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# Exploring the Relationship Between Spatial Ability and Undergraduate Student Performance in Chemistry and Chemical Engineering Courses

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# Exploring the Relationship Between Spatial Ability and Undergraduate Student Performance in Chemistry and Chemical Engineering Courses


## Abstract

This systematic review examined the relationship between undergraduate students' spatial ability and their performance in chemistry and chemical engineering courses. Two research questions guided the study: (1) What types of spatial ability are explored in the literature? and (2) What is the established relationship between spatial ability and course performance? Studies were included if they were published in English between 2000 and 2025, involved undergraduate students enrolled in a chemistry or chemical engineering course, administered a spatial test, and reported a relationship between spatial ability and chemistry performance measures such as exam grades or course grades. A keyword search across Google Scholar, ProQuest, and ASEE PEER, supplemented by forward and backward snowballing, identified 20 eligible articles. Studies were coded and analyzed to identify patterns across spatial skills, assessment tools, and performance outcomes. Of the 20 studies, 14 (70%) reported positive correlations between spatial ability and course performance. Three-dimensional mental rotation was the most studied spatial skill (85% of studies), and the Purdue Spatial Visualization Test: Rotations was the most used assessment tool (60%). Findings are limited by the concentration of studies in organic chemistry and a single institution representing all thermodynamics research. These results highlight spatial ability as a meaningful predictor of undergraduate chemistry and chemical engineering success, suggesting that curricula should explicitly incorporate spatial skill development to improve student outcomes.


## 1. Introduction

The field of chemistry and chemical engineering requires the ability to visualize hidden structures [1][2]. From visualizing the 3D geometry of a carbon atom to interpreting molecular structure to understanding fluid behavior, students are consistently required to use their spatial skills. Spatial ability is the capacity to mentally transform three-dimensional configurations, which is a vital part of problem-solving in STEM education [1].

Although central, spatial ability is often sidelined in undergraduate education. While admissions and core curricula emphasize mathematical and verbal proficiency, explicit instruction in spatial reasoning is rare [3]. Spatial ability is often tested indirectly in challenging courses, such as organic chemistry and thermodynamics [4][5]. Due to this, when students struggle to transform diagrams or are unable to perform mental rotation, they may resort to old school rote memorization, a strategy that is not sufficient in our complex world problem-solving.

Spatial ability is a malleable skill that can be improved over time [6]. Educators have an opportunity to craft lessons that build these spatial skills, making students reach their potential. A number of studies provided students with such an opportunity to improve their spatial ability to promote their class performance through focused areas of teaching within chemistry and chemical engineering [7][8][9]. However, there has been a lack of systematic reviews of the existing findings in the literature. Therefore, this study aimed to investigate the literature from 2000 to 2025 to explore how spatial skills affect undergraduate performance. By looking at 20 studies, it highlights the skills needed for success and shows how training in spatial ability can help students perform better in these demanding fields.

### *1.1. Purpose of the Study*

This systematic review examined the role of undergraduate students' spatial ability in chemistry and chemical engineering education. Two key questions were addressed: (1) What types of spatial ability and spatial skills are explored in chemistry and chemical engineering education literature? and (2) What is the established relationship between undergraduate students' spatial ability and their chemistry/chemical engineering performance?

## 2. Literature Review

### *2.1. Importance of Spatial Ability in STEM Education*

Spatial ability is a crucial skill for most STEM and engineering majors, as they have a high focus on visualization of topics, which implies that students with higher spatial ability will have a higher chance of succeeding in the subject. Decades of research have been done to demonstrate the correlation between spatial ability and achievement in STEM fields [1]. "Results solidify the generalization that spatial ability plays a critical role in developing expertise in STEM and suggest, among other things, that including spatial ability in modern talent searches would identify many adolescents with potential for STEM who are currently being missed" [1, p. 817]. Another study has also provided a comprehensive review underscoring the importance of spatial abilities in chemistry learning and suggesting instructional strategies to cultivate these skills [3].

### *2.2. Spatial Ability in Chemistry and Chemical Engineering Education*

Spatial ability is fundamental for comprehensive understanding and problem-solving in both chemistry and chemical engineering, particularly for engineering students. In chemistry, it's essential for grasping complex molecular structures, stereochemistry, and reaction mechanisms. Students must mentally manipulate 2D representations into 3D molecules [2], a skill foundational to topics like organic chemistry [4] and stereochemistry [10] [11].

This foundational spatial understanding directly extends into chemical engineering. Chemical engineers must interpret and create complex process flow diagrams, understand equipment internals, and visualize entire chemical plants in 3D, demanding strong spatial reasoning and translation between representations. Studies confirm a strong link between spatial skills and chemical engineering problem-solving [5] [12], impacting graphics performance, retention, and even design problem-scoping behaviors [13]. Acquiring technical engineering drawing skills early is also deemed necessary [14].

## 3. Method

### *3.1. Inclusion and Exclusion Criteria*

The following inclusion and exclusion criteria were used: (a) articles must be published in English, (b) articles must be published from 2000 to 2025, (c) study participants must be higher education students, (d) study participants must be enrolled in a chemistry or chemical engineering course, (e) study participants were assessed by a spatial test and the results were reported, (f) study participants' chemistry and/or overall course performance was reported, and (g) a relationship between spatial skills and chemistry performance was reported.

### *3.2. Literature Search Strategy*

Several keywords were first used to search for conference papers and research articles in Google scholar, ProQuest, and ASEE PEER Database published from 2000 to 2025. The search terms are summarized in Table 1.

Table 1. Keywords Used for Search

| Keywords | Search Results | | |
|---|---|---|---|
| | Google Scholar | ProQuest | ASEE PEER |
| "chemical engineering" AND "spatial ability" | 599 | 172 | 519 |
| "chemical engineering" AND "spatial skills" | 464 | 121 | 566 |
| "chemistry" AND "spatial ability" | 9150 | 1870 | 397 |
| "chemistry" AND "spatial skills" | 5750 | 1225 | 436 |

Forwards and backwards snowballing were used to locate additional articles for screening. Based on our inclusion and exclusion criteria, Figure 1 displays the search and screening process following the Preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement [15].

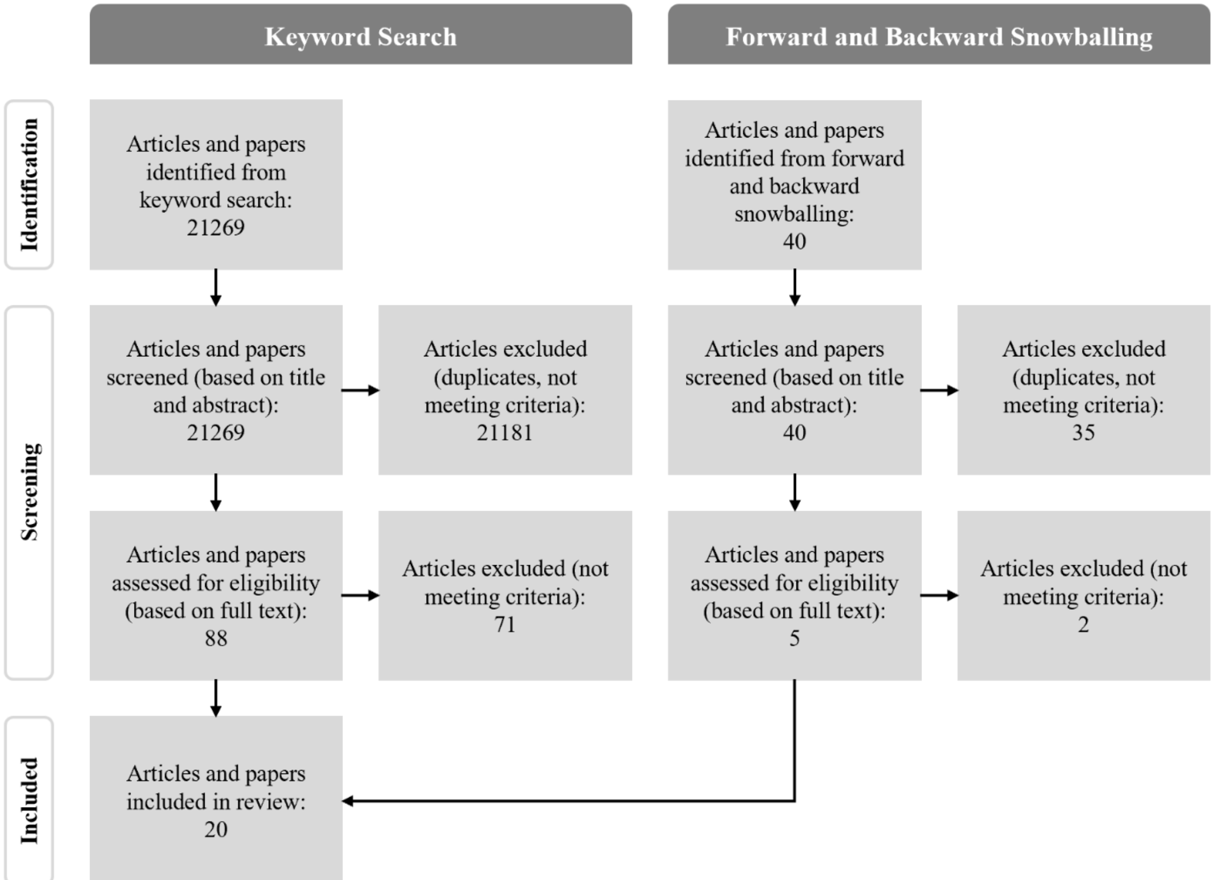


Figure 1. PRISMA Flow Diagram Summarizing the Screening Process [16]

### *3.3. Coding*

Under the supervision of the third author, who has expertise in meta-analysis, the first author, an undergraduate chemical engineering student, and the second author, a doctoral student in engineering education, each independently coded the 20 articles included in this systematic review. For each article, they identified the title of the chemistry or chemical engineering course (e.g., General Chemistry Laboratory, Organic Chemistry I, Thermodynamics), the number of participants in the study, the spatial test administered, the spatial skill being assessed, the chemistry performance measure (e.g., stereochemistry test, final exam grade), and the reported correlation between spatial ability and chemistry performance.

## 4. Results

Table A in the Appendix presents the results of this systematic review of the 20 articles.

### *4.1. Types of Chemistry and Chemical Engineering Courses*

Of the 20 articles included in the systematic review, six articles included participants enrolled in a general chemistry course. This included courses, such as General Chemistry, Chemistry 101, and General Chemistry Laboratory. In 10 of the articles, participants were enrolled in an organic chemistry course. In three of the studies, participants were enrolled in a thermodynamics course. The thermodynamics course is a third-year chemical engineering course in all three of the articles. In one study, participants were enrolled in upper-level chemistry courses.

### *4.2. Types of Spatial Tests*

The Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R; [17]) or the Revised PSVT:R [18] was used in 12 (60%) of the articles examined. This three-dimensional (3D) mental rotation test was the most used spatial test. The Mental Rotation Test (MRT; [9]) was used in five articles (25%), and the Mental Cutting Test (MCT; [19]) was used in three articles (15%). The Paper Folding Test (PFT; [8]) and the Purdue Spatial Visualization Test: Visualization of Views (PSVT:V; [17]) was used in two articles (10%), respectively. The Card Rotation Test (CRT, [8]), the Differential Aptitude Test (DAT; [20]), the Greek Spatial Ability Test (GSAT; [21]), and the Revised Test of Mental Rotation (RTMR; [7]) was used in one article (5%), respectively. More than one spatial test was used in six of the articles (30%).

### *4.3. Types of Spatial Skills*

Of the 20 articles, 17 (85%) examined three-dimensional (3D) mental rotation in spatial visualization. This was the most examined spatial skill. 3D mental transformation in spatial visualization was examined in three of the articles (15%), 2D mental transformation was examined in two of the articles (10%), 3D mental views was examined in one of the articles (5%), and 2D mental rotation was examined in one article (5%).

### *4.4. Types of Chemistry Performance Measures*

Chemistry performance measures used in the 20 articles included tests/exams and course grades. Tests/exams were used in 18 of the articles. Only two articles used overall course grades.

### *4.5. Relationship Between Spatial Ability and Chemistry Performance*

Results varied across the 20 articles. Six of the articles stated that no correlation was found between spatial ability and chemistry performance, or that spatial ability was a poor predictor for chemistry performance [11][22][23][24][25][26]. The other 14 articles found a positive correlation between spatial ability and chemistry performance. Two articles specified that the correlation was weak [27][28], two articles specified that the correlation was moderate [29][30], and four articles specified that the correlation was strong [5][31][32][33].

## 5. Discussion

Most studies included in the systematic review explored spatial ability in the context of general chemistry and organic chemistry courses. These are chemistry courses that chemistry and chemical engineering students are required to take. However, they were not specifically chemical engineering courses. The only chemical engineering course included was thermodynamics, which was used in three of the articles. All three of these articles used participants from the same institution, where thermodynamics is a third-year course for chemical engineering students. This limits the generalizability of the results and reveals a need for more studies about spatial ability and chemical engineering performance within a larger variety of chemical engineering courses.

Over half the studies used the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT: R) as the spatial ability test. The next most common spatial test was the Mental Rotation Test (MRT). Both tests correspond to the same spatial skill: 3D mental rotation. Thus, a large majority of the articles examined 3D mental rotation, while other spatial skills were not as frequently examined. These findings reveal a gap in the research exploring spatial ability and chemistry or chemical engineering performance. There is a need for more research about other forms of spatial visualization. Overall, most articles reported a significant and positive correlation between spatial ability and chemistry or chemical engineering performance, despite varying correlational strengths.

### *5.1. Limitations and Future Research*

Although the researchers tried to be as thorough as possible in their search and coding of the literature, it is possible that some articles or papers were mistakenly excluded or not identified for inclusion. It is also possible that new articles were published in the later part of 2025, after the search and screening process was already complete. Future research can broaden the scope and inclusion criteria to examine not only research examining the correlation between spatial ability and chemistry or chemical engineering performance, but also interventions involving spatial training in chemistry or chemical engineering courses.

### *5.2. Conclusion*

The findings highlight mostly positive correlations between various spatial skills and performance in undergraduate chemistry and chemical engineering courses, identifying evidence regarding spatial ability as a predictor of student success in chemical and chemical engineering education, and revealing unexplored gaps in research on this topic. The results of this review can inform educators in curriculum design to incorporate the development of specific spatial skills relevant to promoting student performance within chemistry and chemical engineering courses.

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## Appendix

Table A. Summary of the 20 Articles Included in the Systematic Review

| **Authors** | **Course Title** | ***N*** | **Spatial Test** | **Spatial Skill** | **Performance Measure** | **Findings** |
|---|---|---|---|---|---|---|
| Antonucci-Durgan & Abramovich (2024) [29] | General Chemistry | 46 | PSVT:R (20Q , 20mins) | SV - 3D mental rotation | Motion of Matter Survey | Moderate positive correlation between mental rotation skills and students' overall model of the structure and motion of matter. |
| Bongers et al. (2020) [34] | Organic Chemistry I, Organic Chemistry II | 45 | Revised PSV T:R (30Q, 25mins) | SV - 3D mental rotation | Epoxide Opening Reactions Test (24Q) | Positive correlation between spatial ability and test performance. |
| Brown et al. (2021) [25] | General Chemistry Laboratory | 45 | PSVT:R (20Q , 10mins) | SV- 3D mental rotation | Course Lab Pre-post Tests | No correlation between visual ability and performance, regardless of the intervention. |
| Casselman et al. (2021) [35] | Organic Chemistry I | 64 | MRT (24Q, 6 mins) | SV- 3D mental rotation | Stereochemistry and Reaction Mechanism Content Assessments | Weak positive correlation between MRT score and stereochemistry pre-test, stereochemistry post-test, and reaction mechanism post-test. No correlation between MRT score and reaction mechanism pre-test. |
| Elford et al. (2022) [30] | Inorganic and General Chemistry | 77 | PSVT:R (20Q , 10mins) | SV- 3D mental rotation | Valence Shell Electron Pair Repulsion (VSEPR) Theory Test | Moderate positive correlation between students' mental rotation ability and VSEPR test scores. |
| Hegarty et al. (2013) [28] | Organic Chemistry | 469 | MRT, PFT, PSVT:V | SV- 3D mental rotation, 2D mental transformation, 3D mental views | Organic Chemistry Problem-Solving Test (12Q) | Spatial ability is a significant predictor of success in chemistry and chemical engineering. W**eak positive correlation** between spatial ability and chemistry problem-solving. |
| Hornbuckle et al. (2014) [35] | Organic Chemistry | 58 | PSVT:R | SV- 3D mental rotation | Final Class Grade | Spatial ability is a key predictor of success in chemistry and engineering. Spatial reasoning improved significantly over the course, with above-average spatial students achieving slightly higher final grades |

| | | | | | | |
|---|---|---|---|---|---|---|
| Knowles (2017) [14] | Organic Chemistry | 137 | MRT (24Q, 6 mins) | SV- 3D mental rotation | 2010 ACS Organic chemistry exam | Significant positive correlation between MRT score and ACS Exam score. |
| Koutalas et al. (2014) [22] | Third and Fourth Year Chemistry Courses | 33 | PSVT:R, GSAT | SV- 3D mental rotation | Fisher Projections Test, Newman Projections Test, and Stereochemistry Test | No correlation between spatial ability and performance in the three molecular diagram matching tests. |
| Laricheva & Il ikchyan (2023) [31] | General Chemistry | 112 | PSVT:R (30Q , 25mins) | SV- 3D mental rotation | Midterm and Final Exam Grades | Visual-spatial skills are strong predictors of STEM success, correlating positively with chemistry performance on both spatial and non-spatial tasks. |
| Loney et al. (2019) [5] | Thermodynamics | 63 | MCT | SV- 3D mental transformation | Chemical Engineering Problems (13Q) | Strong positive correlation between spatial skills test scores and the number of problems solved correctly. |
| Merchant et al. (2013) [32] | Chemistry 101 | 403 | PSVT:R, CRT | SV- 3D mental rotation, 2D mental rotation | Valence Shell Electron Pair Repulsion (VSEPR) Theory Test | Strong positive relationship between spatial ability measures and academic performance on chemistry tests. |
| Nandagopal (2008) [33] | Organic Chemistry | 64 | PSVT:R | SV- 3D mental rotation | Organic Chemistry Course Grade | Spatial ability has a strong positive correlation with course performance. |
| Panther & Sorby (2018) [36] | Thermodynamics | 12 | PSVT:R, DAT, MCT | SV- 3D mental rotation, 3D mental transformation | Chemical engineering Problems (4Q) | Spatial skills are a significant predictor of success in chemistry and chemical engineering. |
| Sorby et al. (2020) [12] | Thermodynamics | 63 | MCT | SV- 3D mental transformation | Chemical Engineering Problems (13Q) | Spatial skills are strongly linked to chemical engineering success. |
| Stieff (2004) [26] | Organic Chemistry | 200 | MRT, PSVT: R | SV- 3D mental rotation | Rotation and Interpretation of Molecular Representations Test (RIMRT) clinical interviews | Visuo-spatial ability is generally a poor predictor of chemistry performance. |
| Stieff et al. (2012) [11] | Organic Chemistry 1 | 103 | MRT, PSVT: V | SV- 3D mental rotation, 3D mental views | organic chemistry assessments | Innate spatial ability has a low correlation with chemistry success. |
| Stieff et al. (2018) [23] | Organic Chemistry | 70 | RTMR (6 questions) | SV- 3D mental rotation | Molecular structure task | Spatial thinking depends more on representational competence than spatial ability. |
| Stieff et al. (2020) [24] | Organic Chemistry | 147 | PFT | SV- 2D mental transformation | Color change detection task | The study found that being good at "spatial tests" (MRT or PFT) did not predict how well students performed on the chemistry task. |

| | | | | | | |
|---|---|---|---|---|---|---|
| Yang et al. (2003) [37] | Introductory Chemistry | 415 | PSVT:R | SV- 3D mental rotation | CCDT (California Chemistry Diagnostic Test), Flashlight Pre-test | Higher spatial ability correlates with better chemistry performance. |

*Note*. CRT = Card Rotation Test; DAT = Differential Aptitude Test; GSAT = Greek Spatial Ability Test; MCT = Mental Cutting Test; MRT = Mental Rotation Test; PFT = Paper Folding Test; PSVT = Purdue Spatial Visualization Test, PSVT:D = PSVT: Visualization of Development; PSVT:R = PSVT: Visualization of Rotations, PSVT:V = PSVT: Visualization of Views; Q = questions; RTMR = Revised Test of Mental Rotation; SV = Spatial visualization