

## COMPARATIVE EFFECTS OF THREE-DIMENSIONAL MODELLING TECHNIQUES ON SPATIAL ABILITY DEVELOPMENT AMONG BUILDING DRAWING STUDENTS' IN TECHNICAL COLLEGES IN EDO STATE, NIGERIA

<sup>1</sup>ENESI, F., <sup>2</sup>ADAVBIELE, J.A. Ph.D, & <sup>3</sup>OVIawe, J.I. Ph.D

<sup>1</sup>Vice-Chancellor's Office;

<sup>2&3</sup>Department of Vocational and Technical Education

Faculty of Education,

Ambrose Alli University, Ekpoma

Corresponding Author: enesi@aauekpoma.edu.ng

### Abstract

*This study investigated the effects of three-dimensional physical and digital modeling on spatial ability among Vocational I Students' offering building drawing in Technical Colleges in Edo State, Nigeria using a non-equivalent quasi-experimental pre-test post-test control group design. The study was guided by three research questions; three hypotheses were formulated and tested at .05 level of significance. The population consisted of all the 216 (156 males and 60 females). Purposive sampling was utilized to select three technical colleges consisting of 125 students (90 males and 35). The students were randomly assigned to conventional teaching method, 3D physical modelling and 3D digital modelling treatments respectively. Instruments used for data collection were: 3D graphics implemented were in terms of the current curriculum of the subject of Building drawing; Spatial Ability Test (SAT) was adopted from a series of standardized test for Spatial Ability (SA) administered to assess students' level of spatial ability before and after treatment. The tests included and limited to Mental Cutting Test (MCT), Spatial Relations Test (SRT) and Purdue Spatial Rotation (PSR). For the experimental groups, students had a total of 15 hours training in three weeks on 3D digital modeling in the design studio with Google SketchUp free version and 12 hours training on the physical modelling with cardboard, straw board and adhesive agent to produce 3D paper or physical modeling. The students were not yet familiar with CAD software nor material modeling before the exercise. The results of the post-test indicated that there is a significant difference between the spatial ability levels acquired by the treatment groups taught with 3D physical modelling and 3D digital modelling respectively, compared to the control group using only the conventional method of pen-on-paper 3D model drawing. However, regardless of the models used, the improvement is quite similar over the treatment groups without any significant difference. The study recommended among others that teachers should incorporate both physical and digital modelling activities more consistently into classroom practice.*

**Keywords:** *Spatial Ability, Mental Cutting Ability, Spatial Visualization, Digital Modelling, Building Drawing, Academic Performance.*

### Introduction

Technical and Vocational Training programme globally, and particularly in Nigeria, aims to equip students with essential knowledge, skills, and expertise for self-sustainability and

employability. This enables them to contribute to technological and commercial growth in their local and global communities. In Nigeria, Technical Colleges offer Vocational Education in various technical fields, emphasizing hands-on experience. Building construction and building/engineering drawing are prominent vocational fields that require creative and innovative abilities, including visual artistic expression, precision, and "techno-art " skills (a blend of art and technology).

These fields demand students to possess effective spatial abilities, particularly visualization skills, to solve problems and visualize technical aspects in three-dimensional (3D) drawing. Visualization skills enable students to mentally manipulate and understand complex spatial relationships, which is crucial for success in these vocational fields. Spatial visualization is the cognitive ability to mentally represent, manipulate, and transform spatial information of visual objects, including mental rotation and spatial reasoning (LeBow, et al., 2018; Škilters, et al., 2020; Mix, et al., 2021; Piri & Çağiltay, 2024). Technically, spatial visualization cannot be exhaustively exhibited without also possessing a measure of some of the components of spatial skills include Mental Cutting, Spatial Relations and Spatial Rotation. Although, each sub-spatial skills have their peculiar area of dominance in applications, their influences or inter-relationship are outstanding.

Mental cutting is a cognitive ability that involves visualizing and mentally sectioning or cutting objects to understand their internal structure. It's like using your imagination to "slice" an object and see what's inside. Part of the requirements in building design is the building sections drawing which commonly includes cross sections and longitudinal sections. Sections drawing in building design plays an essential role in understanding the internal components of a proposed building structure and construction process. The ability to visualize the components or internal structures resulting from this section is highly essential for students in construction fields. Students with mental cutting ability could also be proficient in interior building drawing and design. Research has shown that mental cutting is a complex cognitive process that involves spatial visualization, working memory, and attention (Hegarty & Waller, 2005). Studies have used mental cutting tasks to assess spatial ability in various fields, such as engineering and architecture (Sorby, 2009).

Spatial ability is a critical cognitive skill in building drawing, enabling students to effectively manipulate, and coordinate spatial relationships between various elements of a building. This ability is the designer's and architect's power of design conceptualization which includes but not limited to space inter-connective functions, area convenience and aesthetics that meet the specified needs of intended users. Research has consistently shown that strong spatial relations skills are essential for successful design outcomes (Alias, et al., 2002; Sorby, 2009; Atit, et al., 2021). Students with strong spatial relations skills are better able to optimize space usage, anticipate potential technical drawing issues, and communicate design ideas effectively. Studies have used spatial relations tasks to assess cognitive development in children and adults (Newcombe & Huttenlocher, 2000).

Spatial rotation ability refers to the capacity to mentally rotate objects or shapes in three-dimensional space while retaining the original projection with the eye of the mind. This cognitive skill is essential in various fields of drawing, including architecture, building, engineering, and art/design. Spatial rotation is a critical aspect of spatial ability, and it is closely related to other spatial skills, such as mental cutting and spatial visualization. This ability also facilitates the

visualization of complex spatial relationships between building elements, allowing designers to optimize space usage and anticipate potential design issues. This ability is highly required in building design both in interior and exterior perspective drawing. Spatial rotation ability can be developed and improved through training and practice (Sorby, et al., 2018). Research suggests that spatial training programs can enhance spatial rotation ability and, in turn, improve design performance.

Spatial ability is an important factor in a child's cognitive development. Its development is affected by numerous factors such as general intelligence, problem-solving skills, gender, playing building games, experience with engineering and architectural drawing and 3D modelling. Spatial Visualization Ability is a cognitive skill that empower students mentally to manipulate and visualize complex spatial relationships between building components. It is one of the sub-components of spatial intelligence (Ramful, et al., 2017; LeBow, et al., 2018). Spatial ability is a fundamental aspect of students' development in Science, Technology, Engineering, and Mathematics (STEM) fields (Stieff & Uttal, 2015; Sorby & Veurink, 2019; Uttal, et al., 2020).

Numerous studies have demonstrated the effectiveness of 3D modelling in improving students' spatial skills in STEM fields. Recent advances in technology have made 3D physical and digital modelling more accessible and affordable, offering new opportunities for students to develop their spatial skills. 3D modelling is particularly important within the world of architecture, building construction and engineering. Both 3D physical and 3D digital models have been used to enhance spatial ability, but their impacts has not been thoroughly investigated.

Three-Dimensional conventional drawing involves the traditional pen-on-paper drawing and construction with the aid of drawing materials and equipment: drawing pen, eraser, scraper, drawing paper, tracing paper, compass, pair of dividers, scale rule, T-square, letter and symbol template, adjustable set square, drawing board among others. It requires learners to practically engage in every unit of the drawing process and the technicalities involve in construction. It is a long age method that is still being considered as primary approach to learning and training students' beginning in any technical drawing exercise including building design despite the advent of digital approach to problem solving especially the Computer Aided Design CAD. Studies have shown that traditional drawing techniques can improve some aspects of spatial reasoning, such as orthographic projection and visualization of simple shapes (Alias, et al., 2002).

Three-Dimensional (3D) physical modelling is the process of creating three-dimensional representations of a design with natural materials. It is more or less a craft. A non-computer-based 3D modeling. It involves the creation of physical 3D models, emphasizing a hand-on, practical approach using materials such as clay, wood, or cardboard, metal or plastic. It is a form of conventional or traditional modeling. It uses manual tools and techniques to cut, trim, shape and carve materials. It is often preferred by architects and designers who enjoy working with their hands and expressing their personal style. The tangible and tactile experience of traditional modeling gives a unique appreciation of the weight and texture of the models. Moreover, it enhances spatial and motor skills, as you have to plan and execute your models with precision and accuracy. Physical 3D modelling has proven to be the best presentation form of design to clients and proposed building users. Research has shown that 3D physical modeling can improve students' spatial abilities and enhance their understanding of complex construction concepts (Katsioloudis, et al., 2014; Turgut & Yilmaz, 2022). Having class with regular exercises with

regular solid shapes rather than in planes do improve spatial skills of students (Cheng & Mix, 2014). Similarly, evidence has shown that engagement in structured spatial training activities, particularly those involving three-dimensional forms rather than planar representations, has been shown to improve students' spatial skills (Hawes, et al., 2022).

In a study spanning a period of 10 weeks intervention program carried out by Tom, et al. (2019) on enhancing students' spatial reasoning, which included spatial visualization of geometry, the treatment group exhibited significant improvement in 3D visualization of geometric figures compared to the control group.

Three-Dimensional (3D) digital modelling involves the creation of models using Computer Aided-Design CAD software. Designers use computer graphics such as AutoCAD, Autodesk Revit, SketchUp, etc. to design create and manipulate geometric shapes, textures, colors, and lighting. 3D digital model can be rendered as images, animations, or interactive simulations and is widely used in architectural and engineering drawing. Research has shown that 3D digital modeling can improve students' spatial abilities and enhance their understanding of complex construction concepts (Fonseca, et al., 2020; Šafhalter, et al., 2022). Studies by Šafhalter, et al. (2012) and Marcellina, et al. (2023) on the Developing spatial ability with 3D modeling found that students who used 3D Digital Modelling showed significant improvements in their spatial skills task. 3D digital modeling offers a range of benefits, such as increased creativity and flexibility due to the lack of physical limitations. Additionally, it saves time and money by allowing for quick changes and revisions. Moreover, 3D models can produce realistic and detailed results by adding intricate details, shadows, reflections, and textures.

3D Physical and 3D Digital Modelling has been observed to have significant impact on students' spatial ability. However, the degree of impact and which of these concepts deliver more impact remain less understood. Martín-Gutiérrez, et al. (2013) developed what he called Diedro-3D, a three-dimensional digital viewer, programmed to enhance the teaching of 3D regular solids. Result of the study revealed students' interest in personalized digital learning when compared to those who engaged the traditional hand-on-paper drawing method. Notably, traditional pen-and-paper 3D drawing techniques appear to have a more limited impact on students' spatial skills when compared to more interactive and immersive digital or physical modelling approaches (Alias, et al. 2002; Sorby, 2009; Radianti, et al., 2020; Atit, et al., 2021; Adrian, et al. 2021). While drawing can help students develop some aspects of spatial reasoning, it may not be as effective in enhancing spatial abilities as more interactive and immersive methods. Studies have been carried out on a comparative analysis to finding the effectiveness of 3D physical modeling versus 3D digital modeling in enhancing students' academic performance in the field of building design and construction. Katsioloudis, et al. (2014), LeBow, et al. (2018) and Adrian, et al. (2021) in their various studies found that both 3D physical modeling and 3D digital modeling were effective in improving all areas of students' spatial ability. Studies by LeBow, et al. (2018) and Adrian, et al. (2021) further revealed that 3D physical modelling was more effective in enhancing students' problem-solving skills compared to 3D digital modelling. However, in a comparative study conducted by Katsioloudis, et al. (2014) it was discovered that 3D digital modeling has a more pronounced impact on learners' spatial aptitude compared to 3D physical modeling. In contrast, Basham and Kotrlik (2008) found no significant difference in the impact between 3D digital modeling and 3D physical modeling.

Computer-Aided Design (CAD) Auto-CAD, Rivet, Google SketchUp among others are widely used by Architects and Engineers. However, the simplicity and user-friendly drawing tools especially the transformation of 2D to 3D capacity of the Google SketchUp is far easier than many CAD applications. It is a popular CAD software used especially in a non-complex building drawing and design. Research highlights its effectiveness in enhancing spatial visualization, facilitating design exploration, and streamlining collaboration. Studies have shown that SketchUp's intuitive interface and 3D modeling capabilities improve spatial understanding and skills (Kurtulus & Uygan, 2010; Jaelani, 2021). For instance, CAD-based instructional approaches have been shown to significantly improve students' spatial abilities, particularly when learners actively engage with three-dimensional modelling environments (Wahyudi & Suyanta, 2023).

It is imperative to ensure that part of the assessment to determine the requisite entry behaviour of students in drawing, design and construction encompasses spatial aptitude. When it comes to the processes of teaching, learning and assessment, it is imperative to take into account the specific competencies that students must cultivate. The significance of spatial ability development as a fundamental skill in diverse educational and construction domains cannot be overstated. Key stakeholders in education, including curriculum developers, educators, and students, must embrace and implement effective pedagogical strategies to enhance students' spatial ability proficiency. One approach to bolstering learners' capacity to tackle design and construction challenges involves employing geometric reasoning methodologies (Hardianti, et al., 2017), such as constructing and manipulating two and three-dimensional figures. Pedagogical exercises in building design and construction may be seen to involve the CAD 3D modeling and physical modeling in the instructional curriculum, but little or no idea is known about how effective in developing learners' spatial ability. Since spatial ability is developed mainly by experimental factors; spatial skills may be practiced and developed by Training and practice can improve spatial skills, with growing evidence from both theoretical and empirical studies supporting the malleability of spatial ability (Newcombe, 2020; Uttal, et al., 2020; Hawes, et al., 2022). Spatial skills may be developed by hand-on-paper traditional drawing and computer-aided modeling 3D objects.

### **Gender difference in Spatial Ability**

There has been a long-standing finding indicating gender differences in several spatial ability tests, with result showing male outperforming females in most studies. In mental rotation test performance represents one of the common gender difference among male and female students. The consistency in research results having male seemingly with higher spatial ability especially in mental rotation test has generated debate across several studies. In a study on gender gap in spatial reasoning among elementary school pupils, findings revealed that males gain a slight advantage in mental rotation performance during the first years of formal schooling, and this advantage slowly grows with age, often becoming more pronounced by late adolescence (Lauer, et al., 2019; Newcombe, 2020; Reilly, et al., 2022; Heil, et al., 2021; Rahe et al., 2023).

### **Statement of the Problem**

In my more than a decade experience in teaching design and construction: geometry and construction in mathematics, technical drawing, and building design, from high schools to the university, a number of students seems to struggle with basic technical drawing, building designs

conceptualization and interpretation, especially the ability to generate graphical information from drawings and or visualize hidden details which are essential to understanding, conceptualizing and manipulating a 2D plane shape into a 3D solids and vice-versa. Spatial ability can be significantly enhanced through targeted teaching techniques, yet many students continue to face challenges due to underdeveloped spatial skills. Studies have shown that students with higher spatial visualization ability tend to perform better in building design related tasks (Festus, et al., 2024). However, how this spatial visualization ability is acquired and or developed remain a conflict. Debates among researchers have been on, with some believing it's innate and others arguing it can be developed through training and education. Recent studies support the latter, showing that spatial ability can be improved through targeted interventions (Hawes, et al., 2022). In any professional building design task and learning exercise, the traditional 3D hand-on paper drawing, 3D physical modeling and the 3D digital modeling are the combined common pedagogical and learning activities in the design studios believed to positively enhance spatial ability. However, the degree to which each of these practices impact student's spatial ability in building drawing and design among students in building construction and construction related domains remain understudied especially among Nigerian community of researchers. It is on this background the researchers intend to investigate the comparative effects of three-dimensional modelling instructional technique on students' spatial ability development in building drawing among Vocational I Building Construction Students in Technical Colleges in Edo State, Nigeria.

### **Purpose of the Study**

The purpose of this study was to determine the effect of three-dimensional conventional drawing (3DCD), three-dimensional physical modelling (3DPM) and three-dimensional digital modeling (3DDM) on spatial ability development of Vocational I Building Construction Students in Technical Colleges in Edo State, Nigeria. Specifically, this study sought to:

1. investigate the comparative effects of 3DCD, 3DPM and 3DDM on students' spatial ability development;
2. Examine the effect of gender on students' spatial ability test performance at post-test; and
3. Determine the interaction effects of 3DCD, 3DPM, 3DDM and gender on students' spatial ability development.

### **Methods**

This study employed a quasi-experimental design with a pre-test, post-test non-equivalent control group research design to examine the effects of 3DCD, 3DPM and 3DDM on students' spatial ability development among Vocational I Building Construction students in Technical Colleges in Edo State, Nigeria. Vocational I students' were chosen because they were new entrants and had not been introduced to 3DDM and 3DCD, allowing the study to enhance their competency in building drawing. To avoid disrupting class activities, the study utilized intact classes, comprising male and female students (predominantly male) for the different groups, resulting in non-equivalent and non-randomized control groups.

The population for this study consisted of all the 216 students (156 males and 60 females) of Vocational I Building Construction Students for the 2024/2025 academic session in Technical Colleges in Edo State, Nigeria.

Purposive sampling technique was adopted in selecting three colleges: one from each senatorial district. In each of the Technical College, the Vocational I Building Construction intact classes were randomly assigned to control and experimental groups. 126 students comprised the sample for this study, with 90 males and 35 females among the three classes. Participant were divided into three groups, namely, experimental group 1 (3DPM), experimental group 2 (3DDM) and control group 3 (3DCD).

The instrument used to collect the data for this research is the adopted Spatial Ability Test (SVAT) which constitutes three standardized achievement tests, namely: Mental Cutting Test (MCT), Tsutsumi (2004), Spatial Relations Test (SRT), Bennet, Seashore & Wesman (1947) and Purdue Spatial Visualization for Rotation Test (PSVRT), Branoff (2000). These instruments have been used in several studies with very high reliability and validity (Sorby & Baartmans, 2013). Table 1 shows the value of Cronbach's Alpha for SVAT.

**Table 1**

*Cronbach's Alpha Value for the instruments used in this research*

<b>Instrument</b>	<b>Alpha Cronbach Value</b>
Mental Cutting Test	.803
Differential Aptitude Test: Space Relations	.801
Purdue Spatial Visualization Test for Rotation	.804

Trained teachers used lesson plans prepared by the researcher. Each of the control (conventional group) and experimental groups (3DPM and 3DDM) were taught for two months. In the control group, a trained building drawing and construction teacher exposed the students to the traditional pedagogical approach involving discussions and demonstrations.

In the experimental group 1 (3DPM), materials like cardboard and embossed papers, adhesive, steel ruler and cutter were used by the trained teacher to guide the subjects in the group on how to model various 3D regular physical solids. While in experimental group 2(3DDM), the trained teacher guided the participants in the group on how to model various 3D regular digital solids with CAD: Google SketchUp 8, a free version, simple and user-friendly modelling software, suitable for beginners in CAD.

At the beginning and end of the training, Spatial Ability Test (SAT) was administered as a pre-test and post-test respectively to the students in the control and treatment groups. Mean and Standard Deviation were utilized to answer the research questions. The hypotheses were tested with the t-test, and analysis of covariance (ANCOVA). The pre-test SVAT was used as the covariates to their post-test scores. The researcher's choice for the test of ANCOVA was to serve as a means of controlling the extraneous variables from the dependent variables thereby dealing with the potential threats of initial differences across the groups leading to high precision of the experimental results.

Acceptance and rejection of the null hypotheses depended on .05 alpha level and the degree of freedom in relation to the calculated F-value. Acceptance mean of achievement score was 50% in this study. The mean score obtained is used to determine the skills level of students. The researchers used the interpretation of spatial skills level based on the visualization skills test (Sorby, 2009). Table 2 shows the interpretation of spatial skills level based on SAT.

**Table 2**  
*Spatial Skills Level Interpretation*

Mean Score (Percentage)	Rating	Level of spatial skills	Results
0 - 40	Below average score	Low	
41 - 60	Slightly below average score	Moderate	
61 - 100	Above average score	High	

**Research Question 1:** What are the effects of 3DCD, 3DPM and 3DDM on students' spatial ability development?

**Table 3**  
*Mean of Students' Pre and Post Performance Test Scores in Spatial Ability*

Groups	Sample Size	Pre-test Mean	Remark	Post-test Mean	Remark
3DPM (Treatment Group 1)	36	41.54	moderate	75.36	high
3DDM (Treatment Group 2)	47	38.55	low	67.39	high
3DCD (Control Group)	42	45.23	moderate	56.63	moderate

Table 3 indicates a low and moderate mean scores across groups on pre-test. However, the pre-test mean scores of the students in the control group performed better with 45.23, than the two experimental groups (3DPM and 3DDM), having 41.54 and 38.55 respectively. However, the post-test mean scores showed that students taught with 3DPM and 3DDM had higher post-treatment mean scores of 75.36 and 60.39 respectively, while students in the control group taught with 3DCD had a mean performance score of 56.63. The implication is that the treatment (3DPM and 3DDM) had positive effects on students' performance scores in spatial ability.

**H<sub>0</sub>1:** There is no significant difference in the spatial ability development of students' taught with 3DCD, 3DPM and 3DDM

**Table 4**

***ANCOVA on Difference in Performance of Students in SVAAT after Treatment***

**Tests of Between-Subjects Effects**

Dependent Variable: Posttest

Source	Sum of Squares	df	Mean Square	F-cal	Sig.	Partial Eta Squared
Corrected Model	10171.582 <sup>a</sup>	3	3390.527	60.108	.000	.598
Intercept	5582.189	1	5582.189	98.962	.000	.450
Pretest:covariate	376.282	1	376.282	6.671	.011	.052
Group (techniques)	6525.756	2	3262.878	<b>57.845</b>	<b>.000</b>	.489
Error	6825.266	121	56.407			
Total	530534.000	125				
Corrected Total	16996.848	124				

a. R Squared = .598 (Adjusted R Squared = .588)

**P < 0.05**

b. Mean difference is significant at the .05 level

Table 4 shows an F-calculated value of 57.845 as post-test result for modelling techniques being significant at .000, testing at alpha level of .05. The P-value is much less than the alpha level. Therefore, the null hypothesis which states that there is no significant effect of the modelling techniques on students' spatial ability performance is rejected. It is concluded that there is significant effect of the modelling technique on students' performance in spatial ability.

**Research Question 2:** What is the effect of gender on students' spatial ability test performance at post-test?

**Hypothesis 2:** There is no significant difference in the performance of male and female students' spatial ability test.

**Table 5**

**t-test between Male and Female Students Performance in Technology**

Gender	Number	df	Mean	Standard Deviation	Calculated t-value	Sig.(2tailed)
Male	90	123	69.60	12.029	.177	.040
Female	35		54.03	9.334		

Mean difference is significant at .05 level

**P < .05**

Table 5 shows that the calculated t-test value for students' gender was .177 only significant at .040, testing at an alpha level of .05, the P-value is less than .05 which is the specified

confidence level for this study. Therefore, the null hypothesis which states that there is no significant difference between the spatial ability performance among male and female students is rejected. It is concluded therefore that there is a significant difference in the SVA mean performance among sex.

**Hypothesis 3:** There is no significant interaction effect of the modelling methods and gender on students' spatial ability performance.

**Table 6**  
***ANCOVA Showing Interactive Effects of Treatment and Gender at Post-test***  
**Tests of Between-Subjects Effects**

Dependent Variable: Posttest

Source	Sum Squares	df	Mean Square	F	Sig	Partial Eta Squared
Corrected Model	11009.142 <sup>a</sup>	6	1834.857	36.160	.000	.648
Intercept	5903.709	1	5903.709	116.345	.000	.496
Pretest	229.590	1	229.590	4.525	.035	.037
Group	3407.418	2	1703.709	33.575	.000	.363
Gender	275.921	1	275.921	5.438	.021	.044
Group * Gender	615.517	2	307.758	<b>6.065</b>	<b>.003</b>	.093
Error	5987.706	118	50.743			
Total	530534.000	125				
Corrected Total	16996.848	124				

a. R Squared = .648 (Adjusted R Squared = .630).

**P < 0.05**

b. Mean difference is significant at the .05 level.

Table 6 shows an F value of 6.065 as the post-test result for modelling technique and gender interaction, being significant at .003 testing at an alpha level of .05, the P-value is much less than the alpha level. Therefore, the null hypothesis which states that there is no significant interaction effect of the modelling methods and gender on students' spatial ability performance is rejected. It is concluded that there is significant interaction effect of the modelling methods and gender on students' performance in spatial ability.

### Discussion of Findings

The results of this study point to a noticeable difference in students' spatial visualization ability depending on the instructional approach used. Students who were exposed to three-dimensional modelling for both physical and digital approach tended to perform better than those taught using the conventional hand-drawing method only. That pattern may suggest that when learners are given the opportunity to engage more actively with three-dimensional forms, their understanding of spatial relationships becomes clearer, or at least easier to work with.

Looking more closely, the group exposed to 3D physical modelling recorded slightly higher scores than those who worked with digital modelling tools. The difference was not extreme, but it is difficult to ignore. One possible explanation is that physical modelling introduces a kind

of hands-on engagement that is hard to replicate on a screen. When students cut, assemble, or adjust materials themselves, they may become more aware of how parts connect and occupy space. That sense of contact with materials triggers spatial development. This aligns with earlier observations that the use of tangible 3D objects can support the development of spatial skills (LeBow, et al., 2018; Adrian, et al., 2021).

At the same time, these findings do not fully agree with all previous studies. For instance, Katsioloudis, et al. (2014) reported stronger effects for digital modelling, suggesting that computer-based environments may offer advantages in visual manipulation. Similarly, Basham and Kotrlik (2008) found no significant difference between students exposed to CADD and those who were not. Taken together, these differences across studies may point to something less obvious, as the effectiveness of any modelling approach might depend not just on the tool itself, but on how it is used, the duration of exposure, and even the learners' familiarity with the method.

The performance of the control group, which relied on conventional drawing, appeared moderate by comparison. This does not necessarily mean that traditional drawing methods are ineffective. In many cases, they remain essential for building foundational skills. However, when used on their own, they may not provide enough interaction for students who are still trying to make sense of three-dimensional relationships. It is not uncommon, for example, to see students reproduce drawings accurately yet struggle to interpret those same forms from a different angle.

With regard to gender, the study revealed a significant difference in spatial visualization ability, with male students achieving higher mean scores than their female counterparts. While this finding is consistent with reports from Laucer, et al. (2019) and Festus, et al. (2024), it may be too early to treat it as a fixed outcome. Differences in experience, exposure, or even confidence levels could play a role here. In that sense, gender may be acting less as a cause and more as a reflection of underlying learning conditions.

### **Conclusion and Recommendations**

What emerges from this study is a fairly consistent indication that three-dimensional modelling can support the development of students' spatial ability, particularly when compared to conventional hand-drawing approaches used in isolation. Both physical and digital modelling contributed to improved performance, although the slight advantage observed in favour of physical modelling suggests that direct, hands-on interaction may offer additional benefits. Still, the difference between the two modelling approaches was not significant enough to dismiss digital tools. If anything, the results seem to hint that each method brings something different to the learning process. Physical modelling may encourage deeper engagement through tactile experience, while digital modelling offers flexibility and ease of manipulation.

The gender differences observed in the study add another layer of complexity. While male students performed better on average, this outcome is likely influenced by a range of factors beyond gender alone. It may be more useful to view such differences as context-dependent rather than fixed. Overall, the findings suggest that spatial ability is not simply an inborn trait but one that can develop over time, particularly when students are exposed to more interactive and engaging learning experiences.

Based on the findings, the following recommendations were outlined:

1. Rather than relying solely on traditional drawing methods, teachers should incorporate both physical and digital modelling activities more consistently into classroom practice.
2. Where resources permit, physical modelling activities could be emphasized, especially at the early stages, as they may help students build a more intuitive understanding of spatial relationships.
3. Teachers may need to pay closer attention to how different students engage with spatial tasks, and consider providing additional support where needed, rather than assuming uniform learning outcomes.
4. There is still some uncertainty around what drives differences in spatial ability, particularly across gender and instructional methods. Future studies may need to look more closely at these underlying factors.

## References

- Alias, M., Black, T. R., & Gray, D. E. (2002). Effect of instructions on spatial visualization ability in civil engineering students. *International Education Journal*, 3(1), 1-12.
- Basham, K. L., & Kotrlik, J. W. (2008). The effects of 3-dimensional CADD modeling on the development of the spatial ability of technology education students. *Journal of Technology Education*, 20(1), 27-45. <https://doi.org/10.21061/jte.v20i1.a.2>
- Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1947). *Differential aptitude tests*. Psychological Corporation.
- Branoff, T. J. (2000). Spatial visualization measurement: A modification of the Purdue Spatial Visualization Test-Visualization of rotations. *Engineering Design Graphics Journal*, 64(2), 14-23.
- Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's mathematics ability. *Journal of Cognition and Development*, 15(1), 2-11. <https://doi.org/10.1080/15248372.2012.725186>
- Festus, E., Stephen, A., & Napoleon, E. A. (2024). Relationship between students' spatial visualization ability and academic achievement in building drawing in technical colleges, Edo State, Nigeria. *International Journal of Research Publication and Reviews*, 5(11), 6922-6928. <https://doi.org/10.55248/gengpi.5.1124.3416>
- Fonseca, D., Martí, N., Redondo, E., Navarro, I., & Sánchez, A. (2020). Relationship between student profile, tool use, participation, and academic performance with the use of augmented reality technology for visualized architecture models. *Computers in Human Behaviour*, 110, Article 106412. <https://doi.org/10.1016/j.chb.2020.106412>
- Hardianti, D., Priatna, N., & Priatna, B. A. (2017). Analysis of geometric thinking students and process-guided inquiry learning model. *Journal of Physics: Conference Series*, 895(1), Article 012088. <https://doi.org/10.1088/1742-6596/895/1/012088>
- Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial abilities. In: P. Shah & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking*, 121-169. Cambridge University Press.

- Heil, M., Jansen, P., & Schmelter, A. (2021). Mental rotation performance and gender differences: A meta-analysis and review. *Psychological Research*, 85(4), 1357–1373. <https://doi.org/10.1007/s00426-020-01363-3>
- Jaelani, A. (2021). Improving spatial ability in solid geometry using SketchUp-aided generative learning. *International Journal of Mathematical Education in Science and Technology*, 52(5), 831-846. <https://doi.org/10.1080/0020739X.2020.1736356>
- Katsioloudis, P., Jovanovic, V., & Jones, M. (2014). A comparative analysis of spatial visualization ability and drafting models for industrial and technology education students. *Journal of Technology Education*, 26(1), 88-101. <https://doi.org/10.21061/jte.v26i1.a.6>
- Kurtuluş, A., & Uygan, C. (2010). The effects of Google SketchUp-based geometry activities and projects on spatial visualization ability of student mathematics teachers. *Procedia-Social and Behavioral Sciences*, 9, 384-389. <https://doi.org/10.1016/j.sbspro.2010.12.169>
- Lauer, J. E., Yhang, E., & Lourenco, S. F. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological Bulletin*, 145(6), 537-565. <https://doi.org/10.1037/bul0000191>
- LeBow, V., Bernhardt-Barry, M. L., & Datta, J. (2018). Improving spatial visualization abilities using 3D printed blocks. In *Proceedings of the ASEE Annual Conference and Exposition*. <https://doi.org/10.18260/1-2-30634>
- Lowrie, T., Logan, T., & Ramful, A. (2019). The influence of spatial visualization training on students' spatial reasoning and mathematics performance. *Journal of Cognition and Development*, 20(5), 729-751. <https://doi.org/10.1080/15248372.2019.1653298>
- Marcellina, M., Védaste, M., & Dickson, O. (2023). Assessing the effectiveness of computer-aided instructional techniques in enhancing students' 3D geometry spatial visualization skills among secondary school students in Tanzania. *International Journal of Learning, Teaching and Educational Research*, 22(6), 613-637. <https://doi.org/10.26803/ijlter.22.6.31>
- Martín-Gutiérrez, J., Gil, F. A., Contero, M., & Saorín, J. L. (2013). Dynamic three-dimensional illustrator for teaching descriptive geometry and training visualization skills. *Computer Applications in Engineering Education*, 21(1), 8-25. <https://doi.org/10.1002/cae.20447>
- Mix, K. S., & Cheng, Y. L. (2020). The relation between space and math: Developmental and educational implications. In: *Advances in Child Development and Behaviour*, 58, 97-243. Academic Press. <https://doi.org/10.1016/bs.acdb.2019.11.003>
- Mix, K. S., Levine, S. C., Cheng, Y.-L., Stockton, J. D., & Bower, C. (2021). Effects of spatial training on mathematics in first and sixth grade children. *Journal of Educational Psychology*, 113(2), 304-314. <https://doi.org/10.1037/edu0000494>
- Newcombe, N. S. (2020). The puzzle of spatial sex differences: Current status and prerequisites to solutions. *Child Development Perspectives*, 14(4), 251-257. <https://doi.org/10.1111/cdep.12389>
- Newcombe, N. S., & Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning*. MIT Press.

- Piri, Z., & Çağıltay, K. (2024). Enhancing cognitive fit: Exploring the potential of mixed reality for developing mental rotation skills. *In International conference on human-computer interaction*, 123-135. Springer.
- Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers and Education*, 147, Article 103778. <https://doi.org/10.1016/j.compedu.2019.103778>
- Reilly, D., Neumann, D. L., & Andrews, G. (2022). Gender differences in spatial ability: Implications for STEM education. *Educational Psychology Review*, 34, 1-31. <https://doi.org/10.1007/s10648-021-09624-w>
- Ramful, A., Lowrie, T., & Logan, T. (2017). Measurement of spatial ability: Construction and validation of the Spatial Reasoning Instrument for middle school students. *Journal of Psychoeducational Assessment*, 35(7), 709-727.
- Rahe, M., Schürmann, L., & Jansen, P. (2023). Self-concept explains gender differences in mental rotation performance after stereotype activation. *Frontiers in Psychology*, 14, Article 1168267. <https://doi.org/10.3389/fpsyg.2023.1168267>
- Šafhalter, A., Glodež, S., & Vukman, K. B. (2012). Developing spatial visualization with 3D modeling. *Problems of Education in the 21<sup>st</sup> Century*, 46, 131-141.
- Šafhalter, A., Glodež, S., Šorgo, A., & Ploj Virtič, M. (2022). Development of spatial thinking abilities in engineering 3D modeling course aimed at lower secondary students. *International Journal of Technology and Design Education*, 32(1), 167-184. <https://doi.org/10.1007/s10798-020-09597-8>
- Šafhalter, A., Vukman, K. B., & Glodež, S. (2015). The effect of 3D-modeling training on students' spatial reasoning relative to gender and grade. *Journal of Educational Computing Research*, 54(3), 395-406. <https://doi.org/10.1177/0735633115620430>
- Škilters, J., Newcombe, N. S., & Uttal, D. H. (Eds.). (2020). Spatial cognition XII: 12th international conference, *Spatial Cognition 2020, proceedings*. Springer.
- Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education*, 31(3), 459-480. <https://doi.org/10.1080/09500690802595839>
- Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal*, 63(2), 21-32.
- Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first-year engineering students. *Journal of Engineering Education*, 89(3), 301-307. <https://doi.org/10.1002/j.2168-9830.2000.tb00529.x>
- Sorby, S. A., & Veurink, N. (2019). Preparing for STEM: Impact of spatial visualization training on middle school math performance. *Journal of Women and Minorities in Science and Engineering*, 25(1), 1-23. <https://doi.org/10.1615/JWomenMinorScienEng.2018024516>
- Sorby, S. A., Veurink, N., & Streiner, S. (2018). Does spatial skills instruction improve STEM outcomes? The answer is “yes.” *Learning and Individual Differences*, 67, 209-222. <https://doi.org/10.1016/j.lindif.2018.09.001>

- Tsutsumi, E. (2004). A mental cutting test using drawings of intersections. *Journal for Geometry and Graphics*, 8(1), 117-126.
- Uttal, D. H., & Stieff, M. (2015). How much can spatial training improve STEM achievement? *Educational Psychology Review*, 27, 607-615. <https://doi.org/10.1007/s10648-015-9304-7>
- Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139(2), 352-402. <https://doi.org/10.1037/a0028446>