Polyhedrons vs. Curved Surfaces with Mental Cutting: Impact of Spatial Ability

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Abstract: This study aims to determine and compare first-year engineering students' mental cutting ability, into two new parts, among the students of two universities in Tehran and Debrecen, concerning final mathematical exams and their gender, in order to understand whether the students of the two universities have sufficient spatial abilities. For that purpose; the Mental Cutting Test is applied to first-year engineering students to determine their mental cutting ability, in a current situation. In our research, we separate the tests into two parts, "Polyhedrons" and "Curved Surfaces". The separate tests results have been statistically evaluated and conclusions formulated. According to obtained data, the results are: First-year engineering female students of Debrecen and male students of Tehran, are more successful at Curved Surfaces than Polyhedrons; in addition, male students of Debrecen and female students of Tehran are more successful at Polyhedrons than Curved Surfaces. There is a significant correlation between the male students Polyhedrons and Curved Surfaces solutions, in both countries, but not for the female population.

Keywords: Comparative Analysis; Mental Cutting; Spatial Intelligence; Polyhedrons; Curved Surfaces

1   Introduction

Spatial ability affects performance in science, technology, engineering, and mathematics (STEM), even the control of verbal and mathematical skills [10, 28, 29, 35, 46], and according to Tosto et al. [37], performance of spatial ability tasks correlates with mathematical task performance (spatial reasoning skills and mathematical reasoning skills). Shea and his colleagues [35] examined the connection between spatial ability and mathematics: adolescents with better spatial abilities are more likely to be found in the profession of mathematics,

computer sciences and engineering. STEM "education and research are increasingly recognized globally, as fundamental to national development and productivity, economic competitiveness and societal wellbeing" [10, p. 350].

Capacity in STEM is pivotal to increasing productivity [22] and Sella et al. [34] found a correlation between spatial skills and numerical magnitude representations. A project [22] searches options and solutions could be usefully applied to the formation and improvement of STEM skills. "Productivity and economic growth will result from: an increased understanding in how to best stimulate and support creativity, innovation and adaptability; an education system that values the pursuit of knowledge across all domains, including science, technology, engineering and mathematics; and an increased willingness to support change through effective risk management" [22, p. 179]. According to studies [31, 12, 22], educational quality (tested by cognitive abilities primarily in mathematics and science) is a more potent influence on economic outcomes.

Spatial ability is important for learning anatomy, because students with better Mental Rotation Test score are better in anatomy examinations [45]. There are several research affirmation identifying significant correlation between spatial skills performance and educational performance, especially in parts of STEM [5]. It is important to examine cognitive aspects of spatial mental modeling [21].

According to studies, spatial abilities are described as a complex system, which is essential for success in engineering and other technological fields [1, 23, 24, 32, 36]. We can define spatial ability as a complex system of cognitive components, consisting the ability to connect a constructed and perceived images of 3D world [28]. Spatial relations skill means recognizing relationships between the visual components of a three-dimensional object [4, 41].

Spatial ability has received much attention in recent years, it can be said that the development of this ability is important for each area of science. Researchers interpreted the importance of spatial ability and studies arising in the fields of mathematics education, engineering education, chemistry, physics education and psychology [1, 7, 18, 24, 25, 28, 36].

2   Measurement of Spatial Ability

For engineering, mental cutting ability is very important. The mental cutting ability is a component of spatial ability. Researchers found a correlation between spatial skills and STEM performance [5, 13, 19, 32, 36]. Yüksel and Bülbül [44] examined the prospective mathematics teachers' mental cutting ability with "pattern problems" and "quantity problems" tasks. According to their results, mental cutting levels of prospective mathematics teachers is low and they are more successful at pattern problems than quantity problems.

There are standardized international tests to measurement of spatial abilities. These tests measure the parts of spatial ability (mental rotation, spatial visualization, etc.). A well-known test to measure mental cutting ability is the Mental Cutting Test (MCT) [8]. The MCT has been widely used to measure spatial abilities concerning graphics curricula. The standard MCT (a subset of CEEB Special Aptitude Test in Spatial Relations) consists of 25 tasks. The full score was 25 and the time limit was 20 minutes. Each task presents a three-dimensional figure, which is to be cut with an assumed plane in perspective projection. We have five alternative figures of the results: one is the correct, the other are incorrect alternatives [8]. To solve the MCT problems, there are three phases of information processing: recognizing the solid, cutting the solid with cutting plane, judging the quantity of the section [39]. The subjects who had low MCT scores, however, could not imagine the space itself, when they observed projection drawings [40].

To assess spatial visualization ability, MCT is one of the most used paper-and-pencil tests [11, 30, 38, 42]. Research has reported that female students generally achieve significantly fewer points in the MCT in national and international projects [27, 39, 43] and also longitudinal research by Gorska [11]. Countries all over the world are generally grappling with the issue of under-representation of women in STEM fields [22].

Based on these studies, the present study seeks to answer the following questions and the goal of the authors is to see whether there are any correlations in Polyhedrons and Curved Surfaces parts of MCT, between the two Universities in spatial intelligence of male and female freshmen students. During the research, the authors set up these three research questions (RQ):

RQ1: Is there a significant relationship between engineering students' gender, age, the grade of mathematics and Spatial intelligence scores, especially the Polyhedrons part or Curved Surfaces part of MCT results?

RQ2: Is there a significant relationship between engineering students' Polyhedrons part and Curved Surfaces part of MCT results?

RQ3: Is there a significant difference between freshman engineering students at the University of Sharif University of Technology in Tehran and the University of Debrecen in Polyhedrons part and Curved Surfaces part of MCT?

3   Methods

The participants in this study were 93 freshman engineering students, ranging from 19 to 24 years (mean age = 20.50, SD age = 1.44). Of the 93, 53 were freshman Hungarian Engineering Students (17 females 32.1%, 36 males 67.9%,

mean age = 19.69, SD age = 0.63) and the remaining were 40 Iranian freshman Engineering Students (10 females 25%, 30 males 75%, mean age = 21.57, SD age = 1.51). Information about participants' gender, age, nationality, grade of mathematics and ability to solve the questions, were recorded by the use of a self-assessment questionnaire.

Table 1

Descriptive analysis of information

			Gender		Total
			Male	Female	
Nationality	Hungarian	Count	36	17	53
		% within gender	54.5%	63%	57%
		% of Total	38.7%	18.3%	57%
	Iranian	Count	30	10	40
		% within gender	45.5%	37%	43%
		% of Total	32.3%	10.8%	43%
Total		Count	66	27	93
		% within gender	100%	100%	100%
		% of Total	71%	29%	100%

The demographic data of the participants in the survey are presented in Table 1. The participants were 93 first-year engineering students from Hungarian and Iranian universities, 53 (57%) are Hungarian and 40 (43%) are Iranian students.

In our research, we separate the MCT into two parts such as the Polyhedrons part and the Curved Surfaces part.

This is a descriptive-analytic study. After gathering the data through questionnaires, SPSS software and descriptive statistics and inferential statistics were used to analyze the data. A confidence level of 95% and the significance level of 0.05 were considered in the test.

4   Results

In this section, the statistical analysis both in descriptive and inferential analyses are presented to examine RQs. The tables and diagrams are arranged based on the order of the RQs came in the previous section. Therefore, the tables and diagrams start to illuminate the gender, age and Mathematics score respectively.

Data analysis in Table 2 showed that there was not a significant correlation between gender and spatial intelligence scores of first-year engineering students in Hungary ($p=0.634$, $r=0.067$) and in Iran ($p=0.449$, $r=0.123$). There is not a

significant correlation between the "Polyhedrons" part or "Curved Surfaces" part and gender in both countries.

Table 2

Relationship between Spatial Intelligence score and gender (RQ1)

Nationality			Gender	Spatial Intelligence Scores
Hungarian	Gender	Pearson Correlation	1	0.067
		Sig. (2-tailed)		0.634
		N	53	53
	Spatial Intelligence Scores	Pearson Correlation	0.067	1
		Sig. (2-tailed)	0.634	
		N	53	53
Iranian	Gender	Pearson Correlation	1	0.123
		Sig. (2-tailed)		0.449
		N	40	40
	Spatial Intelligence Scores	Pearson Correlation	0.123	1
		Sig. (2-tailed)	0.449	
		N	40	40

Results in Table 3 indicates that there was not a significant relationship between the spatial intelligence scores of freshman engineering students and their age in both Hungarian (r=0.110, p=0.434) and Iranian (r=0.115, p=0.482).

Table 3

Relationship between Spatial Intelligence score and age (RQ1)

Nationality			AGE	Spatial Intelligence Scores
Hungarian	Spatial Intelligence Scores	Pearson Correlation	0.110	1
		Sig. (2-tailed)	0.434	
		N	53	53
	AGE	Pearson Correlation	1	0.110
		Sig. (2-tailed)		0.434
		N	53	53
Iranian	Spatial Intelligence Scores	Pearson Correlation	0.115	1
		Sig. (2-tailed)	0.482	

		N	40	40
	AGE	Pearson Correlation	1	0.115
		Sig. (2-tailed)		0.482
		N	40	40

Table 4 gives information regarding the correlation between Math scores and spatial intelligence scores: there was not a significant correlation between Math scores and spatial intelligence scores ($r=0.173$, $p=0.215$) in Hungarian engineering students and among Iranian freshmen students ($r=-0.063$, $p=0.699$).

Table 4

Relationship between Spatial Intelligence score and Math score (RQ1)

	Nationality			Math score	Spatial Intelligence Scores
Spearman's rho	Hungarian	Math score	Correlation Coefficient	1.000	0.173
			Sig. (2-tailed)	.	0.215
			N	53	53
		Spatial Intelligence Scores	Correlation Coefficient	0.173	1.000
			Sig. (2-tailed)	0.215	
			N	53	53
	Iranian	Math score	Correlation Coefficient	1.000	-0.063
			Sig. (2-tailed)		0.699
			N	40	40
		Spatial Intelligence Scores	Correlation Coefficient	-0.063	1.000
			Sig. (2-tailed)	0.699	
			N	40	40

Table 5

Relationship between Polyhedrons and Curved Surfaces score, Females (RQ2)

Nationality			Polyhedrons	Curved Surfaces
Hungarian	Curved Surfaces	Pearson Correlation	0.466	1
		Sig. (2-tailed)	0.059	
		N	17	17
	Polyhedrons	Pearson Correlation	1	0.466

		Sig. (2-tailed)		0.059
		N	17	17
Iranian	Curved Surfaces	Pearson Correlation	0.181	1
		Sig. (2-tailed)	0.617	
		N	10	10
	Polyhedrons	Pearson Correlation	1	0.181
		Sig. (2-tailed)		0.617
		N	10	10

Data analysis in Table 6 showed that there is a significant correlation between Polyhedrons and Curved Surfaces solutions of male students in both countries (Hungary: $r=0.394$, $p=0.017$; Iran: $r=0.569$, $p=0.001$). Evidence indicates a significant correlation ($p<0.05$ and $p\leq0.01$) among males between Polyhedrons and Curved Surfaces solutions, but there is not a significant correlation among female students (Hungary: $r=0.466$, $p=0.059$; Iran: $r=0.181$, $p=0.617$) in both countries (Table 5).

RQ3: We found a difference between female and male students Polyhedrons and Curved Surfaces solutions in both countries. The results of male students are better than the results of female students in the Polyhedrons part of MCT in Hungary (males: 68.9%, females: 65%) and Iran (males: 70.8%, females: 67.1%). The results of male students performed better than females in Curved Surfaces part of MCT in Hungary (males: 68.5%, females: 66.7%) and in Iran (males: 76.7%, females: 66.7%). The results of Iranian students being better than Hungarian students in Polyhedrons test. Independent T-test results indicated that there was no significant difference between nationality (Iranian, Hungarian) and scores of MCT tests ($t=0.592$, df=90.823, $p=0.556$), between gender in Polyhedrons solutions (Hungary: $t=-0.661$, $df=29.039$, $p=0.514$; Iran: $t=-0.831$, $df=20.072$, $p=0.416$) and in Curved Surfaces solutions (Hungary: $t=-0.294$, $df=23.059$, $p=0.771$; Iran: $t=-0.840$, $df=11.780$, $p=0.418$).

According to the data obtained, we derived the following result: First-year engineering female students of Debrecen and male students of Tehran are more successful at Curved Surfaces than Polyhedrons; in addition, male students of Debrecen and female students of Tehran are more successful at Polyhedrons than Curved Surfaces.

Table 6

Relationship between Polyhedrons and Curved Surfaces score, Males (RQ2)

Nationality			Polyhedrons	Curved Surfaces
Hungarian	Curved Surfaces	Pearson Correlation	0.394[*]	1
		Sig. (2-tailed)	0.017	
		N	36	36
	Polyhedrons	Pearson Correlation	1	0.394[*]
		Sig. (2-tailed)		0.017
		N	36	36
Iranian	Curved Surfaces	Pearson Correlation	0.569[**]	1
		Sig. (2-tailed)	0.001	
		N	30	30
	Polyhedrons	Pearson Correlation	1	0.569[**]
		Sig. (2-tailed)		0.001
		N	30	30
* Correlation is significant at the 0.05 level (2-tailed)				
** Correlation is significant at the 0.01 level (2-tailed)				

Conclusion and Future Research

The spatial abilities and problem-solving skills of Iranian and Hungarians freshman engineering students have been studied in this paper. Their mental cutting abilities were measured. All data were collected during the spring semester of 2019. Results of the current study indicated that students' performance in Polyhedrons and Curved Surfaces parts of the MCT was related to their gender. Male students were stronger than female students in both countries in both parts of MCT. We found a significant relationship between the Polyhedron part and Curved Surface part of the MCT results of engineering male students, but not females.

Németh et al. [30] attempted to identify possible causes of gender differences in learning. Studies showed that common mistakes in special intelligence can be one of the possible reasons because in some cases, female students often make more mistakes than men especially in spatial abilities [15].

Marginson, et. al. [22] studied measures designed to lift female students in STEM: their mentoring programs have been positively evaluated as improving women's participation and there are gender-related elements in pedagogies in STEM disciplines in several countries. Rocha [33] studies the long-term development by teachers, resource interactions and develop methodologies, for the study of

documentation trajectory and documentation experience. According to Loisy et al. [20], the work of teachers with professional development and resources opens new opportunities for methodological developments. Many students in middle schools need more time and coaching to process the spatial nature of the computer simulations, as well as, a larger variety of experiences, both physical and virtual [9]. Low spatial abilities can lead to dropout. Kocsis and Pusztai [16] tried to identify the process of dropout, using quantitative and qualitative methods.

To help students understand spatial concepts, both physical and virtual models must be used together [3] [28]. According to Budinski et. al. [6] combinations of technology (GeoGebra) and hands-on activities (Origami) to enhance the students' understanding of geometric operations and definitions. According to studies, virtual solids and interactive animations are promising aids for training the spatial abilities of University Students [17, 25, 26]. Studies show that augmented reality integration, with learning of geometry, can also lead to the formation of spatial abilities [2] [14]. It would be very useful to focus on first-person analysis, to reveal the students' awareness of mental manipulation, while solving the task.

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