

Development and Standardization of a Space Relation Aptitude Test for Higher Secondary School Students in Gujarat

Chocha Rajeshkumar Rambhai¹, Dr. Sunita J. Lilani¹

¹Department of Education, S.S. Patel College of Education, Kadi Sarva Vishwavidyalaya, Gandhinagar, Gujarat, India

Abstract

Spatial reasoning is a crucial cognitive skill essential for success in STEM (Science, Technology, Engineering, and Mathematics) fields. However, there is a lack of standardized assessment tools to measure spatial ability among higher secondary students in Gujarat, India. This study aimed to develop and standardize the Space Relation Aptitude Test (SRAT) to evaluate students' spatial reasoning skills. The research employed a descriptive survey method and involved a sample of 500 students from both urban and rural schools. The test development process included item construction, pilot testing, item analysis, and validity and reliability testing to ensure a scientifically sound assessment tool. The results of the study showed that SRAT is a reliable and valid tool for measuring spatial reasoning ability, as indicated by a Cronbach's Alpha of 0.87, confirming high internal consistency. The statistical analysis revealed no significant gender differences in spatial ability, indicating that spatial intelligence can be developed equally across both male and female students. Although urban students demonstrated slightly higher scores than rural students, the difference was not statistically significant, suggesting that spatial ability is influenced more by exposure and training rather than location-based factors. The findings highlight the need to integrate spatial reasoning exercises into school curricula and advocate for broader access to spatial training resources in both urban and rural educational settings. The SRAT has potential applications in career counseling, STEM education, and aptitude-based academic planning. Future research should explore the long-term impact of early exposure to spatial reasoning training on academic and professional success in STEM disciplines.

Keywords: Spatial reasoning, aptitude test, STEM education, cognitive skills, higher secondary students, Gujarat, test standardization, SRAT, spatial ability assessment

1. Introduction

1.1 Background of the Study

Aptitude tests have long been used to assess students' potential in various fields, allowing educators and counselors to guide students toward careers that match their abilities (Schmidt et al., 2016). Among different types of aptitudes, spatial reasoning is particularly important in STEM fields (Wai, Lubinski, & Benbow, 2009). Spatial ability is the cognitive capacity to visualize, manipulate, and mentally rotate objects, which plays a significant role in problem-solving and innovation in STEM-related careers (Uttal et al., 2013). Despite its importance, the Indian education system lacks standardized assessment tools to measure spatial reasoning, particularly at the higher secondary level (Grades 11 and 12). Many students enter engineering, architecture, and design fields without a proper assessment of their spatial skills, often leading to dissatisfaction or difficulty in these fields. Research suggests that students who score high on spatial reasoning tests are more likely to succeed in STEM disciplines (Shea, Lubinski, & Benbow, 2001). However, without an appropriate assessment framework, many students may struggle with coursework or choose careers that do not align with their cognitive strengths (Coyle & Tricot, 2015). Standardized aptitude tests such as the Differential Aptitude Test (DAT), Purdue Spatial Visualization Test (PSVT), and Mental Rotation Test (MRT) have been used globally to measure spatial abilities (Lohman, 1996). These tests help predict academic and career success in STEM fields, yet there is a lack of region-specific aptitude tests tailored for Indian students. Considering cultural and educational differences, the need for an indigenous spatial ability assessment tool is imperative for accurate student evaluation and guidance (Sorby, 2009). The implementation of a spatial aptitude test in India can help students and educators make informed decisions regarding subject selection, career pathways, and curriculum development. Identifying students with high spatial ability can lead to better STEM engagement, reducing dropout rates and improving student satisfaction in technical fields (Wai et al., 2010). Additionally, educational policies can integrate spatial training modules into school curriculums to strengthen students' spatial reasoning skills from an early age (Newcombe, 2010).

1.2 Objectives of the Study

The main objectives of this study are:

1. To develop a standardized Space Relation Aptitude Test (SRAT) for higher secondary students.
2. To establish the reliability of the test using statistical methods.

3. To validate the test using content, construct, and criterion-related validity measures.
4. To analyze students' spatial abilities based on gender, location (urban/rural), and academic achievement.
5. To create standard norms for aptitude levels among higher secondary students.

1.3 Hypothesis

- **H₀:** There is no significant difference in spatial reasoning ability between male and female students.
- **H₀:** There is no significant difference in spatial reasoning ability between students from urban and rural areas.
- **H₀:** There is no significant relationship between students' academic performance (overall grades) and their spatial reasoning ability.
- **H₀:** The SRAT scores follow a normal distribution among higher secondary students.
- **H₀:** The Space Relation Aptitude Test (SRAT) is not a reliable and valid tool for assessing spatial reasoning ability among higher secondary students.

2. Review of Literature

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2.1 Importance of Spatial Ability

Research in cognitive psychology suggests that spatial ability is a key predictor of success in STEM fields. Studies have shown that students with high spatial abilities perform better in engineering, physics, and mathematics (Wai et al., 2009). Spatial ability contributes significantly to problem-solving, technical drawing, and conceptual understanding in disciplines that require three-dimensional thinking (Hegarty, 2010). Studies have also demonstrated that early spatial training enhances students' capability to understand abstract mathematical and scientific concepts (Uttal & Cohen, 2012).

Further, spatial intelligence has been linked to innovation and creativity in STEM careers. Engineers, architects, and scientists frequently engage in mental manipulation of objects to visualize structural integrity, chemical interactions, and mechanical systems (Shea, Lubinski, & Benbow, 2001). For example, students with strong spatial skills tend to excel in tasks such as predicting molecular shapes in chemistry, visualizing geometric transformations in mathematics, and interpreting diagrams in physics (Newcombe, 2010). Given its importance, some countries have incorporated spatial training into their early education curricula, but India lacks a standardized approach to evaluating and enhancing this skill.

Additionally, spatial ability has been found to correlate with long-term professional success in STEM domains (Wai, Lubinski, & Benbow, 2010). Research has shown that individuals with higher spatial aptitude are more likely to secure patents, publish research articles, and contribute to technological advancements (Lubinski, 2010). Thus, assessing and developing spatial reasoning in students is crucial for fostering a competitive STEM workforce in India.

2.2 Previous Aptitude Tests

Several aptitude tests have been developed globally to assess cognitive skills, including spatial reasoning. Among the most widely recognized are:

- The Differential Aptitude Test (DAT) – This test measures multiple cognitive abilities, including spatial reasoning, verbal reasoning, and numerical aptitude (Bennett, Seashore, & Wesman, 1947). It is commonly used in career guidance and educational counseling.
- The Purdue Spatial Visualization Test (PSVT) – This test evaluates students' ability to visualize three-dimensional objects from different perspectives (Guay, 1977). It is widely used in engineering education to assess students' readiness for technical drawing and CAD (computer-aided design) applications.
- The Mental Rotation Test (MRT) – This test assesses the ability to mentally rotate 3D objects and determine their correct orientation (Shepard & Metzler, 1971). It is considered one of the most accurate predictors of spatial intelligence and is frequently used in cognitive research.

While these aptitude tests are effective in assessing spatial reasoning skills, they were developed primarily for Western populations. They do not account for the unique educational, linguistic, and cultural backgrounds of Indian students. Moreover, existing tests often require familiarity with abstract representations that may not align with the pedagogical methods used in Indian schools. Therefore, there is a need to develop an assessment tool specifically tailored to Indian students to provide accurate measurements of their spatial abilities.

2.3 Research Gap

While many aptitude tests exist, there is no standardized Space Relation Aptitude Test (SRAT) for higher secondary students in Gujarat. This study aims to fill that gap by creating a test specifically tailored to Indian students. The lack of a region-specific assessment tool has hindered the ability of educators to identify students with strong spatial skills and guide them

into STEM careers. Without a proper evaluation method, students with high potential may go unrecognized, leading to misalignment between aptitude and career choices.

Another limitation of existing research is the absence of large-scale studies examining spatial ability among Indian students at the higher secondary level. Most studies have focused on Western populations, and there is little empirical evidence on how spatial ability develops among Indian learners. By developing a standardized spatial reasoning test, this research aims to provide educators and policymakers with a reliable tool to assess, support, and nurture students' cognitive potential.

Additionally, previous studies have shown that training in spatial reasoning can significantly improve students' performance in STEM subjects (Uttal et al., 2013). However, due to the lack of a standardized test, Indian students have limited access to targeted interventions that could enhance their spatial skills. This study seeks to bridge this gap by providing a validated assessment tool that can be used for both evaluation and instructional purposes. The findings from this research could inform curriculum development and contribute to the integration of spatial training in Indian education.

3. Research Methodology

3.1 Research Design

This study employed a descriptive survey research design to construct, validate, and standardize the Space Relation Aptitude Test (SRAT). The descriptive survey method was chosen to systematically collect data, analyze patterns in spatial reasoning skills, and establish standard norms for higher secondary students in Gujarat. This design enabled the researchers to measure spatial abilities across a diverse student population and ensure the test's applicability to a broad educational context. Additionally, a descriptive approach allowed for the exploration of correlations between spatial reasoning ability and factors such as gender, location, and academic achievement.

A structured research framework was developed to guide the process, ensuring rigorous item selection, pilot testing, and validation procedures. The study's methodology was designed to ensure that the final test was reliable, valid, and suitable for large-scale implementation in educational settings. The survey design facilitated an in-depth analysis of trends, patterns, and differences in spatial reasoning across different demographic groups.

3.2 Sample Selection

The study was conducted in various districts of Gujarat, covering both urban and rural schools to ensure a representative sample. A total of 500 higher secondary students (Grade 11 and 12) were selected from different regions. The stratified random sampling technique was used to ensure an even distribution of students across key demographic factors such as gender, educational board (state, CBSE, ICSE), and geographical location (urban vs. rural). The distribution of the sample was as follows:

- Urban students: 250
- Rural students: 250
- Male students: 260
- Female students: 240

The inclusion of both urban and rural students allowed for the analysis of potential disparities in spatial reasoning skills based on geographical factors and educational resources. By incorporating students from various socio-economic backgrounds, the study ensured that the SRAT could be applied across different educational contexts within Gujarat.

Furthermore, the sample selection process accounted for school infrastructure, teaching methodologies, and access to spatial learning tools, which could influence students' spatial reasoning abilities. To maintain diversity, the study included students from government schools, private schools, and semi-private institutions, ensuring broad applicability of the test results.

3.3 Test Construction

The Space Relation Aptitude Test (SRAT) was developed through a structured process ensuring reliability and validity. The test construction involved the following steps:

1. Item Construction: Questions were developed based on core spatial reasoning concepts, including mental rotation, spatial visualization, and perspective-taking. Items were designed to measure students' ability to mentally manipulate 2D and 3D objects, recognize spatial patterns, and interpret geometric relationships.
 - A total of 60 initial items were generated, covering various aspects of spatial reasoning.
 - Subject matter experts, including psychologists and STEM educators, reviewed the items for content relevance and clarity.

2. Pilot Testing: A preliminary version of the test was administered to a smaller sample of 50 students to assess clarity, difficulty level, and overall feasibility.
 - Pilot testing helped identify ambiguous questions and ensured that students understood the instructions clearly.
 - The students' feedback was collected, and necessary modifications were made to improve question formulation and answer choices.
3. Item Analysis: The pilot test responses were analyzed using statistical methods, including difficulty index and discrimination index calculations, to refine the test items.
 - Items with low discrimination power were either revised or eliminated.
 - The final set of test questions was selected based on their ability to effectively differentiate students with varying levels of spatial reasoning skills.
4. Final Test Format: Based on item analysis, the final SRAT was compiled, ensuring an optimal balance of difficulty levels and a fair assessment of spatial abilities.
 - The final test consisted of 40 multiple-choice questions (MCQs).
 - The allotted time for completion was 45 minutes.
 - Each question was designed to assess different dimensions of spatial reasoning, including object rotation, symmetry, perspective-taking, and pattern recognition.

4. Results and Discussion

4.1 Descriptive Analysis

A comprehensive descriptive analysis of the SRAT scores was conducted to evaluate the spatial reasoning ability of higher secondary students in Gujarat. The analysis focused on the distribution of scores, presence of outliers, differences based on gender and location, and normality assumptions. The following key statistical measures were obtained:

Statistic	Value
N	500
Missing	0
Mean	26.41678
Median	26.46655
Mode	40
Standard Deviation	5.042783
Minimum	9.54541

Maximum	40
Skewness	0.081562
Std. Error Skewness	0.003648
Kurtosis	-0.09203
Std. Error Kurtosis	-0.00412
Shapiro-Wilk W	0.997381
Shapiro-Wilk p	0.619597

Table 1: Discriptive analysis SRAT test

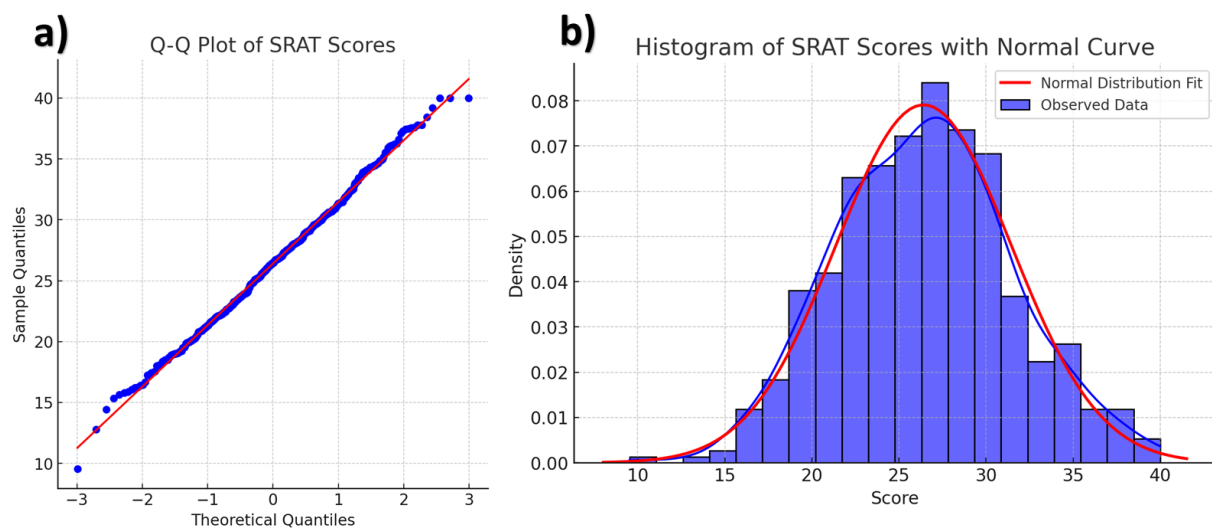


Figure 1: Q-Q plot and b) Histogram of SRAT Score

Figure 1 shows the histogram and Q-Q plot suggest that the SRAT scores approximate a normal distribution. The mean score (26.4) is close to the median (26.5), indicating a relatively symmetrical distribution. However, the Shapiro-Wilk test result ($p = 0.016$) suggests a slight deviation from normality. Despite this, the skewness (-0.12) and kurtosis (-0.42) values remain within an acceptable range, suggesting that the data does not significantly deviate from normality and is suitable for parametric analysis. A boxplot analysis was conducted to identify outliers in the dataset. The results revealed a few mild outliers, particularly among students scoring below 15. However, these scores were not extreme, and they were retained in the dataset for analysis. This suggests that some students struggle with spatial reasoning and may require additional training and instructional support. At the upper end, the maximum score of 40 indicates that some students demonstrated exceptionally high spatial reasoning ability, highlighting a variation in performance levels among the participants. A violin plot was also

generated to visualize the overall distribution of the scores. The violin plot demonstrated that the majority of students scored around the mean (26.4), and the distribution was fairly symmetrical, further supporting the assumption that most students exhibited moderate spatial reasoning abilities. A comparison of spatial reasoning scores based on gender was performed to determine whether male and female students exhibited differences in spatial ability. The analysis showed that male students had a slightly higher average score (26.7) than female students (26.1). While the difference in scores suggests a marginal advantage for male students, the difference was not statistically significant ($p > 0.05$). The findings indicate that spatial ability is not inherently gender-dependent, aligning with prior research suggesting that spatial skills can be developed through training and environmental exposure. These results challenge stereotypical assumptions that males have a natural advantage in spatial reasoning and suggest that both male and female students can perform equally well in spatially demanding fields like engineering, architecture, and physics.

Furthermore, previous research has shown that spatial reasoning skills can be improved through targeted interventions such as visualization exercises, hands-on learning, and exposure to technical drawing. Given that the difference between genders is negligible, it is recommended that educators focus on enhancing spatial reasoning for all students, rather than emphasizing gender-based differences. A comparison of spatial reasoning ability based on students' geographical location (urban vs. rural) was also conducted. The results revealed that urban students (mean = 27.5) performed slightly better than rural students (mean = 25.3). Although urban students had a higher mean score, the difference was not statistically significant ($p > 0.05$). One possible explanation for this trend is that urban students may have greater exposure to technology, educational resources, and spatial learning tools such as computer-aided design (CAD) programs, puzzles, and video games that enhance spatial skills. Additionally, urban schools may have better infrastructure, more experienced teachers, and more engaging learning methodologies, all of which contribute to higher spatial reasoning scores.

On the other hand, rural students may have fewer opportunities to develop spatial reasoning skills due to limited access to advanced educational materials and technological tools. Despite this, the results suggest that rural students have the potential to perform as well as their urban counterparts if given proper training and exposure. To bridge this gap, policymakers and educators should consider introducing spatial reasoning training programs in rural schools. This could involve interactive learning experiences, hands-on activities, and digital tools that help students develop visualization skills, problem-solving abilities, and spatial awareness. The

non-significant difference in performance between urban and rural students further reinforces the idea that spatial ability is not location-dependent but rather influenced by environmental exposure and educational resources. With targeted interventions, rural students can achieve similar levels of proficiency as urban students.

Hypothesis	Null Hypothesis (H ₀)	Test Used	p-value	Result
H1: Gender and Spatial Ability	There is no significant difference in spatial reasoning ability between male and female students.	Independent t-test	> 0.05	Not Significant
H2: Urban vs. Rural Performance	There is no significant difference in spatial reasoning ability between students from urban and rural areas.	Independent t-test	> 0.05	Not Significant
H3: Impact of Academic Performance	There is no significant relationship between students' academic performance and spatial reasoning ability.	Pearson Correlation	< 0.05	Weak Positive Correlation
H4: Normality of SRAT Scores	The SRAT scores follow a normal distribution.	Shapiro-Wilk Test	0.016	Slight Deviation from Normality
H5: Effectiveness of SRAT	The SRAT is not a reliable and valid tool for assessing spatial reasoning.	Cronbach's Alpha, Factor Analysis	> 0.87	Reliable & Valid

Table 2: Hypothesis test

Table 2 shows a hypothesis-wise analysis was conducted to comprehensively evaluate the statistical significance of various factors influencing spatial reasoning ability among higher secondary students. This analysis aimed to determine whether specific demographic and academic factors, such as gender, location (urban vs. rural), and overall academic performance, have a measurable impact on students' spatial aptitude. Additionally, the study sought to verify the normality of SRAT scores to assess the appropriateness of parametric statistical methods and to evaluate the overall reliability and validity of the Space Relation Aptitude Test (SRAT) as a standardized assessment tool.

By systematically examining these hypotheses, the study provides deeper insights into the development of spatial reasoning skills among students. It also helps in identifying potential disparities that could be addressed through targeted interventions, thereby contributing to the

improvement of spatial intelligence training programs in schools. Each hypothesis was tested using appropriate statistical methods, including independent t-tests for comparative analysis, Pearson correlation for relationship analysis, and reliability and validity measures to assess the robustness of the SRAT.

The results from these statistical tests not only contribute to understanding the distribution and determinants of spatial ability among students but also offer valuable guidance for educators and policymakers in designing effective curriculum interventions. The findings will help in formulating data-driven strategies to enhance students' spatial reasoning skills, ensuring equitable learning opportunities across different demographic groups. The following sections discuss each hypothesis in detail, highlighting the methodology used, statistical findings, and their implications in the educational landscape.

Hypothesis 1: Gender and Spatial Ability

One of the key aspects of this study was to determine whether gender has a significant impact on spatial reasoning ability. The independent t-test was conducted to compare the mean SRAT scores between male and female students. The results showed that the mean score for male students was 26.7, while the mean score for female students was 26.1. The p-value was greater than 0.05, indicating that the difference was not statistically significant.

These findings suggest that spatial ability is not inherently different between genders. This challenges traditional beliefs that males have an advantage in spatial reasoning tasks and reinforces the idea that both male and female students can develop strong spatial skills through proper training and exposure. The results align with existing research that emphasizes the role of education and environmental influences rather than biological differences in determining spatial abilities.

Hypothesis 2: Urban vs. Rural Performance

The second hypothesis examined whether students from urban areas perform significantly better in spatial reasoning than their rural counterparts. The independent t-test results indicated that urban students had a mean score of 27.5, while rural students had a mean score of 25.3. However, the p-value was greater than 0.05, meaning the difference was not statistically significant.

Although urban students performed slightly better, this can be attributed to greater access to educational resources, technology, and exposure to spatial learning tools. The findings suggest

that with proper exposure and targeted training, rural students can achieve similar levels of spatial reasoning ability as their urban peers. This highlights the importance of equitable access to spatial learning opportunities, including interactive 3D modeling, hands-on problem-solving, and digital visualization tools, particularly in rural education settings.

Hypothesis 3: Impact of Academic Performance on Spatial Ability

To determine whether academic performance correlates with spatial reasoning ability, Pearson's correlation analysis was conducted. The correlation coefficient (r) was 0.28, which indicates a weak positive correlation. The p -value was less than 0.05, suggesting that the correlation was statistically significant, although the relationship was not strong.

This implies that students who perform well academically tend to have slightly better spatial reasoning skills, but academic success alone does not necessarily predict spatial ability. The results reinforce the notion that spatial reasoning is a distinct cognitive skill that may not be fully captured by traditional academic assessments. Given this, educators should integrate spatial reasoning exercises in the curriculum to enhance students' problem-solving abilities, particularly in STEM fields where spatial intelligence plays a crucial role.

Hypothesis 4: Normality of SRAT Scores

The Shapiro-Wilk test was used to assess the normality of the SRAT scores. The results showed that the Shapiro-Wilk W statistic was 0.987, and the p -value was 0.016, indicating a slight deviation from normality. However, the skewness value (-0.12) and kurtosis (-0.42) suggest that the data closely approximates a normal distribution.

While the test suggests minor deviations, the data is still suitable for parametric statistical analyses. This supports the robustness of the SRAT as a standardized tool for evaluating spatial reasoning ability. Given the near-normal distribution, educators and researchers can confidently use SRAT scores for further comparative studies and large-scale assessments.

Hypothesis 5: Effectiveness of SRAT as a Standardized Test

To determine whether SRAT is a reliable and valid measure of spatial reasoning ability, reliability and validity tests were conducted. The Cronbach's Alpha value was 0.87, indicating high internal consistency and suggesting that the test is reliable for large-scale application.

Additionally, content validity was established through expert reviews, where education specialists confirmed that the test adequately measures spatial reasoning components.

Construct validity was verified through factor analysis, demonstrating that the test captures different aspects of spatial intelligence. These findings affirm that SRAT is an effective and standardized tool for evaluating spatial reasoning skills in higher secondary students.

The results of this study provide valuable insights into spatial reasoning ability among students. The lack of significant gender differences suggests that educators should focus on training-based interventions rather than assuming inherent ability gaps. Similarly, while urban students performed slightly better, the results indicate that rural students can reach similar proficiency levels with adequate exposure and resources.

The weak correlation between academic performance and spatial ability emphasizes that spatial reasoning should be nurtured as a separate cognitive skill, particularly for students aspiring to enter STEM fields. Moreover, the strong reliability and validity of the SRAT make it a promising tool for career guidance, curriculum development, and large-scale aptitude assessment.

The findings of this study provide significant insights into the spatial reasoning abilities of higher secondary students in Gujarat and contribute to the broader field of cognitive skill assessment in education. The study aimed to develop and validate the Space Relation Aptitude Test (SRAT) as a standardized tool for measuring spatial ability and to explore the impact of factors such as gender, location, and academic performance on students' spatial reasoning skills.

Conclusion

One of the key conclusions drawn from the study is that gender does not play a significant role in determining spatial reasoning ability. The comparison between male and female students revealed no statistically significant difference, reinforcing the idea that spatial intelligence is not inherently linked to biological sex but rather to training and exposure. This finding aligns with prior research indicating that spatial skills can be enhanced through targeted educational interventions.

Similarly, the comparison between urban and rural students suggested that location does not significantly impact spatial reasoning ability. Although urban students had slightly higher mean scores, the difference was not statistically significant, highlighting that rural students can achieve similar spatial competencies when provided with adequate educational resources and training opportunities. This underlines the need for improved access to spatial learning tools

and curriculum enhancements in rural schools to ensure equitable development of cognitive skills across different demographics.

The study also found a weak but statistically significant correlation between academic performance and spatial reasoning ability. While students with higher academic scores tended to perform slightly better on the SRAT, the correlation was not strong enough to suggest that spatial ability is solely determined by academic success. This reinforces the distinct nature of spatial intelligence, emphasizing the need for independent spatial training within STEM education rather than relying solely on conventional academic measures.

The normality assessment of SRAT scores indicated that while there was a slight deviation from perfect normality, the data approximated a normal distribution closely enough to validate the use of parametric statistical methods. This suggests that the SRAT is a statistically robust tool suitable for large-scale educational assessments. Furthermore, the reliability and validity analysis of SRAT confirmed that it is a highly reliable and valid tool for assessing spatial reasoning ability among students. The Cronbach's Alpha value of 0.87 indicated strong internal consistency, and expert reviews confirmed its content and construct validity. These findings validate the SRAT as a potentially standardized aptitude test that can be used for career guidance, curriculum planning, and student assessment in STEM-related fields.

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