Evaluation on Spatial Ability:

A Comparison between the Performances on Spatial Aptitude and Engineering Drawing Tests

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Abstract: Prior study found that subject with high and low spatial aptitude could be utilizing different problem-solving methods: constructive and analytic [6]. The main focus of prior spatial studies is identifying faster problem-solving strategies [17]. According to the findings of Ho and Eastman (2006), since some problem solvers adopted more complex strategies, they seemed to show low spatial aptitude [15]. If the problem solver adopts the Non-Spatial Strategy that requires no mental 3D construction and rotation, answering the task becomes efficient. Efficiency leads to higher scores. Therefore, the study examines whether higher score on Spatial Aptitude Test represent better performance on Engineering Drawing Test. The goal of the study is to discuss the correlation between the scores of Spatial Aptitude Test and Engineering Drawing Test. The results provided implications on spatial ability evaluation. In this study, 42 undergraduate Industrial Design students took a paper-based test including three sections: Spatial Aptitude test-Paper Folding, Spatial Aptitude test-Cube Comparison, and Engineering Drawing. No significant differences were found between male and female participants in terms of spatial ability. The findings showed that higher score on Spatial Aptitude Test does not necessarily represent better performance on Engineering Drawing Test.

Key words: Spatial ability, design cognition, Engineering Drawing, spatial ability evaluation

1. Introduction

The significance of spatial aptitude in the design discipline has been highlighted by numerous studies. With higher spatial ability, students are more likely to interpret graphs [20]. In the field of architecture, almost all research projects focused on either spatial or structure design [16]. In industrial design, various product designs are absolutely expressed in the form of 2D engineering drawings [11]. Among the different representations in the design disciplines, three-dimensional perspective is frequently highlighted [15] and the development of 3D cognitive ability has to be considered indispensable [21]. Therefore, in the field of industrial design, architecture, and engineering, freshmen take *Engineering Drawing* as a required course.

Prior study found that subject with high and low spatial aptitude could be utilizing different problem-solving methods: *constructive* and *analytic* strategies [6]. The *constructive* strategy contains the generation of a mentally constructed model. The *analytic* strategy involves serial comparisons between features of the two representations instead of generating a mental spatial model. The Engineering Drawing course aims to train the *constructive* strategy of students.

However, not all students can produce *Engineering Drawing* successfully. According to a previous interview already conducted before this study, a teacher of Engineering Drawing course in the department of industrial design pointed out that some students encounter obstacles and could not produce the correct isometric drawing based on the three orthographic projections. To students exhibiting low performance on Engineering Drawing, an approach to investigate their spatial ability would be necessary.

In evaluating spatial ability, the widely used method is the test known as the Spatial Aptitude Test—ETS's Kit of Factor-Referenced Cognitive Tests [9]. The *Spatial Aptitude* Test presents questions with single or multiple choices. *Spatial Aptitude* Test refers to the Measures of spatial abilities contains tasks such as imagining the folding and unfolding of sheets of paper, solving mazes, mental rotation of shapes, and finding hidden figures [13]. Besides the Spatial Aptitude Test featuring single-choice questions, the study incorporate *Engineering Drawing* Test requiring problem solvers to draw the isometric drawing based on the three orthographic projections by themselves.

Besides, in terms of research, the main focus of prior spatial studies is identifying faster problem-solving strategies [17,6,10]. According to the arguments of Ho and Eastman (2006), since some problem solvers adopted more complex strategies, they seemed to show low spatial aptitude. They supposed that once the problem solver adopts the *Non-Spatial* Strategy that requires no mental 3D construction and rotation, answering the test becomes efficient. Efficiency might then leads to higher scores.

Spatial Aptitude Test problems can be solved with either *constructive* strategy or *analytic* strategy. Therefore, this study first examined whether higher score on *Spatial Aptitude* Test represent better performance on *Engineering Drawing* Test. The correlation between the *Spatial Aptitude Test* and *Engineering Drawing* results were compared. The findings of this research would generate implications on the evaluation on spatial abilities.

The goal of the study is to (1) discuss the correlation between the scores of *Spatial Aptitude* Test and *Engineering Drawing* Test, including individual differences and (2) provide implications on spatial ability evaluation and *Engineering Drawing* teaching.

Different from prior research identifying faster problem-solving strategies, this study highlights the important role of *Engineering Drawing,* to design students. *Engineering Drawing* requires the *constructive* strategy instead of analytic spatial ability. Therefore, to students in the design field where *constructive* strategy is significant, *Spatial Aptitude* Test that can be solved with either constructive or analytic strategy is rather insufficient. Therefore, the study proposes the hypothesis that *Spatial Aptitude* Test and *Engineering Drawing* Test are rather complementary in terms of understanding a person's spatial ability. An *Engineering Drawing* Test has to be conducted after the *Spatial Aptitude* Test as a set, as the experiment sequence designed in this study.

2. Literature Review

2.1 Spatial and Non-Spatial strategies

Various researches have presented the findings on the two types of problem-solving strategies on spatial problems: one type involves the 3D abilities, and the other involves 2D abilities [6,10,15,20]. The prior mental cube rotation research conducted by Gittler and Glück (1998) obviously presented the existence of the two problem-solving strategies: a *spatial* strategy and a *pattern rotation* strategy. A Three-dimensional Cube test was the task adopted in the study. The study identified two matching operations—*Spatial* Strategy and *Non-Spatial* Strategy. The *Spatial* (Two-Turn) Strategy is a type of 3D strategy since a problem solver has to generate a 3D cube in mind and mentally rotate it around various axes to solve the task. Differently, the *Non-Spatial* (Pattern

Rotation) Strategy is a type of 2D strategy since the cube is regarded as a 2D figure in which a problem solver can solve by rotating the figure without constructing a mental 3D cube.

Studies shown that individuals differ in the way they process and perceive two and three-dimensional stimuli [20]. Besides, the individual may be highly efficient in carrying out a particular strategy once it is selected for the spatial task at hand [6]. Besides, students should understand recognize the multiple mental strategies and select the correct spatial strategy responding to various situations no matter what types of representations are presented [15].

Based on the above task and findings, the experiment task of the research is selected. The Engineering Drawing requires the constructive strategy. As a result, the individual who only has the analytic strategy would exhibit a relatively low performance on the Engineering Drawing section. The research of Carpenter and Just (1975) presented the findings on two types of strategies that corresponded to the above studies.

2.2 Engineering Drawing

An Engineering Drawing is a graphic definition of product [8]. When understanding an engineering object or designing a product, an engineer utilize their trained of thought to interpret its orthographic drawings [2]. The reasoning process is trained through the engineering drawing course. A general engineering drawing course fundamentally concerns planar projections in which students are instructed to *construct* the projections of mental or actual objects onto orthogonal projection planes [12]. As Gradinscak (1998) pointed out, by providing exercises to students, teachers try to compel them to visualize spatial relationships between 3D objects in an attempt to improve their visual abilities.

2.3 Gender differences

In previous research on spatial ability [15, 18], sex difference is frequently discussed. Some researchers concluded that the noticed gender difference in three-dimensional mental rotation might be related to cognitive processes occurring before the actual mental rotation process [1]. In the mental rotation and spatial visualization ability study conducted by Kaufman, the result also suggested a direct effect of sex on the special variance in three-dimensional rotation ability [18]. Therefore, the sex difference in the spatial abilities would also be compared in the study.

3. Method

In order to investigate the correlation between Spatial Aptitude Test and Engineering Drawing Test performances, the experiment adopts both tests. The experiment is divided into two sections. Section A contains the Spatial Aptitude Test (single choice questions) while Section B covers the Engineering Drawing (drawing). To ensure a better flow, the study arranges the three tests in a sequence moving from relatively easy to complex. The sequence of the tests—Section A Spatial Aptitude Test (Paper Folding, Cube Comparisons), and Section B Engineering Drawing.

3.1 Participants

A total of 42 undergraduate students participated in the study. Among them were 20 male students and 22 female students. The participants were students taking product design course and KANSEI studies course in the Department of Industrial Design, National Cheng Kung University.

3.2 Tests

The experiment was a paper-based test including two types of tests—Spatial Aptitude test and Engineering Drawing test. Spatial Aptitude test contained two sections: Paper Folding Test (10 questions) and Cube Comparisons Test (42 questions). Engineering Drawing test presented 3 questions. While Spatial Aptitude test sections were timed according to the instructions [9], Engineering Drawing test was timed based on the advice of engineering drawing course teacher.

Section A, Spatial Aptitude Test, is composed of two sub-tests, both with stimuli selected from ETS's Kit of Factor-Referenced Cognitive Tests [9]. Widely utilized in schools and military, the set of cognitive tests has been validated throughout a long period of time as a standard cognitive test [14]. In the tests selected here, the Paper Folding test mainly relies on the *spatial visualization* factor and the *Cube Comparisons* test depends on the *spatial* factor [9]. Spatial visualization ability refers to the ability to control, rotate, or modify the position of an object in mind [19]. The figure below shows the samples of "Paper Folding Test" and "Cube Comparisons Test."

In the Paper Folding Test, the participant has to mentally fold a square paper in accordance with the directions given on the left vertical line. The whole process must not involve the folding of real paper. Based on the study of Gittler and Glück (1998) using the Three-dimensional Cube Test, the Cube Comparisons Test serving the same function is selected as part of the experiment of this study. The Cube Comparisons Test requires the participants to judge if the pair of cubes are the drawings of the same cube. To complete this section, the participants have to mentally reason the possible rotation of the cube.

In Section B, *Engineering Drawing* test requires the participants to generate an isometric drawing based on the three orthographic projections. Since drawing requires sufficient time, a total of 30 minutes are provided to solve three *Engineering Drawing* problems. Professional teachers of Engineering Drawing courses will grade the drawings collected from the subjects.

4. Results and Discussion

The performance on tests (see Table 1): Compared to Cube Comparisons test and Engineering Drawing test, the accuracy of Paper Folding test is the highest. This could be suggesting that the Paper Folding test is the easiest. Among the three tests, Engineering Drawing had the lowest accuracy. The standard deviation of Engineering Drawing test was also the highest, suggesting a wider variation on performances.

Table 1. Performances on tests (Mean of accuracy)

	N	Mean of Accuracy	Std. deviation
Paper Folding	42	0.840	0.126
Cube Comparisons	42	0.734	0.175
Engineering Drawing	42	0.681	0.317

When compared according to gender (see Table 2), the accuracy of the male and female performances was almost the same in Spatial Aptitude test (including Paper Folding and Cube Comparisons). In the Engineering Drawing test, the accuracy of male students was slightly higher then female. However, the result did not show significant differences.

Table 2. Performance on tests according to gender

		N	Mean of Accuracy	Std. deviation
Spatial Aptitude test –Paper Folding				
	Male	20	0.86	0.137
	Female	22	0.82	0.115
Spatial Aptitude test –Cube Comparisons				
	Male	20	0.75	0.157
	Female	22	0.72	0.191
Engineering Drawing test				
	Male	20	0.72	0.287
	Female	22	0.65	0.345

Table 3. Percentage of participants exhibiting consistent and inconsistent performance on each test-type pairing

	Spatial Aptitude test Paper Folding (%)		Spatial Aptitude test Cube Comparisons (%)		Engineering Drawing test Engineering Drawing (%)	
	C	InC	C	InC	C	InC
Paper Folding	—	—				
Cube Comparisons	8	3	—	—		
Engineering Drawing	14	8	10	5	—	—

(C): consistent (InC): inconsistent

To compare the performance of participants in the three tests, this study adopted a procedure used in previous research [15] studying the correlative performance on various spatial tests. From each of the three tests, participant whose score fitted in the first (good) and the last quartile (bad) was selected. Among the six groups (first quartile from the three tests and last quartile from the three tests), the scores of the selected participants were compared. Consistency (C) means that an individual has consistent performances, either good or bad, on two different tests. Inconsistency (InC) means that an individual was good at one test but bad at the other. The results of paired comparison were presented in the table (see Table 3).

The table (see Table 3) showed the participant's correlative performance with paired comparison. In other words, consistency means that performances on Engineering Drawing test and Paper Folding test had the highest consistency. However, the same paired comparison also exhibited the highest inconsistency. In all three paired comparisons, the amount of "consistency" is almost two times of the "inconsistency."

Table 4. Numbers of the paired comparison between Engineering Drawing and Cube Comparisons tests

Engineering Drawing		Cube Comparisons	
Good (First Quartile)	16	Good (First Quartile)	6
		Bad (Last Quartile)	3
Bad (Last Quartile)	15	Good (First Quartile)	2
		Bad (Last Quartile)	4

This study examined whether higher score on *Spatial Aptitude* Test represent better performance on *Engineering Drawing* Test. Among the first quartile (good performance) of Engineering Drawing scores, 3 participants were in the last quartile (bad performance) of Cube Comparisons. In the last quartile (bad performance) of Engineering Drawing, 2 participants were in the first quartile (good performance) of Cube Comparisons (see Table 4).

The result demonstrated that some participants with high score on Spatial Aptitude test (either Paper Folding or Engineering Drawing) showed low performance in *Engineering Drawing* Test. Therefore, higher score on *Spatial Aptitude* Test does not necessarily represent better performance on *Engineering Drawing* Test. According to the findings, the study suggested that Spatial Aptitude test alone might not be sufficient in evaluating spatial ability. *Engineering Drawing* Test has to be taken into consideration.

The factor affecting the above result could be "the two types of problem-solving strategies on spatial problems" compared in the literature review. Highlighted by prior studies [6,10,15,20], *analytic* strategy involves 2D abilities while *constructive* strategy involves 3D abilities. Among the participants who acquired higher score on *Spatial Aptitude* Test, some could be utilizing the *analytic* strategy [6] that involves comparisons between features of the two representations instead of generating a mental spatial model. However, *analytic* strategy is rather insufficient in the *Engineering Drawing* Test, which requires the *constructive* strategy. As a result, higher score on *Spatial Aptitude* Test does not necessarily represent better performance on *Engineering Drawing* Test.

As for the participants exhibiting high score on *Engineering Drawing* Test but low performance on *Spatial Aptitude* Test, the two types of problem-solving strategies on spatial problems could also be the influencing factor. High score on *Engineering Drawing* Test requires the *constructive* strategy. However, pointed out by Ho and Eastman (2006), since some problem solvers utilized more complex strategies, they seemed to demonstrate lower spatial aptitude [15]. Generating a mentally constructed model is a more complex strategy and may lead to lower efficiency when taking *Spatial Aptitude* Test.

5. Conclusions

When comparing the performances on Paper Folding, Cube Comparisons, and Engineering Drawing tests, the accuracy of Paper Folding test is the highest. This could suggest that the Paper Folding test is the easiest among the three tests. Engineering Drawing test exhibits the lowest mean on accuracy and a wider variation on performances. When compared according to gender, the accuracy of the male and female performances was almost the same in Spatial Aptitude test and Engineering Drawing test. Similar to previous research [15], no significant differences were found between male and female participants in terms of spatial ability.

The paired comparison between the Paper Folding, Cube Comparison, and Engineering Drawing did not exhibit obvious correlation. However, some participants with high score on Spatial Aptitude test (either Paper Folding or Engineering Drawing) showed low performance in *Engineering Drawing* Test. The findings showed that higher score on *Spatial Aptitude* Test does not necessarily represent better performance on *Engineering Drawing* Test. Since individuals differ in the ways they process two-dimensional and three-dimensional stimuli, the two different problem-solving strategies (*analytic* strategy and *constructive* strategy) could be a factor that leads to the results of the study. Therefore, when evaluating the spatial ability of individuals, both Spatial Aptitude test and Engineering test should be adopted to present a more complete and objective measurement and result, especially to students in the field of design.

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