observer's frame of reference is updated while the object remains stationary. Spatial visualization is central to the interpretation of important STEMM concepts, such as technical drawings or multiple-view representations.	Viewpoint transformation (observer movement)	PSVT:V, PTAT	[11], [12], [13]
Mental Rotation	The ability to mentally rotate objects in 3D space while maintaining a fixed observer viewpoint. Tasks evaluating mental rotation require individuals to imagine objects being turned on one or more axes and to then determine	Object-based rotation	CCT, MRT, PSVT:R	[14], [15], [16], [17]

	equivalence across orientations. This ability emphasizes object manipulation rather than changes in perspective.			
Spatial Orientation	The ability to understand, maintain, and reason about the orientation of objects or scenes relative to a stable reference frame, such as identifying which edge or direction corresponds to a given viewpoint. This skill supports navigation, alignment, and interpretation of spatial layouts without needing full mental rotation or perspective shifts.	Orientation relative to the reference frame	SOT	[18], [19]
Spatial Relations: Mental folding	The ability to mentally transform 2D representations into 3D forms by visualizing how surfaces fold, bend, or connect along shared edges. Mental folding requires reasoning about the spatial relationships between faces of an object and predicting the resulting three-dimensional structure without physical manipulation. This skill emphasizes object-based spatial relations rather than changes in observer perspective.	Object-based transformation (surface folding and face adjacency)	DAT:R, PFT, PSVT:D	[1], [3], [20]
Spatial Relations: Mental Cutting	The ability to mentally visualize changes to the *internal* structure of an object, such as imagining the shape of a cross-section produced by a cutting plane. This ability requires coordinated object-based transformations and internal visualization rather than observer movement and is particularly relevant for the interpretation of engineering-based schematics.	Internal object transformation	MCT; SBST	[3], [5], [21]

Note. CCT = Cube Comparison Test; DAT:R = Differential Aptitude Test: Relations; MCT = Mental Cutting Test; MRT = Mental Rotation Test; PFT = Paper Folding test; PSVT = Purdue Spatial Visualization Tests; PSVT:D = PSVT: Visualization of Developments; PSVT:R = PSVT: Visualization of Rotations; PSVT:V = PSVT: Visualization of Views; PTAT = Perspective-Taking Ability Test; SBST = Santa Barbara Solids Test; SOT = Spatial Orientation Test

3. Method

This review was guided by established foundational practices and methods for systematic literature reviews with the intention of upholding replicability, transparency, and precision. This detailed process involved a comprehensive search across several academic databases to identify the full range of studies that employed the PSVT:V. Based on this extensive initial search, inclusion and exclusion criteria were clearly defined and applied to filter studies at both the title/abstract and full-text levels. After establishing the inclusion criteria, we created a structured coding system that organized data from eligible studies and allowed for the consistent coding of study characteristics, interventions, demographic factors, and findings. Due to the range in variation of interventions, study designs, and, importantly, reporting practices, a descriptive synthesis was used instead of a meta-analysis, with our investigation structured around the two guiding research questions.

3.1 Inclusion and Exclusion Criteria

To focus on spatial visualization research related to the involvement of the PSVT:V, an explicit set of inclusion and exclusion criteria was established prior to screening. Inclusion criteria required that studies:

- Are written in English to confirm a consistent interpretation of the study design and results
- Are published between 1976 in accordance with the development of the PSVT:V [6] and 2025.

- Deliberately administered the total or partial portions of the PSVT:V, either as a stand-alone instrument, as part of the larger Purdue Spatial Visualization Test (PSVT) battery, or as a part of a broader battery of existing spatial assessments.
- Reported empirical data involving participants in professional or educational training contexts, including K-12 students, undergraduates, graduate students, or adults engaged in spatially demanding disciplines.

Exclusion criteria applied to studies that:

- Did not use any form or part of the PSVT:V for data collection.
- Did not present any empirical findings; instead, they reported only theoretical commentary or literature reviews.
- Did not provide sufficient data to analyze PSVT:V performance correctly.
- Are inaccessible in full-text form

3.2 Search Strategy

Using Google Scholar, this initial step for search was intentionally broad, as it allowed for the detection of recurring authors, common terminology and themes, and frequently cited studies or evidence related to the PSVT:V. The opening search presented several vital insights. First, terminology throughout the literature varied, with some studies choosing to refer to the visualization assessment as the "views test", "perspective-taking," or simply just the "PSVT." Second, the PSVT:V was also often referenced interchangeably with the greater PSVT battery. These observations thus informed the refinement of search strings. Building on this exploratory phase, the finalized searches were conducted across several academic research databases and conference archives to ensure comprehensive coverage of both peer-reviewed and gray literature. Specifically, nine databases, repositories, and search engines were utilized:

1. ERIC (EBSCOhost)
2. PsycINFO
3. ProQuest Research Library
4. Scopus (Elsevier)
5. Wiley Online Library
6. ASEE PEER
7. IEEE Xplore Conference Paper Archives
8. ACM Digital Library
9. Google Scholar

In total, 521 records were identified at this stage. After removing 48 duplicates, 473 unique records were identified as included in studies. Search strings were also employed by combining research question-related and assessment-specific terms to both broader construct and contextual terms. Boolean operators (e.g., AND, OR, NOT) and abbreviated or outlier terms were also tailored to the specific notation required by each database. However, across the databases, these searches were collectively designed to capture studies that directly referenced the PSVT:V or used closely aligned terminology. Some search strings used included:

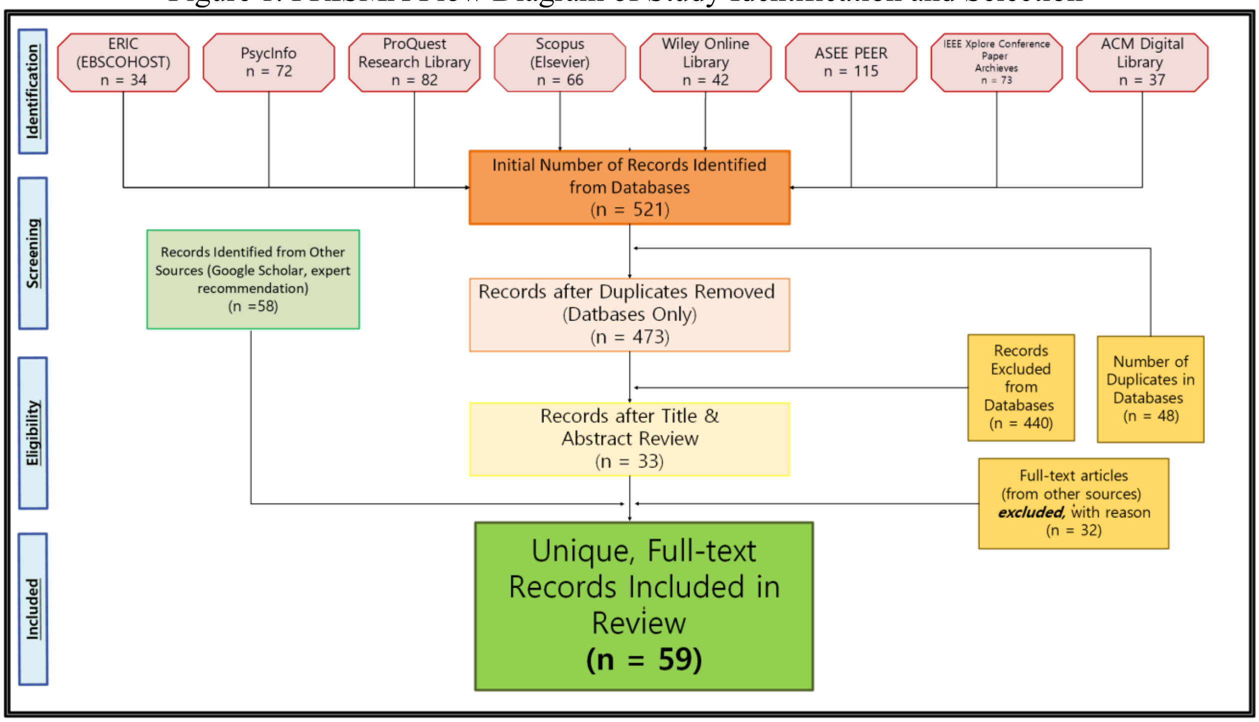
- "Purdue Spatial Visualization Test" AND "views"
- "PSVT" AND "views"
- "Spatial visualization" AND "PSVT"
- "Purdue Spatial Visualization Test" AND "spatial visualization" AND "views"

- “PSVT:V" OR “visualization of views”

To extend database retrieval, some citation chaining was performed to locate additional related studies, both by identifying newer works that cited included studies (i.e., forward snowballing) and by reviewing the reference lists of foundational papers (i.e., backward snowballing). All collected and included records were then exported into a framework in a Microsoft Excel spreadsheet to manage the detailed review process. This spreadsheet was used to log key information, including inclusion/exclusion decisions, bibliographic details, and search documentation adaptations.

3.3 Study Selection Process

Figure 1. PRISMA Flow Diagram of Study Identification and Selection



As delineated in Figure 1, study selection was conducted following a staged procedure, PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses), with multiple phases to assess and revise cases, thereby ensuring that only studies meeting the predefined criteria were included. At the initial search stage, records were first identified across multiple databases and archival sources by using predefined search terms and inclusion criteria focused on the visualization of views and spatial ability. This expansive search yielded **521 records.** Following this, there was a database-level filtering and removal of duplicate records, thus creating a pool of unique articles retained for the subsequent screening. **440 records** were excluded for having failed to meet the necessary inclusion criteria, including lack of relevance to spatial visualization or absence of some kind of visualization-of-views assessment. An additional **48 records** were also removed as duplicates being published across multiple databases. After this screening stage, **33 articles** identified through database searching were retained for full-text consideration. An additional 58 articles were identified through Google Search and archived articles maintained by one of the authors, bringing the pool to 91 articles. After further screening, a final set of **59 unique articles** using the PSVT:V, was retained for the dataset used in this review.

3.4 Data Extraction and Coding

All included articles were coded into a Microsoft Excel spreadsheet, which served as the primary data management tool for this study. Each row in the spreadsheet corresponds to a unique study, with multiple categories organized to facilitate systematic comparison of necessary information regarding each case. The coding framework included categories for information such as:

- Study identifiers: article title, author(s), publication type (conference, journal, dissertation, etc.), publication year, data collection year, and country.
- Participant characteristics: total sample size (N), student level (K-12, undergraduate, graduate, professional, etc.), whether participants were engineering students or from other majors/disciplines, and gender distribution.
- Intervention and design features: Presence of spatial training, type of training (physical, digital, hybrid, etc.), whether spatial training was implemented into an academic curriculum, study design type, duration of intervention, and the presence of experimental or control groups.
- Assessment tools: Identification of common spatial assessments, any custom-developed assessments, duration of the assessment-taking sessions, and other outcome measures (e.g., academic performance or strategy-use).
- Qualitative results: When available, pre- and post-test means and standard deviations for the PSVT (total) or for the PSVT:V, further separated by gender (male and female pre-/post- means and standard deviations).
- Qualitative and contextual notes: Role of the PSVT:V specific to the study (diagnostic, comparative, evaluative), initial research questions or hypothesis, study findings, references, and additional reviewer comments.

Coding was conducted manually by the first author, an undergraduate research assistant majoring in psychology and neuroscience, and then reviewed again by another undergraduate research assistant majoring in mechanical engineering to ensure accuracy and consistency across cases. The coding framework was developed in consultation with the senior author, whose expertise lies in psychometrics, spatial assessment, and systematic review, including meta-analysis. To also support efficiency in the early stages of organization, an AI-assisted tool was used to generate preliminary summaries and to refine the coding framework. However, and importantly, all final entries were individually verified and adjusted against the original articles to maintain accuracy and reliability.

Extracted and coded data from the studies were further organized by recurring research question themes. Cross-coding was employed to prevent data loss and enable the uniquely connected findings to contribute significantly to both research questions. This formatted data entry enabled both general quantitative compilation (e.g., the number of studies that completed each test, the proportion of studies reporting gender distributions, etc.) and qualitative synthesis (e.g., differences in strategies or narrative descriptions of intervention effectiveness).

The analysis focused on comparing findings narratively, building patterns, and observing points of similarity and difference. This approach enabled comparisons to be made across the created research themes, as well as for findings to be integrated both numerically and through narrative insights. The analysis proceeds in two parts:

(1) Studies were sorted according to the administration of the PSVT:V alone, with the larger PSVT-specific battery, or alongside other spatial assessments, such as the Mental Rotation Test (MRT), Mental Cutting Test (MCT), Cube Comparison Test (CCT), or Perspective-Taking Ability Test (PTAT). Distinctions focused on identifying whether the presented connections between the PSVT:V and other spatial tests overlap or exhibit clear distinctions in correlations.

(2) Studies were organized based on the types of interventions employed (physical tools, digital/virtual, curriculum-integrated, or hybrid). When recorded and reported, pre- and post-scores on the PSVT: V or other spatial assessments were compiled to showcase performance gains. Descriptions were also created to compare other important study design characteristics, such as feedback, duration, or curriculum integration.

4. Results

4.1 Convergence and Divergence of the PSVT:V with Other Spatial Tests

The PSVT:V can be found in the literature as a stand-alone 30-item test, a 12-item section within the larger PSVT battery, or in other forms of a developed study tool [6], [22]. Regardless of format, studies that examined the PSVT:V alongside other spatial ability assessments were included in this review to provide the convergence and divergence between the PSVT:V and other spatial assessments. As shown in Table 2, the most commonly co-administered and compared assessments were the MRT [16], the PSVT:R, the PSVT:D, the PTAT [18], the MCT [23], and the CCT [24]. Other tests, such as the Transformation 3D to 2D Test (T3D2DT; [25]), were also frequently included in the literature but were typically not analyzed in relation to the PSVT:V. These tools each emphasize the distinct theoretical domains within spatial cognition and offer insight into the convergent and divergent validity of the PSVT:V.

Table 2. Divergent and Convergent Validity Evidence of the PSVT:V with Other Spatial Tests

Spatial Test	Correlation (r)	Sample	Study
CCT	0.288 ($p > 0.05$)	7 adult aerospace engineering professionals	[13]
	0.30 ($p < 0.001$)	128 allied medical students	[2]
	No significant correlation	23 MIT students and 3 professionals engaged in space teleoperation tasks	[13]
DAT:AR	0.30 ($p < 0.01$)	118 dental students	[14]
	0.38 ($p < 0.01$)	206 dental and psychology students	[14]
HFT	-.049 ($p = 0.583$)	128 allied medical students	[2]
MCT	0.023	12 secondary students with math learning difficulty	[26]
MPFB	0.28 ($p < 0.01$)	101 undergraduate students enrolled in a required first-year psychology course	[20]
MRT	0.42 ($p < 0.05$)	128 allied medical students	[2]
	0.32 ($p > 0.05$)	30 undergraduate psychology students	[27]
	0.45 ($p < 0.01$)	118 dental students	[14]
	0.53 ($p < 0.01$)	206 dental and psychology students	[14]
	0.52 ($p < 0.001$)	101 undergraduate students enrolled in a required first-year psychology course	[20]
	0.529 ($p < 0.05$)	21 adults with STEM backgrounds, excluding 6	[28]

	0.45 ($p < 0.05$)	40 astronauts	[28]
	0.612 ($p = 0.004$)	20 adults	[29]
NOCST	0.40 ($p < 0.01$)	118 dental students	[14]
PAT	0.42 ($p < 0.01$)	118 dental students	[14]
	0.37 ($p < 0.01$)	206 dental and psychology students	[14]
PSVT:D	0.222 ($p < 0.012$) 0.328 ($p < 0.001$)	128 allied medical students	[2]
	0.370	93 tenth-grade students in geometry class	[30]
	0.297	64 tenth-grade students in geometry class	[30]
	0.326 ($p = 0.008$)	68 students enrolled in a first-year engineering design foundation course	[9]
	0.45 ($p < 0.001$)	101 undergraduate students enrolled in a required first-year psychology course	[20]
PSVT:R	0.390 ($p < 0.001$)	128 allied medical students	[2]
	0.458	93 tenth-grade students in geometry class	[30]
	0.534	64 tenth-grade students in geometry class	[30]
	0.451 ($p < 0.001$)	68 students enrolled in a first-year engineering design foundation course	[9]
	0.56 ($p < 0.001$)	101 undergraduate students enrolled in a required first-year psychology course	[20]
	0.054	12 secondary students with math learning difficulty	[26]
PTAT	0.569 ($p < 0.05$)	21 adults with STEM backgrounds, excluding 6	[28]
	0.635 ($p < 0.05$)	40 astronauts	[28]
	0.577 ($p < 0.05$)	23 MIT students and 3 professionals engaged in space teleoperation tasks	[13]
	0.771 ($p < 0.05$)	7 adult aerospace engineering professionals.	[13]
	0.020 ($p > 0.05$)	23 adults	[29]
	0.760 ($p < 0.001$)	20 adults	[29]
RAPMT	0.22	124 veterinary medical students in an anatomy lab	[31]
T3D2DT	0.203	12 secondary students with math learning difficulty	[26]
TCST	0.29 ($p < 0.01$)	206 dental and psychology students	[14]

Note. CCT = Cube Comparison Test [24]; DAT:AR/SR = Differential Aptitudes Tests: Abstract Reasoning Test/Spatial Relation [32]; HFT = Hidden Figure Test [24]; MCT = Mental Cutting Test [23]; MPFB = Minnesota Paper Form Board (MPFB) tests; MRT = Mental Rotation Test [16]; NOCST = Novel Object Cross-Section Test; RAPMT = Raven's Advanced Progressive Matrices Test; T3D2DT: Transformation 3D to 2D Test; PAT = Perceptual Ability Test of the Dental Admission Test [25]; PSVT:D/R/V = PSVT: Visualization of Development/Rotations/Views [6]; PTAT = Perspective Taking Ability Test [33]; TCST = Tooth Cross-Section Test [14]

4.2 Instructional Approaches and Their Effects on PSVT:V Scores

When addressing the PSVT:V assessment in relation to its effects on spatial ability to test performance, many distinct instructional approaches have been explored. These interventions aim to target key aspects of spatial reasoning, such as mental rotation, spatial working memory, or spatial visualization. They can range from physical manipulatives to digital and virtual tools, curriculum-integrated training, and many other hybrid interventions. These differing interventions across the literature have shown varying degrees of success in improving participants' spatial skills, depending on factors, such as modality and learner characteristics. Table 3 summarizes our review of the impact of various instructional approaches that have been employed, with the PSVT:V also being used to focus on the approaches' effectiveness in enhancing assessment scores and thus increasing spatial visualization skills.

Digital-Based / Virtual Tool Interventions. As technology and the digital space continue to evolve, virtual and digital-based tools have become increasingly integral to spatial ability interventions and training. These tools are also relevant when evaluating the skills explicitly measured by the PSVT:V. Digital tools often provide learners with practical experiences that encourage active engagement, and VR environments can add a layer of immersion, placing participants in real virtual spaces where they can manipulate or interact with real-time 3D objects. These digital tools can provide immediate feedback to learners and create a comfortable learning environment that allows users to set their own pace or apply unique concepts to complex content. Literature exploring these tools has shown their effectiveness in enhancing not only spatial ability but also PSVT:V scores following training.

Physical / Hands-On Tool Interventions. Other studies have used physical model construction within larger, more elaborate project-based engineering contexts. This includes [34], who incorporated isometric model building with foam core and cardboard into an engineering graphics curriculum. Through these repeated manufacturing exercises, not only were scores on the PSVT:V increased, but also strategies involving intuitive shape manipulation improved, thereby decreasing completion time on spatial tasks. [35] also integrated foam and wood-block modeling, alongside sketching, kit assembly, such as LegoTM, and even a mousetrap-powered vehicle, throughout a 75-hour-long first-engineering graphics course. These activities engaged students in assembling mechanical systems, cutting materials to exact measures, and switching between differing dimensional representations. The shortened PSVT, taken by participants in this study and containing only the views and rotations sections, reported an average gain of 13.4% points, indicating that repetitive and applied assembly tasks can yield sustained improvements in visualization skills. [36] also used a similar hands-on strategy in a first-year engineering design course. There were significant improvements in PSVT:V after the course was completed, and indications that the physical handling and construction of objects enhanced the ability to manipulate mentally.

Curriculum-Integrated Interventions. Curriculum- or course-integrated interventions embed spatial skill development throughout the structure of an existing or newly created academic course, ensuring that students engage with spatial tasks as part of the standard teaching that may also surround other topics, rather than in isolated sessions or additional programs. This approach allows learners to apply and reinforce spatial ability and visualization skills over extended periods by providing repeated practice, contextual relevance, and alignment with the course objectives. Typically, in this context, the PSVT:V was utilized as a pre-/post-measure of spatial skill development and as a diagnostic tool to assess how discipline-specific and prolonged exposure to spatial problems influences spatial performance.

Simulation/Robotics-Based Training. Another type of spatial training or intervention found in the literature is simulation- and robotics-based training that uses immersive, interactive systems to create complex, real-world spatial tasks in controlled, repeatable environments. The approach allows spatial subskills, such as mental rotation or dynamic spatial tracking, to be targeted while also enabling iterative practice without the usual limitations of materials or safety concerns. The reviewed studies emphasize that such interventions can produce significant improvements in visualization skills, especially when paired with other active problem-solving tasks, integrated with multiple perspectives, and/or evaluated for effectiveness by the PSVT:V.

Explicit Spatial Strategy Instruction. When instructional approaches aim to teach spatial strategies explicitly, researchers often focus on helping students recognize and reflect on their own cognitive processes while intentionally solving problems that match the specific demands of spatial reasoning tasks.

Other / Hybrid Interventions. Besides these intentional, strategy-based approaches, many studies have employed hybrid or other unconventional interventions that involve multiple types of training to achieve the best blend of spatial reasoning practice with smaller, domain-specific activities. These explicit, strategy-focused, and hybrid interventions demonstrate the extensive breadth of educational approaches available for improving spatial visualization skills, as measured by the PSVT:V.

With some interventions focused on a single spatial subskill through direct instruction, while others layer spatial reasoning practices across greater disciplinary contexts or combine multiple modalities for reinforcement, the literature consistently suggests that intentional engagement with spatial tasks can produce measurable gains in PSVT:V performance. The variety of intervention types underscores the adaptability of spatial training while also setting the stage for further examination of how different methods best align with a participant's demographics, learner needs, and instructional goals, as well as the context in which spatial reasoning is most critical.

Table 3. Instructional Approaches and Their Effects on PSVT:V Scores

Intervention Category	Studies	Typical Implementation Context	Synthesized Effects on PSVT
Digital-Based / Virtual Tool Interventions	[26], [37], [38], [39], [40], [41], [42], [43], [44]	CAD platforms, GeoGebra, SketchUp, VR environments, web-based visualization tools	Software-based interventions consistently produced improved PSVT scores. Gains were strongest when tools were embedded within structured, guided activities aligned with viewpoint transformation and mental rotation demands.
Physical / Hands-On Tool Interventions	[7], [34], [36], [38], [42], [45], [46]	Tangible 3D objects, model construction, sketching, origami, and kinesthetic manipulation	Physical interventions produced significant PSVT gains, particularly when learners repeatedly manipulated objects and translated between 2D and 3D representations, supporting embodied spatial reasoning.
Curriculum-Integrated Interventions	[10], [34], [35], [47], [48], [49], [50], [51]	Spatial training embedded within mathematics, engineering, or computer graphics coursework	Curriculum-integrated approaches yielded sustained improvements in PSVT scores and were frequently associated with gains in academic or task performance, suggesting durable and transferable spatial learning.
Simulation / Robotics-Based Training	[11], [13], [28], [42], [52], [53]	Teleoperation tasks, robotic interfaces, VR simulators, aerospace or medical simulation environments	Simulation-based interventions were particularly effective when tasks required dynamic viewpoint shifts and spatial coordination. Higher PSVT scores were often associated with improved task accuracy and efficiency.
Explicit Spatial Strategy Instruction	[10], [30], [54], [55], [56]	Direct instruction in spatial strategies (e.g., mental rotation, perspective-taking, cross-sectioning)	Explicit strategy instruction supported PSVT improvement by making spatial reasoning processes explicit and teachable, particularly when reinforced through guided practice and reflection.
Other / Hybrid Interventions	[30], [36], [38], [42], [49], [57], [58]	Direct instruction in spatial strategies (e.g., mental rotation, perspective-taking, cross-sectioning)	Hybrid interventions generally produced broad spatial gains, including improvements on the PSVT, though isolating the contribution of individual components was sometimes challenging.

5. Discussion

This systematic review using the PSVT:V offers a multi-layered perspective, revealing both convergences and divergences in its relationship to other spatial assessments, the effects of instructional approaches, and the role of demographic factors in shaping performance outcomes. When considered together, these results not only aid in synthesizing patterns that have emerged from the literature but also identify critical conceptual and methodological gaps that may warrant further investigation. Interpreting these patterns requires placing them within the broader spatial ability research landscape, where they can be further evaluated.

5.1 Interpreting Assessment Tool Relationships

The theoretical distinctions outlined earlier in this review indicate that spatial visualization, as measured by the PSVT:V, inhabits a specific subdomain within the broader spatial ability framework, and the patterns observed across the reviewed literature also align. Consistent with current models that distinguish between abilities, such as mental rotation, perspective-taking, and visualization, the focus of the PSVT:V is to serve as a targeted measure of viewpoint-based visualizations, as evidenced by the task requirements in the test questions, such as interpreting and transforming orthographic projection positions. This is further supported by the varying correlations between PSVT:V and other spatial measures, such as the CCT, MCT, MRT, and PTAT, also depending on the characteristics of participants. While a moderate connection is made in many studies suggesting a shared reliance on mental manipulation of 3D information, many weak or inconsistent correlations support the idea that the PSVT:V pushes the use of a more specialized set of cognitive approaches.

5.2 Instructional Approaches Effectiveness

Across the literature, structured interventions, regardless of format, consistently result in the greatest measurable improvements in PSVT:V scores, affirming the idea that spatial visualization is a malleable skill that can be cultivated through intentional practice. However, the degree and durability of improvement also varied depending on format, duration, training structure, and learning characteristics, further highlighting not only these consistent patterns but also unresolved complexities in the instructional design of spatial training.

At the same time, several gaps remain in the body of spatial research on instructional approaches. Often, follow-ups are brief, leaving open questions about the durability of gains beyond immediate intervention. Also, a few studies included randomized controls or effect sizes, which consequently limits the amount of cross-study comparability that can be performed. Hybrid interventions remain one of the more underexplored training types despite their promise, and while some effort has been made to explore equity amongst these interventions, most of the literature did not analyze intervention outcomes across demographic groups or characteristics, leaving uncertainty about whether these trainings help students equally. In summary, these findings propose that the most effective interventions for improving spatial visualization ability and thus PSVT:V score are curriculum-integrated, extended in duration, and structured to provide opportunities for feedback and self-correction. Hybrid intervention designs may ultimately give the most balanced approach if researched and tested further, although physical tools do offer strong foundational benefits, and digital tools hold potential for advanced visualization training. The collective evidence generally underscores the malleability of spatial visualization and the need for more longitudinal, detailed, and comparative research to determine which instructional models yield enduring improvements in spatial reasoning, not just short-term score gains.

5.3 Limitations of The Study

Despite the breadth of studies included in the literature, this systematic review identifies several limitations in the studies themselves and in the current synthesis that must be acknowledged. First, from a methodological standpoint, this review was limited by the amount of variability in how individual studies reported their participant samples, designs, and statistical outcomes. For instance, many studies did not include full pre- and post-test means, standard deviations, or effect sizes, making it more difficult to calculate consistent differences across contexts. Second, the literature itself also identifies significant challenges across the nearly five decades of research. Oftentimes, multiple assessments are administered to participants, yet many researchers rarely discuss how these tools differ or are similar in what they measure. This lack of conceptual clarity only complicates interpretations of validity, particularly in light of the persistent debates over spatial visualization's place within the theorized broad models of spatial ability.

Finally, the wide variation in instructional approaches across the literature makes it difficult to identify the essential elements of effective training. For example, instructional approaches can differ significantly in delivery mode, training intensity and duration, feedback structures, and the use of control groups or randomization. However, if studies do not provide these details or report them inconsistently, it becomes difficult to interpret their findings, identify which components meaningfully contribute to training effectiveness, and compare results across studies.

5.4 Conclusion

This review synthesized evidence from studies using the PSVT:V to evaluate spatial visualization in STEM and engineering education. Two central conclusions have begun to manifest:

- Convergence and divergence of the PSVT:V: The PSVT:V has shown consistent convergence with other spatial measures, such as the PTAT, MRT, and PSVT:R, while also offering distinctive insights into visualization abilities as a view transformation challenge. This balance of common assessment techniques and style, combined with the unique underscoring of the differing spatial domains, only highlights the enduring value the PSVT:V holds as a core spatial ability instrument.
- Instructional approaches of the PSVT:V: A scope of interventions, from hands-on manipulatives to digital/virtual environments, has all been shown to improve PSVT:V performance. Expanded and structured approaches tend to produce the strongest and most sustained gains, while short-term interventions typically yield only limited effects.

Together, these findings confirm that the PSVT:V is an adaptable and reliable tool for both spatial skill diagnosis and evaluating the impact of educational interventions.

References

*References marked with an asterisk indicate studies included in the systematic review.

[1] M. C. Linn and A. C. Petersen, "Emergence and characterization of sex differences in spatial ability: A meta-analysis," Child Development, vol. 56, no. 6, pp. 1479–1498, 1985.

[2] *T. A. Bruckner, Using an argument-based approach to validity for selected tests of spatial ability in allied medical professions students. Unpublished Doctoral Dissertation, The Ohio State University, Columbus, OH, USA, 2013.

[3] M. G. McGee, "Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences," *Psychological Bulletin*, vol. 86, no. 5, pp. 889–918, 1979.

[4] D. H. Uttal, N. G. Meadow, E. Tipton, L. L. Hand, A. R. Alden, C. Warren, and N. S. Newcombe, "The malleability of spatial skills: A meta-analysis of training studies," *Psychological Bulletin*, vol. 139, no. 2, pp. 352–402, 2013.

[5] S. A. Sorby, "Educational research in developing 3-D spatial skills for engineering students," *International Journal of Science Education*, vol. 31, no. 3, pp. 459–480, 2009.

[6] R. Guay, *Purdue spatial visualization test*. Princeton, NJ, USA: Educational Testing Service, 1976.

[7] *C. Uygan and A. Kurtuluş, "Effects of teaching activities via Google SketchUp and concrete models on spatial skills of preservice mathematics teachers," *Turkish Journal of Computer and Mathematics Education,* vol. 7, no. 3, pp. 510–535, 2016.

[8] *D. Toplu, *A descriptive investigation of Turkish high school students' spatial visualization ability.* Master's thesis, Bilkent University, Ankara, Turkey, 2020.

[9] *S. Guidera, "Spatial skill assessment as a predictor of student performance in a first-year design foundations course," in *Proc. ASEE Annual Conference & Exposition*, Louisville, KY, USA, Jun. 2010. doi: 10.18260/1-2--16415.

[10] *G. V. S. S. Sharma, J. R. Murugadoss, and V. Rambabu, "Fostering higher order thinking skills in engineering drawing," *Journal of Engineering Education Transformations*, vol. 34, no. 1, pp. 28–40, 2020.

[11] *A. Collins, Z. Tomlinson, C. Oman, A. Liu, and A. Natapoff, "Investigating the effects of frame disparity on the performance of telerobotic tasks," in *Proc. International Astronautical Congress*, 2008.

[12] M. Hegarty and D. Waller, "A dissociation between mental rotation and perspective-taking spatial abilities," *Intelligence*, vol. 32, no. 2, pp. 175–191, 2004.

[13] *A. M. Menchaca Brandan, *Influence of spatial orientation and spatial visualization abilities on space teleoperation performance*. Master's thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, USA, 2007.

[14] *M. Hegarty, M. Keehner, P. Khooshabeh, and D. R. Montello, "How spatial abilities enhance, and are enhanced by, dental education," *Learning and Individual Differences*, vol. 19, no. 1, pp. 61–70, 2009.

[15] R. N. Shepard and J. Metzler, "Mental rotation of three-dimensional objects," *Science, vol.* 171, no. 3972, pp. 701–703, 1971.

[16] S. G. Vandenberg and A. R. Kuse, "Mental rotations: A group test of three-dimensional spatial visualization," *Perceptual and Motor Skills*, vol. 47, no. 2, pp. 599–604, 1978. doi: 10.2466/PMS.47.6.599-604.

[17] J. Wai, D. Lubinski, and C. P. Benbow, "Spatial ability for STEM domains: Aligning over

50 years of cumulative psychological knowledge solidifies its importance," *Journal of Educational Psychology*, vol. 101, no. 4, pp. 817–835, 2009.

[18] M. Kozhevnikov and M. Hegarty, "A dissociation between object-manipulation and perspective-taking spatial abilities," *Memory & Cognition*, vol. 29, no. 5, pp. 745–756, 2001.

[19] S. M. Weisberg, V. R. Schinazi, N. S. Newcombe, T. F. Shipley, and R. A. Epstein, "Variations in cognitive maps: Understanding individual differences in navigation," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, vol. 40, no. 3, pp. 669–682, 2014.

[20] R. B. Guay and E. McDaniel, *Correlates of performance on spatial aptitude tests*. Technical report, U.S. Army Research Institute for the Behavioral and Social Sciences, 1978.

[21] *S. Charles and N. Peyret, "How to characterise performance in engineering freshmen's modelling tasks?" in *Proc. 51st Annual Conf. European Society for Engineering Education (SEFI)*, Dublin, Ireland, 2023. doi: 10.21427/SBXG-KN47.

[22] R. B. Guay, "Spatial ability measurement: A critique and an alternative," in *Proc. Annual Meeting of the American Educational Research Association*, Boston, MA, USA, 1980. ERIC Document ED189166.

[23] College Entrance Examination Board, *CEEB special aptitude test in spatial relations*. New York, NY, USA: College Entrance Examination Board, 1939.

[24] R. Ekstrom, J. W. French, and H. Harman, *Manual for kit of factor-referenced cognitive tests*. Princeton, NJ, USA: Educational Testing Service, 1976.

[25] R. Gorska and S. Sorby, *"Testing instruments for the assessment of 3-D spatial skills," in Proc. 2008 Annual Conf. & Exposition, Jun. 2008, pp. 13–1196.*

[26] *Y. F. Hanim, M. Wasilatul, and S. Suparman, "Experts and designated users evaluations on visual tools screencast SketchUp Make (ViToS-SUM)," *Perspektivy Nauki i Obrazovania,* vol. 6, no. 54, pp. 460–472, 2021.

[27] *C. Cohen and M. Hegarty, "Individual differences in use of external visualisations to perform an internal visualisation task," *Applied Cognitive Psychology*, vol. 21, no. 6, pp. 701–711, 2007.

[28] *T. M. Pontillo, *Spatial ability and handedness as potential predictors of space teleoperation performance*. Doctoral Dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 2010.

[29] *Z. A. Tomlinson, *Influence of spatial abilities on primary and secondary space telerobotics operator performance*. Doctoral Dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 2009.

[30] *M. Eraso, *connecting visual and analytic reasoning to improve students' spatial visualization abilities: A constructivist approach*. Doctoral Dissertation, 2007. ProQuest Dissertations & Theses Global, Order No. 3298580.

[31] *J. C. Gutierrez, S. D. Holladay, B. Arzi, M. Gomez, R. Pollard, P. Youngblood, and S. Srivastava, "Entry-level spatial and general non-verbal reasoning: Can these abilities be used as a predictor for anatomy performance in veterinary medical students?" *Frontiers in Veterinary Science*, vol. 5, Art. no. 226, 2018.

[32] G. K. Bennett, H. G. Seashore, and A. G. Wesman, *Differential aptitudes test*. San Antonio, TX, USA: The Psychological Corporation, 1981.

[33] M. Kozhevnikov, M. A. Motes, B. Rasch, and O. Blajenkova, "Perspective taking vs. rotation transformations and how they predict spatial navigation performance," *Applied*

Cognitive Psychology, vol. 20, no. 3, pp. 397–417, 2006.
[34] *S. Miner and T. Tyler, "A project based introduction to mechanical engineering," in *Proc. ASEE Annual Conf.*, Albuquerque, NM, USA, 2001. doi: 10.18260/1-2--9684.
[35] *M. A. Carr, "Sketching, drafting, & developing engineering visualization skills," in *Proc. ASEE Annual Conf. & Exposition*, Jun. 2011, pp. 22–1299.
[36] *O. S. LoPiccolo, "Improving spatial reasoning ability while learning energy efficient construction: Students who build physical models vs. students who develop 3D computer models," in *Proc. Zone 1 Conf. American Society for Engineering Education*, 2014.
[37] *A. H. Abdullah, R. Abd Wahab, M. Mokhtar, N. A. Atan, N. D. Abd Halim, J. Surif, and S. N. S. Abd Rahman, "Does SketchUp Make improve students' visual-spatial skills?" *IEEE Access*, vol. 10, pp. 13936–13953, 2022.
[38] *A. Baki, T. Kosa, and B. Guven, "A comparative study of the effects of using dynamic geometry software and physical manipulatives on the spatial visualisation skills of pre-service mathematics teachers," *British Journal of Educational Technology*, vol. 42, no. 2, pp. 291–310, 2011.
[39] *B. Güven and T. Kösa, "The effect of dynamic geometry software on student mathematics teachers' spatial visualization skills," *Turkish Online Journal of Educational Technology–TOJET*, vol. 7, no. 4, pp. 100–107, 2008.
[40] *T. Kösa, "Effects of using dynamic mathematics software on preservice mathematics teachers' spatial visualization skills: The case of spatial analytic geometry," *Educational Research and Reviews*, vol. 11, no. 7, pp. 449–458, 2016.
[41] *A. Kurtuluş, "The effects of web-based interactive virtual tours on the development of prospective mathematics teachers' spatial skills," *Computers & Education*, vol. 63, pp. 141–150, 2013.
[42] *P. Oliver, A. Fong, Z. Wang, and B. C. Wünsche, "Spatial mini golf: Game-based spatial intelligence testing and training using VR and non-VR platforms," in *Proc. 39th Int. Conf. Image and Vision Computing New Zealand (IVCNZ)*, 2024, pp. 1–6.
[43] *M. I. Serrano and S. Zurn-Birkhimer, "Using origami and CAD as tools for spatial ability training for first-year female engineering students," in *Proc. ASEE Virtual Annual Conf. Content Access,* Jun. 2020.
[44] *F. H. Yahya, N. H. Adenan, W. Murtafiah, and N. R. Shamsuddin, "Integration of video tutorial screencast SketchUp Make (VTS-SUM) to enhance students' visual spatial skills," *Central Asia & the Caucasus*, vol. 23, no. 1, 2022.
[45] *K. L. Huffman, *What is the effect of real versus augmented models for the advancement of spatial ability based on haptic or visual learning style of entry-level engineering graphics students?* Master's thesis, Purdue University, West Lafayette, IN, USA, 2011.
[46] *E. A. Pan, *The use of physical and virtual manipulatives in an undergraduate mechanical engineering (dynamics) course.* Unpublished Doctoral Dissertation, University of Virginia, Charlottesville, VA, USA, 2013.
[47]* J. S. González Campos, J. Sánchez-Navarro, and J. Arnedo-Moreno, "An empirical study of the effect that a computer graphics course has on visual-spatial abilities," *International Journal of Educational Technology in Higher Education*, vol. 16, pp. 1–21, 2019.
[48] *A. J. Kaucher, *The effects of teaching relational geometry to entry-level engineering students*. Doctoral Dissertation, 2010. ProQuest Dissertations & Theses Global, Order No. 1489631.
[49] *L. A. Prugh, *Spatial reasoning in undergraduate mathematics: A case study.* Unpublished

Doctoral Dissertation, University of Oklahoma, Norman, OK, USA, 2013.
[50] *J. X. Watt, *The effects of an experimental spatial ability treatment program on calculus achievement with university students*. Unpublished doctoral dissertation, Indiana University, Bloomington, IN, USA, 1990.
[51] *S. Zurn-Birkhimer, M. I. Serrano, B. M. Holloway, and R. A. Baker, "Work in progress: Online training in spatial reasoning for first-year female engineering students," in *Proc. ASEE Annual Conf. & Exposition*, Salt Lake City, UT, USA, 2018. doi: 10.18260/1-2--31298.
[52] *J. M. Luursema, S. N. Buzink, W. B. Verwey, and J. J. Jakimowicz, "Visuo-spatial ability in colonoscopy simulator training," *Advances in Health Sciences Education*, vol. 15, no. 5, pp. 685–694, 2010.
[53]* E. Çam and K. Kılıçer, "The effect of virtual reality assisted robotics coding teaching on spatial visualization and coding skills," *Eğitimde Kuram ve Uygulama,* vol. 18, no. 2, pp. 68–84, 2022.
[54] *A. E. C. Hanlon, *Investigating the influence of Quick Draw on pre-service elementary teachers' beliefs, in concordance with spatial and geometric thinking: A mixed methods study*. Doctoral Dissertation, Oklahoma State University, Stillwater, OK, USA, 2010.
[55] *M. Keehner, M. Hegarty, C. Cohen, P. Khooshabeh, and D. R. Montello, "Spatial reasoning with external visualizations: What matters is what you see, not whether you interact," *Cognitive Science*, vol. 32, no. 7, pp. 1099–1132, 2008.
[56] *M. Stieff, M. Ryu, and B. Dixon, "Students' use of multiple strategies for spatial problem solving," in Learning in the Disciplines: *Proc. 9th Int. Conf. Learning Sciences (ICLS 2010)*, vol. 1: Full Papers, K. Gomez, L. Lyons, and J. Radinsky, Eds. International Society of the Learning Sciences, 2010, pp. 765–772.
[57] *R. Onyancha, M. Derov, and B. Kinsey, "The Anatomy of Spatial Ability improvement over the course of a semester-long computer aided design class," in *Proc. ASEE Annual Conf. & Exposition, Pittsburgh*, PA, USA, Jun. 2008. doi: 10.18260/1-2--3482.
[58] *R. M. Onyancha, M. Derov, and B. L. Kinsey, "Improvements in spatial ability as a result of targeted training and computer-aided design software use: Analyses of object geometries and rotation types," *Journal of Engineering Education,* vol. 98, no. 2, pp. 157–167, 2009.
[59] *R. Abd Wahab, A. H. Abdullah, M. S. Abu, M. Mokhtar, and N. A. Atan, "A case study on visual spatial skills and level of geometric thinking in learning 3D geometry among high achievers," *Man in India*, vol. 96, no. 1–2, pp. 489–499, 2016.
[60] *C. A. Cohen, "The influence of spatial ability on the use of dynamic, interactive animation in a spatial problem-solving task," conference paper, Department of Psychology, University of California, Santa Barbara, CA, USA, 2005.
[61] *R. Fosu, K. Sukumar, and P. E. Connolly, "Spatial visualization ability and learning style preference assessment among construction related undergraduate engineering and technology students," in *Proc. ASEE Annual Conf. & Exposition*, New Orleans, LA, USA, Jun. 2016. doi: 10.18260/p.25855.
[62] *M. Keehner, Y. Lippa, D. R. Montello, F. Tendick, and M. Hegarty, "Learning a spatial skill for surgery: How the contributions of abilities change with practice," *Applied Cognitive Psychology*, vol. 20, no. 4, pp. 487–503, 2006. doi: 10.1002/acp.1198.
[63] *B. Kinsey, E. Towle, G. Hwang, E. J. O'Brien, and C. F. Bauer, "The effect of spatial ability on the retention of students in a college of engineering and physical science,"

Proc. ASEE Annual Conf. & Exposition, Chicago, IL, USA, June. 2006. doi: 10.18260/1-2-529.

[64] *B. L. Kinsey, E. Towle, E. J. O'Brien, and C. F. Bauer, "Analysis of self-efficacy and ability related to spatial tasks and the effect on retention for students in engineering," *International Journal of Engineering Education*, vol. 24, no. 3, pp. 488–497, 2008.

[65] *T. Kösa, "The effect of using dynamic mathematics software: Cross section and visualization," *International Journal for Technology in Mathematics Education*, vol. 23, no. 4, pp. 121–128, 2016.

[66] *A. M. Liu, C. M. Oman, R. Galvan, and A. Natapoff, "Predicting space telerobotic operator training performance from human spatial ability assessment," *Acta Astronautica*, vol. 92, no. 1, pp. 38–47, 2013.

[67] *M. A. Menchaca Brandan, A. M. Liu, C. M. Oman, and A. Natapoff, "Influence of perspective-taking and mental rotation abilities in space teleoperation," in *Proc. ACM/IEEE Int. Conf. Human-Robot Interaction*, Mar. 2007, pp. 271–278.

[68] *A. Ş. Özdemir and S. G. Yıldız, "The analysis of elementary mathematics preservice teachers' spatial orientation skills with SOLO model," *Eurasian Journal of Educational Research,* no. 61, pp. 1–16, 2016.

[69] *A. L. Santone, *Visuospatial characterization and analysis of spatial abilities of video game players.* Doctoral Dissertation, Purdue University, West Lafayette, IN, USA, 2009.

[70] *A. Y. Sheikh, M. Keehner, A. Walker, P. A. Chang, T. A. Burdon, and J. I. Fann, "Individual differences in field independence influence the ability to determine accurate needle angles," *The Journal of Thoracic and Cardiovascular Surgery*, vol. 148, no. 5, pp. 1804–1810, 2014. doi: 10.1016/j.jtcvs.2014.05.008.

[71] *K. Sukumar, Correlating the Purdue spatial visualization test with the Wonderlic Personnel test for American football players. Master's thesis, Purdue University, West Lafayette, IN, USA, 2012.

[72] *K. Sukumar, *Electrophysiological and spatial orientation ability differences in expert and novice aircraft pilots*. Doctoral Dissertation, Purdue University, West Lafayette, IN, USA, 2018.

[73] *T. Thayban, H. Munandar, E. Kurniawati, and L. Alio, "Spatial ability: Measuring its contribution to symmetry understanding," *Jurnal Pembelajaran Kimia*, vol. 7, no. 2, 2022.

[74] *T. Tseng, *Spatial-visual skills and engineering design*. Doctoral Dissertation, Massachusetts Institute of Technology, Cambridge, MA, USA, 2009.

[75] *T. Tseng and M. Yang, "The role of spatial-visual skills in a project-based engineering design course," in *Proc. ASEE Annual Conf. & Exposition*, Vancouver, BC, Canada, Jun. 2011. doi: 10.18260/1-2--18466.

[76] *E. Yazici, "Spatial visualization abilities of field dependent/independent preservice teachers," *Electronic Journal of Research in Education Psychology*, vol. 12, no. 33, pp. 371–390, 2014.

[77] *J. Yue, "Spatial visualization by isometric drawing," *Proc. 2006 IJME-INTERTECH Conf.*, Union, NJ, USA, Oct. 2006, vol. 3.