

Article

The Role of Spatial Ability in Academic Success: The Impact of the Integrated Hybrid Training Program in Architecture and Engineering Higher Education

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Abstract: Spatial ability (SA) is a critical cognitive skill across various disciplines, particularly in architecture and engineering. This research, comprising two main studies, investigates the relationship between SA and academic performance among first-year students. The first study examines the impact of the targeted Integrated Hybrid Training (IHT) SA intervention on the achievements of two main groups: engineering (electrical, software, and chemical) students and architecture students. The results indicate that, while the intervention significantly improved SA, the impact on academic performance varied. Architecture students, whose curriculum relies heavily on spatial reasoning, showed significant gains in courses such as studio design, with higher SA scores correlating with improved grades. Engineering students exhibited SA improvement without corresponding gains in the first-year core courses like calculus and physics. The second study focuses on architecture students who did not receive the intervention, revealing a strong positive correlation between inherent SA and success in architecture-specific courses. Correlation coefficients (r) ranged from 0.46 to 0.67, with adjusted p -values between 0.007 and 0.024, underscoring SA's importance in architecture. These findings suggest that integrating SA training into architectural education can enhance academic performance, while disciplines might benefit from specialized SA training introduced or expanded in later years. This research contributes to educational theory by demonstrating SA's impact across disciplines and supports the development of customized SA training programs. Future studies should explore long-term benefits, advanced SA training technologies, and individual differences in response to spatial interventions, providing insights for curriculum development in spatially demanding fields.

Keywords: spatial ability; integrated hybrid training; architecture education; engineering education; STEM; spatial visualization; spatial reasoning; cognitive skills; higher education



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1. Introduction

The term spatial ability (SA) connects studies from different fields of knowledge. This term has various definitions and is referred to by other names, such as ‘spatial cognition’, ‘spatial thinking’, ‘spatial intelligence’, and ‘spatial sense’ [1]. Despite the different definitions, all those involved in the field agree that SA plays a vital role in the proper function of the environment in which we live and develop [2].

Eliot and Smith’s definition [3] of SA is the perception and recall of visual forms, manipulation of structures (changes of position, orientation or shape, cutting, joining, etc.), and reconstruction of them. In articles reviewed by Linn and Petersen [4], the various definitions of SA usually relate to the skills of representing, modifying, creating, and remembering symbolic and non-verbal information.

Gardner [5], in his model of multiple intelligences, sees SA as one of the intelligences. By his definition, spatial intelligence is the ability to create a mental image of a spatial

world, to imagine the motion of bodies or changes and processes occurring in them. This ability makes it possible to grasp the visual world accurately, change it, and process it in the imagination. According to Gardner [6], spatial intelligence includes several capabilities: the ability to capture two-dimensional shapes or objects in space accurately, the ability to imagine and graphically represent visual or spatial ideas, the ability to evaluate a shape or object's appearance after imagination's manipulation, and the ability to evaluate what a shape or object will look like from another point of view.

Maier [7] improves Gardner's multiple intelligences model and theory when he distinguishes between five elements of SA that include spatial perception, visualization, mental rotation, spatial relations, and spatial orientation. The first element, spatial perception, refers to the ability to identify a horizontal or vertical orientation despite distracting information. The second element, visualization, involves the ability to mentally visualize a configuration in which parts are moving or changing positions internally. The third element, mental rotation, is the skill of quickly and accurately rotating a 2D or 3D figure in the mind. The fourth element, spatial relations, is the capacity to understand the spatial configuration of objects or their components and how they relate to each other. The final element, spatial orientation, is the ability to physically or mentally orient oneself within a given spatial environment.

Armstrong [8] notes that, following this ability, it is possible to reconstruct and activate the imaginary parts of the visual world even without seeing them. Thus, for example, the ability to visualize the route up to a particular destination you want to reach is a complex task that requires a series of actions, such as imagining the route of the roads leading to the destination: imagining the road route to describe in which section there is an ascent successfully and where the parking lot or supermarket is located, and planning your way back based on directions to your destination. In mathematical language, the organization of space is its conceptualization of lines, angles, polygons, bodies, and the like, from performing sliding transformations, rotating, and reflecting on them [9].

Buckley et al. [10] explored the origins and evolution of SA in the broader context of human intelligence, aiming to provide a refined contemporary definition. One of its main discussions is the Cattell–Horn–Carroll (CHC) theory [11,12]. The CHC theory is currently recognized as the principal framework for describing individual differences in the structure of human intelligence. As the CHC theory suggests a contemporary framework of cognitive factors, it is most appropriate to define SA based on its factor structure within this framework. The CHC theory presents this framework as a hierarchical structure containing one third-order factor, the general intelligence (g), and 16 second-order factors representing the primary mental abilities. SA is represented as a second-order factor; however, it is referred to as the Gv factor or visual processing. While these two terms describe the same factor, SA is its more commonly used name. The Gv factor is the ability to leverage mental imagery to address problems [12]. The CHC theory further breaks down SA into 11 first-order factors, which can be grouped into spatial skills, perceptual factors, and memory factors.

Sorby [13] offers a nuanced perspective, differentiating between innate spatial skills and learned SA, which has implications for educational strategies aimed at enhancing SA. In a study conducted among engineering students, it was observed that spatial imagery ability developed more effectively in courses where students engaged in drawing models by hand rather than using a computer, and worked with tangible models instead of virtual ones displayed on a monitor. This suggests that hands-on, physical interaction with models may contribute significantly to improved spatial performance.

1.1. SA as a Malleable Cognitive Skill

The malleability of SA has been a topic of significant interest in educational psychology. Traditionally, SA was considered an innate ability that individuals either possessed or lacked. However, more recent research has shown that targeted interventions can train and improve SA [14]. This shift in understanding has important implications for education,

particularly in Science, Technology, Engineering, and Mathematics (STEM) and architecture, where spatial reasoning is essential.

Uttal et al. [2] conducted a meta-analysis of training studies. They found that SA can be improved through various methods, including hands-on model building, computer-aided design (CAD) software, and interactive 3D simulations. The study also emphasized that the improvements in SA were durable and could be transferred to other cognitive tasks. This finding supports the rationale for incorporating SA training into educational curricula, particularly for students in spatially demanding fields such as engineering and architecture.

Sorby's research [15] further reinforced the idea that SA can be developed through structured training programs. Her work focused on engineering students and demonstrated that those who participated in SA training significantly improved their ability to visualize and manipulate objects in 3D space. These gains in SA translated into better performance in technical courses, such as engineering graphics and mechanical design [16].

In the context of architecture, similar interventions have been less widely studied. However, the initial work by Maier [7] and another later one by Berkowitz et al. [17] suggest that architecture students can also benefit from SA training. Maier's modular construction system, which involved physical model building, was one of the earliest attempts to improve SA in architecture students. Although effective, this approach was resource-intensive and time-consuming. In contrast, the current study builds on these earlier efforts by introducing the Integrated Hybrid Training (IHT) program, which combines traditional methods with technological tools like augmented reality (AR) and computer-based learning (CBL) to enhance SA more efficiently [18].

1.2. SA and Academic Performance in STEM and Architecture

In STEM fields, particularly engineering, SA has been identified as a strong predictor of academic success. For example, engineers rely on SA to visualize and manipulate technical diagrams, models, and complex systems. Engineering students often face challenges in courses that require visualizing abstract mathematical concepts in a spatial context, such as calculus, physics, and mechanical design [13,19]. This aligns with research showing that students with high SA perform better in subjects requiring the interpretation of 3D structures and spatial reasoning [20,21].

While sharing some cognitive demands with engineering, architecture places an even greater emphasis on SA due to the need for spatial visualization in design processes. Architects must mentally transition between 2D representations (plans and sketches) and 3D constructions, which requires a high amount of spatial thinking [22]. However, architecture students are underrepresented in SA research compared to engineering students. Studies conducted by Berkowitz et al. [17] have demonstrated that architecture students improve their SA throughout their studies in both undergraduate and graduate programs. Nevertheless, the long-term effects of such improvements on academic performance remain underexplored [23,24].

1.3. SA in Engineering and Architecture Higher Education

SA is widely considered as a critical cognitive skill for success in STEM fields, including science, technology, engineering, and mathematics. Researchers have established that SA enables individuals to visualize and manipulate objects in space, which is essential for understanding complex concepts and solving problems in disciplines requiring abstract reasoning. Several studies have demonstrated a strong correlation between SA and academic achievement in STEM fields [2,25]. One of the most influential early works on the relationship between SA and academic performance in STEM was conducted by Sorby [15]. Sorby's research highlighted that students with higher SA scores were better equipped to understand technical drawings, interpret 3D models, and solve problems related to mechanical design. This connection between SA and academic performance in STEM was further supported by Wai, Lubinski, and Benbow [20], who found that SA better predicted long-term success in STEM fields than verbal or quantitative abilities.

For engineering students, understanding spatial relationships is crucial not only in design but also in core subjects such as mathematics and physics, where students must solve problems involving spatial visualization and design [26,27]. SA is pivotal in facilitating the mastery of three-dimensional concepts essential for engineering education. Engineering students typically begin their academic journey in their first mathematics and physics courses by dealing with two-dimensional scenarios, engaging with basic functions from the XY plane (2D) and single-variable functions. This foundational knowledge in algebra, calculus, and physics is critical for mastering linear equations and differential calculus, preparing students to tackle more complex, multidimensional problems [28]. As engineering students progress in their studies, they are gradually introduced to three-dimensional representations, particularly in courses such as multivariable calculus and physics (see Figure 1). This transition is fundamental for understanding volumes and planes within the XYZ space (3D), a necessary skill for visualizing and solving complex scenarios in mathematics, physics, and engineering [29]. By the second year, students explore geometric transformations in higher-dimensional spaces, such as ellipsoids and hyperboloids, essential for comprehending spatial relationships [30].

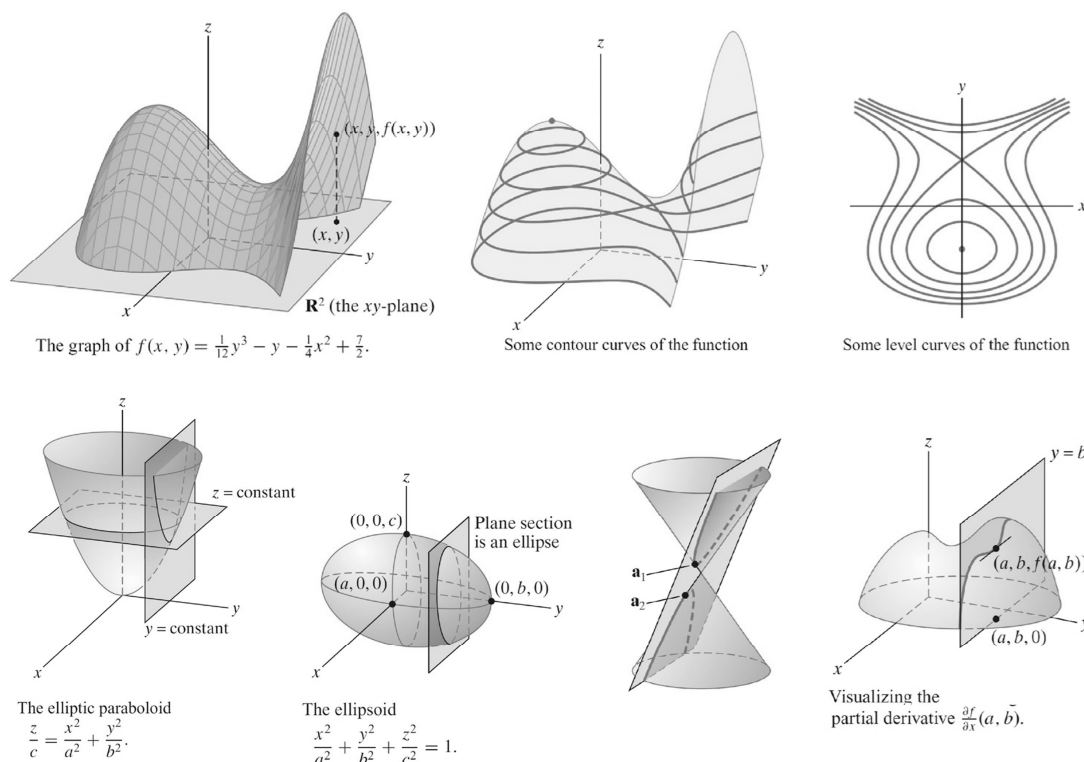


Figure 1. Top row: Example of contour and surface visualization in multivariable functions in calculus. Bottom row: Example of the intersection of geometric shapes with planes in calculus: elliptic paraboloid, ellipsoid, hyperbola, and general two variables function [26,27,31].

Recent studies have emphasized the importance of SA in architecture, where it plays a vital role [17]. Architects also require strong mathematical competence to calculate structural strength, determine optimal stabilization methods, and more [32]. When designing objects such as buildings, including the surrounding indoor and outdoor spaces, architects use a multi-step process of manipulating spatial configurations and switching between perspectives [33]. Moreover, they need to visualize various structure components, using direct tools and representations to implement their spatial designs. These include schemes with sections cut through different planes, such as parallel or perpendicular to the orthogonal axes. Architects also rely on other representations, such as plans, 3D sketches, views, and elevations, to construct the entire 3D design (see Figure 2). These tasks require strong SA skills, essential for packing and unpacking multiple models and 3D designs. Additionally,

architects often use and evaluate objects' sizes, lengths, and spatial arrangement, enabling them to explore different configurations and ensure the seamless integration of all design elements. Very few studies have demonstrated a correlation between improved SA and success in architecture studies. Some recent studies have shown that architecture students, as engineering students, become better at SA after the first year of academic studies [14]. Moreover, Leopold et al. [23] found an improved performance on the SA test among first-year students both in engineering and architecture after taking introductory engineering graphics courses.

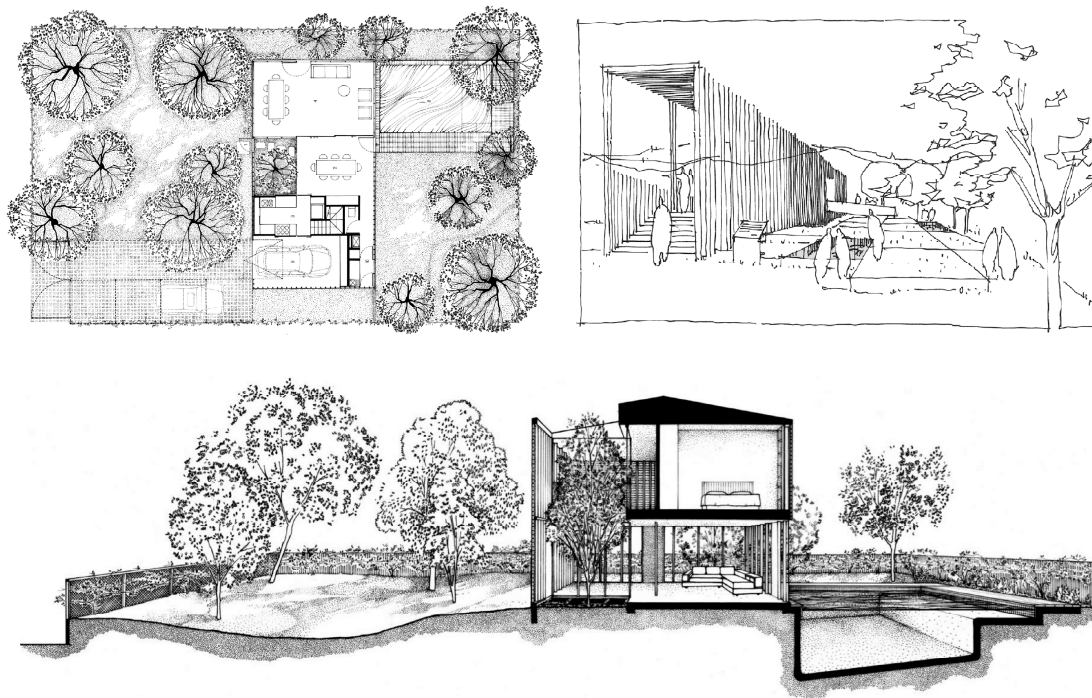


Figure 2. Examples of architectural spatial layouts: top-down plan, exterior perspective, and sectional view of a building, illustrating both indoor and outdoor environments.

1.4. Integrated Hybrid Training (IHT): A Multidisciplinary Approach to SA Development

The Integrated Hybrid Training (IHT) program, detailed by Porat and Ceobanu [18], was designed to address some of the limitations of earlier SA training programs. While traditional methods such as physical model building and computer-aided design (CAD) software were shown to be effective, they often lacked integration and flexibility. The IHT program seeks to combine the best aspects of both approaches—melding traditional tactile learning with modern technological tools to create a more comprehensive learning experience.

The IHT program, first tested on engineering and architecture students, incorporates hands-on activities, traditional lectures, computer-based simulations, and augmented reality (AR) technology. AR, in particular, has been recognized as a valuable tool for enhancing SA, as it allows students to interact with digital 3D models overlaid in real-world settings. This immersive experience helps to strengthen spatial reasoning by providing both visual and interactive elements in real time [34,35]. Additionally, integrating computer-based learning (CBL) tools such as SketchUp and GeoGebra enhances the flexibility of SA training, allowing students to practice spatial transformations and visualizations in virtual environments [36,37]. The IHT program has significantly improved SA among engineering and architecture students. This improvement was particularly notable among architecture students, who benefited from combining traditional and technological methods. By providing a multidimensional approach to learning, IHT allows students to strengthen their SA skills in ways that single-method programs cannot. This flexibility is especially

important in architecture, where design processes require constant shifts between 2D and 3D thinking.

1.5. Gaps in Current Research and the Need for Multidisciplinary Analysis

While previous studies have laid the groundwork for understanding the importance of SA in education, there is still a significant gap in examining how SA impacts academic performance across both engineering and architecture. The last research made by Porat and Ceobanu [14,18] has focused on short-term intervention and its immediate effects on SA scores, but little is known about the lasting impact of these interventions on students' overall academic success. Furthermore, the existing literature rarely compares the SA development of students across different disciplines. This study aims to fill this gap by analyzing students from both engineering and architecture faculties and assessing the impact of SA training on their academic performance over two semesters. Doing so highlights the multidisciplinary nature of SA and its differing applications in these two fields.

In summary, this research builds on two earlier studies focusing on improving SA in first-year students using traditional and innovative methods. The first study examined the effectiveness of SA training on a sample of first-year engineering and architecture students, concluding that SA can be improved in time-efficient and cost-effective sessions but still without correlating with better academic performance. The second study introduced the Integrated Hybrid Training (IHT) program, which used traditional teaching methods, hands-on model building, and advanced technological tools like augmented reality (AR) to enhance students' SA. The IHT approach is unique in that it integrates various pedagogical strategies and aims to address the diverse learning styles of students from both faculties. It also seeks to maximize the efficiency of SA training by condensing it into a short, intensive program while still achieving significant cognitive gains. This study expands the focus beyond SA improvement alone, examining how these SA improvements translate into enhanced academic performance over an academic year.

1.6. Objectives and Hypotheses of the Study

The primary objective of this study is to evaluate the long-term impact of the IHT program on academic performance among first-year engineering and architecture students. The study aims to investigate whether the improvements in SA achieved through the IHT intervention are sustained across two semesters and how these improvements correlate with students' grades in key courses and overall grade point average (GPA). This leads to the following hypotheses:

Hypothesis #1:

Directional Hypothesis: Students who participate in the IHT program will achieve higher first-year GPAs and grades in key engineering and architecture courses compared to students who do not participate in the program. Null Hypothesis: There will be no significant difference in first-year GPA and grades in key engineering and architecture courses between students who participate in the IHT program and those who do not.

Hypothesis #2:

Directional Hypothesis: There will be a positive correlation between initial SA scores and academic success in architecture-specific courses, as measured by first-year GPA and grades in relevant courses. Null Hypothesis: There will be no significant correlation between initial SA scores and academic success in architecture-specific courses, as measured by first-year GPA and grades in relevant courses.

2. Materials and Methods

The research was conducted at Shenkar College in Israel, an academic institution for education and research in engineering, design, and art. Two integrated studies investigated the effects of SA on academic performance among first-year students at this multidisciplinary college. The research expanded upon previous findings, demonstrating the potential for targeted interventions to enhance SA. It highlighted the critical role of

spatial reasoning in disciplines such as architecture and engineering. By examining the impact of an SA-focused intervention and the natural correlation between SA and academic success, this study aimed to provide a comprehensive understanding of how spatial skills contribute to academic achievement, particularly in architecture.

The primary objective of this study was to explore the relationship between SA and academic performance. Specifically, it aimed to assess whether participation in a targeted SA intervention program could lead to improved academic outcomes in terms of GPA and performance in core courses. Additionally, the study sought to address a knowledge gap regarding the correlation between SA and academic success in architecture students who had not undergone SA intervention or improvement programs. By focusing on non-intervention architecture students in Study 2, the study aimed to understand better how inherent SA influences academic achievement in architecture without the impact of any training.

2.1. Participation Criteria

All participants were required to be first-year college students in their bachelor's degree and had not previously attended academic studies at other institutions. Each participant had completed 12 years of secondary education, with assessments in mathematics and English according to national curriculum standards. Proficiency in the local language was necessary, as all materials, including the SA test and academic coursework, were administered in that language. Students who had previously participated in university-level education or undergone any specific SA training were excluded from the study, ensuring that the effects of the intervention could be measured without prior exposure to similar academic content. Ethical standards were maintained throughout the study, with participants providing informed consent after being fully briefed on the study's aims, methods, and confidentiality protocols. Anonymized data were collected to protect participant privacy. Engineering students included in the study were enrolled in Electrical and Electronic Engineering, Software Engineering, and Chemical Engineering. Their first-year curriculum focused on foundational mathematics and physics courses, including Differential and Integral Calculus and Physics. These courses are critical to their success and require strong spatial and abstract reasoning skills—the intervention program aimed to enhance these skills, hypothesizing that this would lead to better academic outcomes. The architecture students who participated in the research are from the architecture department in the design faculty. Relevant core courses, such as Architecture Studio A and B and Architecture Tools A and B, designed to develop spatial abilities, were chosen as a crucial focus for measuring the impact of the SA intervention. Additionally, these courses were used to assess whether inherent SA naturally correlates with better academic performance among students who did not receive targeted SA training.

2.2. Data Collection and Sample Size

The research was divided into two Studies, each designed to collect comprehensive data on academic performance and SA. A total of 154 engineering and architecture students in their first year of study participated in this research, consisting of 79 engineering students and 75 architecture students. Among the engineering group, 47 students participated in the SA training program, while 32 others constituted the engineering control group, who did not undergo the training and practice program. In architecture, the same program was delivered to 42 students, and 33 architecture students were part of the control group that did not undergo the program.

It should be noted that every student who participated in the program, whether from engineering or architecture and regardless of whether they were in the group that was trained and practiced by intervention or in the control group, was tested in the SA test twice: SA pre-test and post-test, under the same examination conditions and in an identical timeframe.

2.2.1. Study 1: Intervention Program and Academic Performance

In Study 1, the focus was on measuring the impact of the SA intervention program on academic performance. The intervention group consisted of both engineering and architecture students who participated in an SA training program that aimed to improve their spatial visualization, mental rotation, and spatial perception. The control group followed the regular curriculum without additional SA training.

Key courses were selected for analysis to assess the intervention's impact. For engineering students, courses such as Differential and Integral Calculus 0, 1, and 2 and Physics 0, 1, and 2 were analyzed. These courses are critical for first-year engineering education, requiring spatial and abstract reasoning skills that were expected to improve through the intervention. Courses like Architecture Studio A and B and Architecture Tools A and B were chosen for architecture students. These courses directly assess the students' ability to apply spatial reasoning in design tasks, making them an ideal measure of the intervention's effectiveness. Academic performance data, including GPAs and final grades for the first and second semesters, were collected at the end of the academic year.

2.2.2. Study 2: Correlation Between SA and Academic Performance for Control Group Architecture Students

Study 2 was designed to investigate the correlation between inherent SA and academic success, focusing exclusively on architecture students who had not participated in previous SA intervention programs. This study aimed to address a critical knowledge gap regarding how initial SA level impacts academic outcomes in architecture without the influence of targeted training. The goal was to narrow the understanding of how SA independently affects academic performance in architecture-related subjects.

These architecture students completed a standardized SA test at the beginning of the academic year. This test, widely used and validated in educational research, measured three dimensions of SA: spatial visualization (the ability to manipulate complex objects mentally), mental rotation (the ability to rotate objects in space), and spatial perception (the ability to understand spatial relationships between objects). The results of this test provided a baseline measure of each student's inherent SA, which was then correlated with their academic performance at the end of the year.

Academic performance in Study 2 was measured through GPAs and final grades in key architecture courses, such as Architecture Studio A and B and Architecture Tools A and B. These courses were chosen specifically because they demand high levels of spatial reasoning and design skills, making them ideal for assessing the natural influence of SA on academic success.

2.3. Research Instruments

2.3.1. SA Test

At the start of the academic year, participants in Study 2 completed a standardized SA test designed to measure their spatial visualization, mental rotation, and spatial perception abilities. This test was administered in a controlled environment and provided a quantitative baseline measure of each student's inherent SA. The test has been widely validated in educational research, particularly in disciplines that require strong spatial reasoning skills, such as architecture and engineering [14,38–41].

2.3.2. Academic Performance Data

Academic performance data were collected from the college's official records at the end of the first and second semesters. These records included GPA data and grades in key courses selected for their relevance to spatial reasoning and academic success. The study ensured that the performance data were accurate and free from reporting bias by using official academic records. All data were anonymized before analysis to protect the privacy of participants.

2.4. Statistical Analysis

In Study 1, statistical comparisons between the intervention and control groups were performed using t-tests and analysis of variance (ANOVA) to determine whether the SA intervention led to significant differences in academic performance. The analysis focused on comparing GPAs and final grades in the selected courses. Bonferroni corrections were applied to control for multiple comparisons, ensuring the validity of the results. Covariates, including sociodemographic factors such as age and prior academic performance, were considered to account for any pre-existing group differences.

In Study 2, regression analyses were conducted to explore the predictive power of inherent SA on academic performance. Pearson's correlation coefficients were calculated to determine the strength of the relationship between SA scores and academic outcomes in architecture courses. The analysis controlled for additional variables, such as secondary school performance, to isolate the specific contribution of SA to academic success. This Study focused on identifying whether higher SA scores were associated with better performance in architecture courses that require spatial reasoning.

3. Results

3.1. Results for Study 1

3.1.1. Sample Demographics

Faculties' differences: The mean age was similar among students of different faculties ($t = 1.17, p = 0.24$), averaging 22.75 (3.94) among architecture students (AS) and 23.47 (2.41) among engineering students (ES). The groups differed significantly on sex distribution, with 82.7% of AS being female, and only 45.6% of ES being female ($\chi^2(1) = 21.3, p < 0.0001$). ES had a higher percentage than AS of students with medium to advanced levels of high-school math (4–5-units level, 69.9% vs. 38.7%, $\chi^2(2) = 16.1, p = 0.0003$) and English (100% vs. 80.0%, $\chi^2(2) = 18.1, p = 0.0001$) education. Among ES, 74.6% majored in sciences, and 24.1% majored in humanities in high school, while, among AS, 45.3% majored in sciences, 28.0% majored in humanities, and 26.7% majored in arts. These distributions differed significantly ($\chi^2(2) = 26.8, p < 0.0001$). There were no faculty differences in the percentage of students employed parallel to their studies (ES = 64.6%, AS = 58.7%, $\chi^2(1) = 0.34, p = 0.56$).

Intervention groups' differences: The intervention and control groups did not differ in age (intervention = 23.0 + 2.78, control = 23.16 + 3.85, $t = 0.27, p = 0.78$) or sex distribution (intervention = 59.6% female, control = 69.2% female, $\chi^2(1) = 1.13, p = 0.29$). The groups did not differ in high-school level math ($\chi^2(2) = 0.45, p = 0.80$) or English studies ($\chi^2(2) = 1.85, p = 0.40$), or in high school majors ($\chi^2(2) = 0.16, p = 0.92$), but differed in the percentage of students employed (intervention = 53.9%, control = 72.3%, $\chi^2(1) = 4.61, p = 0.032$). The sample's sociodemographic properties stratified by faculty and group are summarized in Table 1.

Table 1. Sociodemographic properties stratified by faculty and group.

Variable	Arch. (<i>n</i> = 75)	Eng. (<i>n</i> = 79)	<i>t</i> / χ^2	<i>p</i> -Value	Intervention (<i>n</i> = 89)	Control (<i>n</i> = 65)	<i>t</i> / χ^2	<i>p</i> -Value
Age	22.75 (3.94)	23.37 (2.41)	1.17	0.24	23.0 (2.78)	23.16 (3.85)	0.27	0.78
%Female	82.7%	45.6%	21.3	<0.0001	59.6%	69.2%	1.13	0.29
High School math:								
3 units (basic)	60.0%	29.1%	16.1	0.0003	46.1%	41.5%	0.45	0.80
4 units (medium)	32.0%	53.2%			41.6%	44.6%		
5 units (advanced)	6.7%	17.7%			11.2%	13.8%		
High School English:								
3 units (basic)	18.7%	0.0%	18.0	0.0001	11.2%	6.2%	1.84	0.40
4 units (medium)	29.3%	26.6%			24.7%	32.3%		
5 units (advanced)	50.7%	73.4%			62.9%	61.5%		

Table 1. Cont.

Variable	Arch. (<i>n</i> = 75)	Eng. (<i>n</i> = 79)	<i>t</i> / χ^2	<i>p</i> -Value	Intervention (<i>n</i> = 89)	Control (<i>n</i> = 65)	<i>t</i> / χ^2	<i>p</i> -Value
High School Major:								
Arts	0.0%	26.7%	26.7	<0.0001	12.4%	13.8%	0.16	0.92
Humanities	24.1%	28.0%			27.0%	24.6%		
Sciences	74.6%	45.3%			59.6%	61.5%		
Employed	58.7%	64.6%	0.34	0.56	72.3%	53.9%	4.61	0.03

3.1.2. Study 1 First Hypothesis—SA Pre-Assessment Scores

We computed Pearson correlations to assess the association between SA scores in the pre-assessment and course scores/GPA in the first two terms of the degree and at the end of the first year. To control for multiple comparisons, we corrected our significance values using Benjamini and Hochberg’s False Discovery Rate (FDR) correction and present the adjusted *p*-values. As expected, SA scores in the pre-assessment correlated with the course scores and GPA in both terms as well as the final GPA, but only among architecture students ($0.37 < r < 0.55$, $t(65) = 3.23$ to 5.22 , $p < 0.002$). Among engineering students, SA scores at pre-assessment were significantly associated with the final GPA ($t(66) = 2.85$, $p = 0.006$) but not with the course scores or with the GPA in either term (Table 2).

Table 2. Correlations among SA scores in the pre-assessment and course scores/GPA.

Course	<i>r</i>	Architecture			<i>r</i>	Engineering		
		<i>t</i>	<i>df</i>	<i>p</i> -Value ¹		<i>t</i>	<i>df</i>	<i>p</i> -Value ¹
Tools 1	0.47	4.32	65	<0.001	-	-	-	-
Studio 2	0.37	3.23	65	0.002	-	-	-	-
Tools 2	0.39	3.40	65	0.001	-	-	-	-
Calculus 0	-	-	-	-	0.03	0.22	51	0.83
Physics 0	-	-	-	-	-0.21	-1.46	47	0.15
Calculus 1	-	-	-	-	-0.06	-0.39	50	0.70
Physics 1	-	-	-	-	-0.02	-0.11	42	0.92
Calculus 2	-	-	-	-	-0.24	-1.32	29	0.20
Physics 2	-	-	-	-	0.03	0.14	25	0.89
GPA (1st term)	0.50	4.55	63	<0.001	0.12	0.88	51	0.38
GPA (2nd term)	0.42	3.67	63	0.001	0.15	1.11	51	0.27
GPA (final)	0.55	5.22	63	<0.001	0.33	2.85	66	0.006

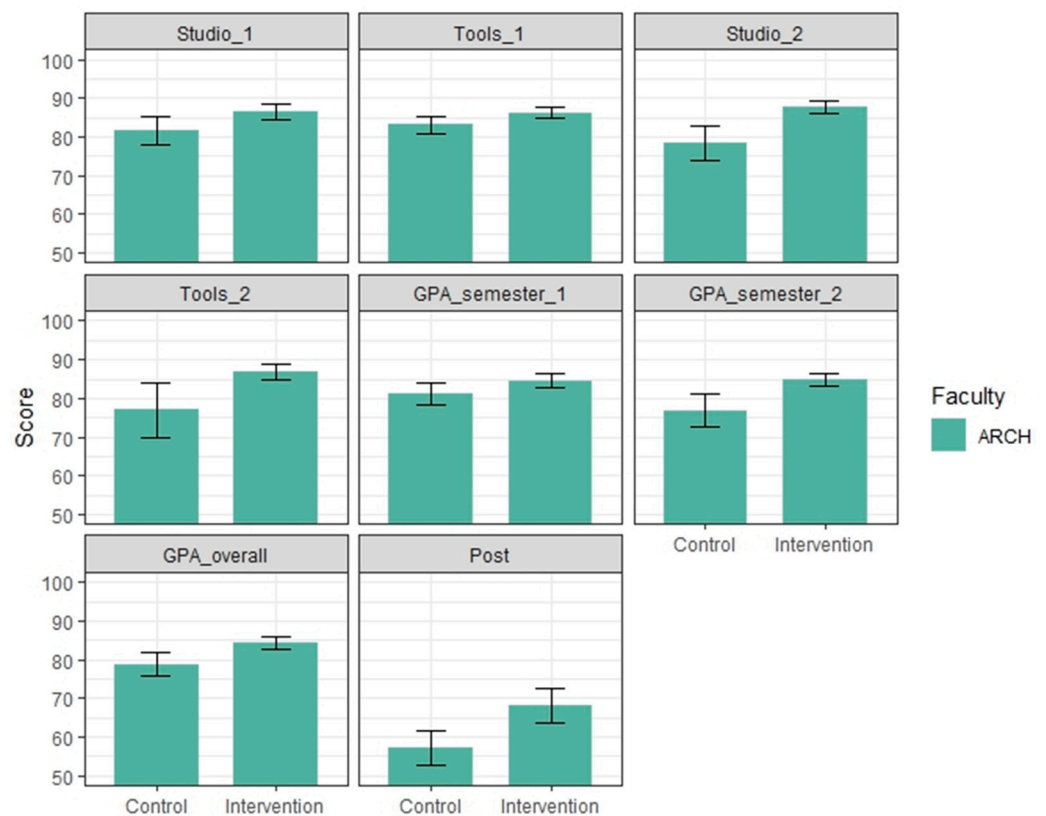
¹ *p*-values are corrected for multiple comparisons using the Benjamini–Hochberg False Discovery Rate (FDR) correction [42].

3.1.3. Study 1 Second Hypothesis—Intervention Effects on Course Scores/GPA

To examine the intervention’s effects on course scores/GPA, we conducted linear regressions with the course/GPA score as the dependent variable. The intervention/control group served as the predicting independent variable in the model, while pre-SA scores were modeled as a continuous covariate to control baseline interpersonal differences. As previously described, we used FDR to adjust *p*-values for multiple comparisons. Among architecture students, the intervention group scored significantly higher on the SA post-assessment ($B = 10.2$, $t(71.4) = 6.6$, $p < 0.0001$) and on all courses ($2.85 < B < 9.34$, $t(63$ to $64) = 2.69$ to 5.03 , $p < 0.01$). See Table 3 and Figure 3.

Table 3. Correlations among course scores and GPA for intervention and control groups of architecture students.

Course	Intervention Mean (SD)	Control Mean (SD)	B	t	p-Value
Studio_1	86.57 (6.59)	81.48 (8.74)	4.73	2.69	0.009
Tools_1	86.24 (4.12)	83.12 (5.51)	2.85	2.69	0.009
Studio_2	87.69 (5.46)	78.32 (10.46)	8.99	5.03	0.000
Tools_2	86.93 (6.23)	77.04 (16.98)	9.34	3.46	0.001
GPA_semester_1	84.54 (5.39)	81.23 (6.36)	2.98	2.29	0.026
GPA_semester_2	84.86 (4.73)	76.90 (10.15)	7.55	4.58	0.000
GPA_overall	84.39 (4.95)	78.85 (7.47)	5.12	4.06	0.000

**Figure 3.** Course scores and GPA among the intervention and control groups of architecture students.

Among engineering students, the intervention significantly improved SA scores at post ($B = 7.82$, $t(75) = 4.88$, $p < 0.0001$) but had no effect on any course scores or GPA in either term or at the end of the first year. See Table 4 and Figure 4.

Table 4. Correlations among course scores and GPA for intervention and control groups of engineering students.

Course	Intervention Mean (SD)	Control Mean (SD)	B	t	p-Value
Calculus_0	79.00 (10.66)	77.05 (11.40)	1.91	0.60	0.55
Physics_0	87.27 (11.75)	81.50 (13.92)	6.19	1.63	0.11
Calculus_1	75.09 (17.13)	69.16 (17.12)	6.11	1.21	0.23
Physics_1	77.44 (13.57)	75.00 (17.38)	2.64	0.54	0.59
Calculus_2	69.05 (22.87)	65.30 (24.43)	3.95	0.44	0.67
Physics_2	79.40 (16.06)	77.71 (26.01)	1.68	0.19	0.85

Table 4. Cont.

Course	Intervention Mean (SD)	Control Mean (SD)	B	t	p-Value
GPA_semester_1	79.83 (8.79)	76.78 (8.49)	2.90	1.16	0.25
GPA_semester_2	74.89 (11.70)	68.52 (12.66)			
GPA_overall	73.28 (10.57)	71.03 (10.92)			

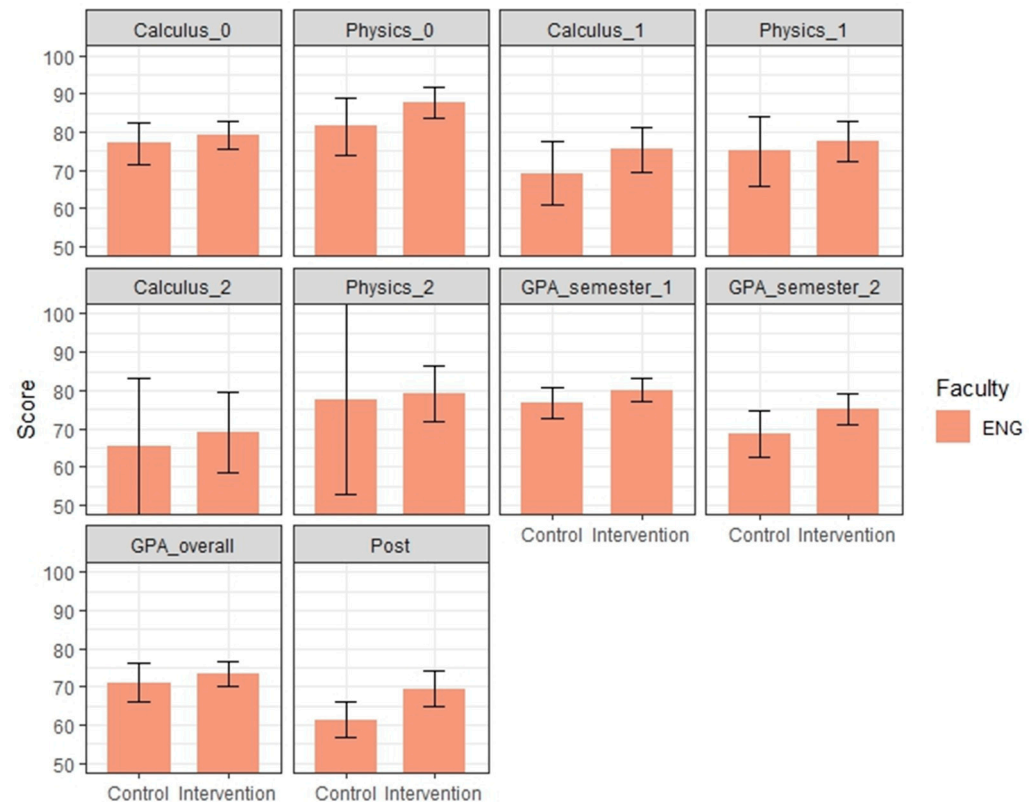


Figure 4. Course scores and GPA among the intervention and control groups of engineering students.

3.2. Results for Study 2

Study 2 aimed to find the relationship between SA and academic performance among first-year architecture students, focusing on specific architecture courses and the overall GPA. This section includes the correlation and regression analyses, utilizing the provided statistical data to illustrate the significant impact of SA on academic success.

This Study tested whether higher SA scores pre-intervention predict higher scores on specific courses, as well as a higher GPA at the end of the year, using Pearson correlations for the control group only (comprised exclusively of architecture students), as we were interested in ruling out any effect caused by the intervention. *p*-values were adjusted for multiple comparisons using the False Discovery Rate. However, we also report original *p*-values in cases of marginal significance due to the relatively small sample size, with restricted statistical power.

3.2.1. Detailed Correlation Results

The study's findings, based on Pearson correlation analysis, reveal a consistent positive relationship between SA scores and academic outcomes, detailed as follows:

Studio 1: The correlation coefficient (*r*) for SA scores with grades in Studio 1 was 0.54. The adjusted *p*-value was 0.010, indicating a significant positive correlation.

Tools 1: A stronger correlation was observed in Tools 1, where *r* = 0.59. The adjusted *p*-value was 0.007, confirming a robust link between SA and tool-based architectural skills.

Studio 2: The continuation of studio-based learning showed a correlation coefficient of 0.49, with an adjusted p -value of 0.018, supporting the sustained influence of SA across different stages of design education.

Tools 2: Similar to Tools 1, the second tools course had a correlation coefficient of 0.46 and an adjusted p -value of 0.024, reinforcing the importance of SA in more advanced tool-based applications.

3.2.2. GPA Results

The course scores and overall GPA at the end of the year significantly correlated with SA scores, with medium to medium-strong effect sizes (r between 0.46 and 0.67) and adjusting for multiple comparisons with FDR ($p < 0.024$). See Table 5 and Figure 5.

Table 5. Correlations between SA in the pre-assessment and course scores/GPA in the architecture control group.

	Studio 1	Tools 1	Studio 2	Tools 2	GPA
SA—Pearson r	0.54	0.59	0.49	0.46	0.67
SA—adjusted p -value	0.010	0.007	0.018	0.024	0.002

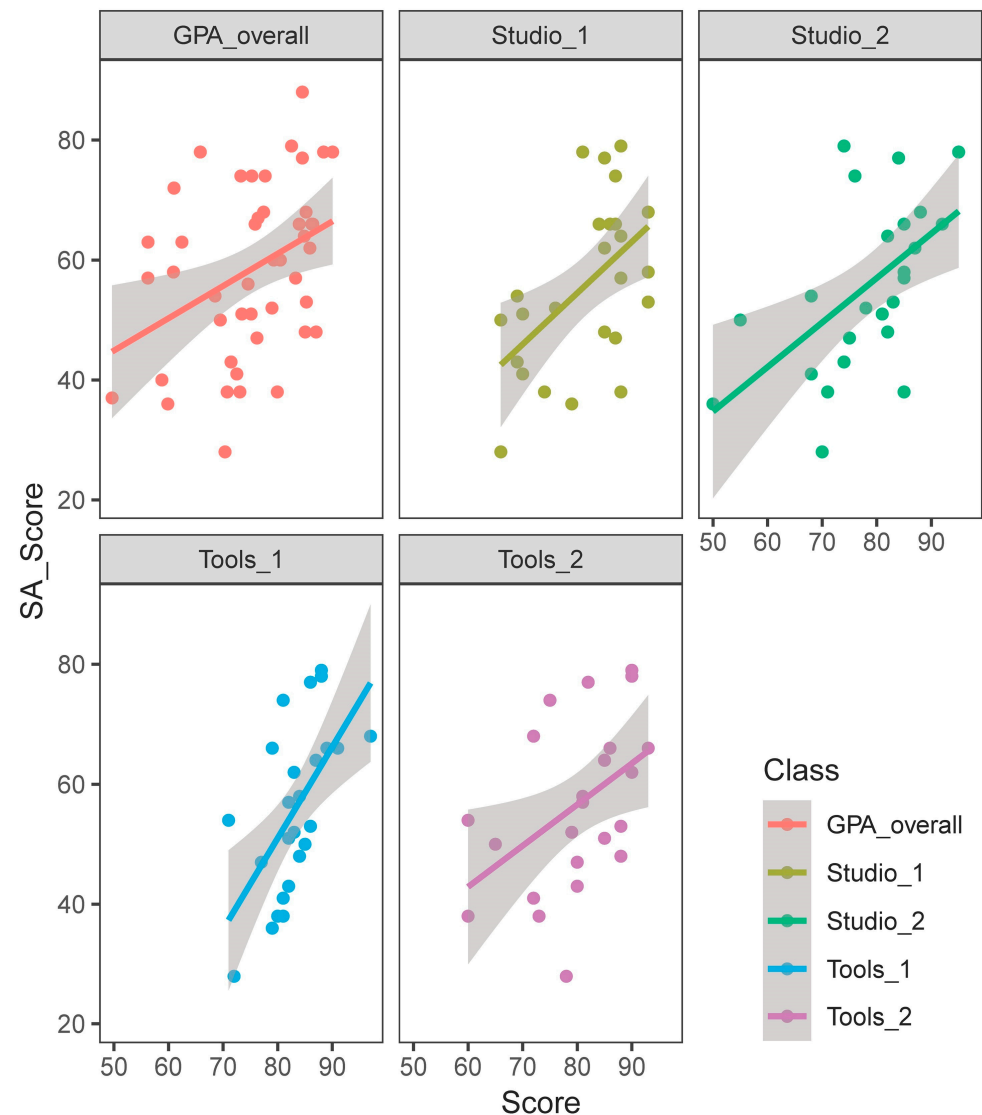


Figure 5. Correlations between SA in the pre-assessment and courses scores/GPA in Architecture control group.

3.2.3. Regression Analysis Insights

Linear regression models were applied further to quantify the predictive power of SA on academic results. The analyses adjusted for covariates such as age, sex, and secondary school achievements. The beta coefficients (β) indicated that, for every one-unit increase in SA score, there was a significant improvement in course grades and GPA. These results persisted even after adjusting for demographic and academic background, underscoring the intrinsic value of spatial abilities in architectural education.

3.2.4. Group Comparisons and Statistical Significance

The study also involved comparative analyses between different quartiles of SA scores. Students with the highest SA scores consistently outperformed those in the lower quartiles across all measured academic outcomes. This pattern was statistically significant and suggests that higher initial SA capabilities strongly predict better academic outcomes in architecture. The consistent positive correlations and significant regression outcomes across various courses and GPA measurements illustrate that SA benefits isolated courses and is a crucial factor in architectural education. These findings are pivotal for educators and curriculum developers, indicating that interventions to enhance SA could substantially benefit student academic success.

4. Discussion

This discussion integrates the findings from both research Studies: Study 1, which evaluated the impact of an SA intervention program, and Study 2, which examined the correlation between inherent SA and academic performance in architecture students who did not participate in the intervention. The findings reveal important insights into how SA influences academic success, particularly in architecture and engineering, and offer significant implications for educational practices and future research.

4.1. Summary of Key Findings

Study 1, which focused on first-year engineering and architecture students, assessed the impact of an SA intervention program on academic performance. The results indicated that the intervention significantly improved SA, especially among architecture students. These students demonstrated a strong correlation between improved SA scores and higher academic performance in spatially intensive courses like studio and tools classes. However, while SA scores improved for engineering students, this did not translate into significantly better outcomes in courses like calculus and physics.

Study 2 provided a deeper investigation into the role of inherent SA in academic success, specifically among architecture students who did not receive any SA training. The results revealed a significant positive correlation between students' inherent SA and academic performance, particularly in design-intensive courses. The correlation coefficients, ranging from 0.46 to 0.67, indicated a strong relationship between SA and success in architecture, reinforcing the critical role of spatial reasoning in this field.

4.2. Interpretation of Results

The differential impact of the SA intervention across the two disciplines highlights the varying cognitive demands of architecture and engineering education. In architecture, spatial skills are central to tasks such as design, spatial planning, and three-dimensional visualization. The improvement in SA directly translated into better performance in courses requiring these skills. In contrast, the core engineering courses, such as calculus and physics, are more analytical and abstract, relying less on visual-spatial abilities and more on mathematical reasoning. As a result, the improvement in SA among engineering students did not lead to a measurable impact on their academic performance in these courses during the first year. Specifically, no significant improvement was observed in first-year basic courses like calculus and physics.

This difference likely stems from the fact that architecture education relies more heavily and directly on visual-spatial skills, while engineering focuses more on analytical reasoning in the early semesters. However, SA may be more critical in later engineering courses, particularly those involving spatially complex tasks such as multivariable calculus and physics. This differential impact emphasizes the need for tailored SA training that aligns with the specific cognitive demands of each discipline. Engineering students may benefit more from spatial skills training as they progress into more visually demanding subjects later in their academic journey.

Study 2's results further underscore the importance of SA in architecture, showing that, even without formal intervention, students with higher inherent SA tend to perform better academically. This finding suggests that spatial reasoning is beneficial and essential for success in architecture. Architecture students must frequently engage in tasks that require manipulating and visualizing complex spatial structures, making SA a foundational skill for their academic and future professional success.

4.3. Implications for Educational Practice

The findings from both studies offer significant implications for educational practices, particularly in architecture and engineering education. For architecture, it is evident that integrating SA training into the curriculum can enhance students' performance in design-oriented courses. Given the strong correlation between SA and academic success in this field, educators should consider incorporating targeted spatial reasoning exercises, such as 3D modeling and CAD-based tasks, into the early stages of architectural education. This would ensure that students develop these critical skills early, preparing them for more complex design challenges later in their studies.

For engineering, while the direct academic benefits of SA training were less pronounced in first-year courses, there remains potential for SA improvements to contribute to performance in later stages of education, particularly in courses involving spatially intensive tasks such as multivariable calculus and physics. Educators may consider introducing SA-focused workshops or modules in the second year when students encounter more visually demanding concepts that require applying spatial reasoning skills.

Additionally, the study suggests that SA assessments could be integrated into admissions processes, particularly for architecture programs. Identifying students with lower SA scores could help institutions provide targeted support through tutoring or specialized workshops to enhance spatial skills. This proactive approach would help bridge the gap between students with varying levels of inherent SA and ensure that all students are equipped to succeed in their studies.

4.4. Contributions to Cognitive and Educational Research

The findings from this study contribute to both cognitive and educational research, reinforcing the role of SA as a key predictor of success in spatially demanding disciplines such as architecture. The study supports existing cognitive theories, posing that SA is essential for tasks requiring spatial visualization, mental rotation, and spatial perception. Moreover, the study highlights the value of assessing cognitive skills, such as SA, as part of the educational framework. By understanding how these cognitive abilities influence academic performance, educators can design curricula that align more closely with students' cognitive strengths and areas for improvement.

In architecture education, the study emphasizes the need for curriculum design that fosters the development of spatial reasoning skills. Introducing spatially intensive tasks early in the curriculum can help students build a strong foundation, improving their ability to handle complex design projects as they progress through their education. Furthermore, this study supports the broader application of cognitive theories in educational practices, suggesting that cognitive assessments should play a larger role in shaping educational strategies.

4.5. Implications for Future Research

The results of this study open several avenues for future research. One critical area for further investigation is the long-term impact of SA improvements on academic and professional success. Longitudinal studies that follow students through their academic careers and professional lives could provide valuable insights into how SA training contributes to long-term outcomes. Additionally, future research could explore the potential benefits of SA training in fields outside architecture and engineering, such as medicine or geography, where spatial reasoning also plays a critical role.

Another area for exploration is the use of advanced technologies, such as virtual and augmented reality, in SA training. These tools have the potential to provide immersive and interactive learning experiences, enhancing students' ability to visualize and manipulate complex spatial structures. Investigating the effectiveness of these technologies in improving SA could lead to developing more engaging and effective training programs.

Finally, future research should consider the role of individual differences in the effectiveness of SA training. Baseline SA levels, learning styles, and gender differences could influence how students respond to spatial training. Tailoring interventions to meet the needs of diverse student populations could enhance the overall effectiveness of SA training programs.

5. Conclusions and Future Directions

This study highlights the critical role of SA in architecture and engineering education. The findings from both studies demonstrate that SA is a key cognitive skill that significantly influences academic success, particularly in architecture. The study also underscores the importance of targeted SA training in educational curricula, suggesting that integrating such training into the early stages of education could help students develop the skills necessary for success in their chosen fields.

For architecture students, the correlation between inherent SA and academic performance emphasizes the need for curriculum adjustments focusing on developing spatial reasoning skills. While the immediate impact of SA improvements was less pronounced for engineering students, the potential for SA to influence later academic and professional success remains an important area for future exploration.

In conclusion, this study contributes to the growing research on cognitive skills and educational success, offering valuable insights for educators, curriculum developers, and researchers. By integrating SA training into educational programs and exploring the long-term benefits of such training, institutions can better prepare students for the cognitive demands of their future careers in architecture and engineering.

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