

## CONTRIBUTION OF STUDENTS' MATHEMATICAL SKILLS AND SPATIAL ABILITY TO ACHIEVEMENT IN SECONDARY SCHOOL PHYSICS

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**ABSTRACT:** This study investigates the contribution of mathematical skills and spatial ability to achievement in secondary school physics. Sixty-eight 10th grade students from a high school in Ankara were given mathematical skill test (MST), spatial ability tests (SAT) and physics achievement test (PAT). Correlational analysis showed that the correlation coefficient for mathematical skills and physics achievement was 0.46 ( $p<0.05$ ), and for spatial ability and physics achievement was 0.45 ( $p<0.05$ ). To see the combined contribution of mathematics and spatial ability to physics achievement, multiple regression analysis was applied. The results showed that the contribution of the two predictor variables (mathematical skills and spatial ability) accounted for almost 31 % of the variance in the physics achievement test scores.

**KEY WORDS:** *Cognitive development, mathematical skills, spatial ability, spatial orientation, spatial visualization.*

**ÖZET:** Bu çalışmanın amacı, matematik becerisi ve uzaysal yeteneğin orta öğretim öğrencilerinin fizik başarısına katkısını incelemektir. Ankara'daki bir lisenin 62 öğrencisine Matematik Beceri Testi (MST), Uzaysal Zeka Testleri (SAT) ve Fizik Başarı Testi (PAT) uygulanmıştır. Korelasyon analizi sonucunda matematik becerisi ve fizik başarısı arasındaki korelasyon katsayısı 0.46 ( $p<0.05$ ) olarak, uzaysal zeka ve fizik başarısı arasındaki korelasyon katsayısı 0.45 ( $p<0.05$ ) olarak bulunmuştur. Matematik becerisi ve uzaysal zekanın fizik başarısına bileşik katkısını görmek için çoklu regresyon analizi uygulanmıştır. Sonuçlar bu iki değişkenin (matematik becerisi ve uzaysal yetenek) fizik başarısındaki değişkenliğin %31'ini açıklayabildiğini göstermiştir.

**ANAHTAR SÖZCÜKLER:** *Zihinsel gelişme, matematik becerisi, uzaysal yetenek, uzaysal yönelme, uzaysal görme.*

### 1. INTRODUCTION

After 1950 there has been a great effort of researchers dealing with science education on determining the factors effecting the achievement in science courses. Many factors, such as level of thinking, problem solving, conceptual organization, socioeconomic status, language of thought, anxiety and so forth, have been studied. Researchers have shown that intellectual factors played an important role in physics achievement. Four general intellectual factors or abilities are seen to be most important [1]:

1. The ability to reason in terms of visual images (visualization or spatial ability).
2. Mathematical insight (mathematics).
3. The ability to evaluate the logic of arguments (logical thinking ability).
4. The ability to attack problems in a potentially productive way (problem solving).

The present study deals with the combined contribution of the first two of these four variables.

The ability to form and control a mental image is termed visuo-spatial ability. Researchers in areas such as neurology and cognitive psychology investigated the nature of spatial thought. Lateralization, the differentiatism of function of the left

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and right hemisphere of the brain, was explored through such research. Accordingly visuo-spatial or configurational phenomena are processed in the right hemisphere while linear or verbal information is more likely to be processed in the left hemisphere. The cognitive psychologist Hunt contends that the hemispheres of the brain are used differentially in linguistic and visuo-spatial reasoning [2]. Visuo-spatial ability is now recognized as an important aspect of thought and accordingly as an important factor in learning. Researchers have found that over half of the adult population has difficulty in manipulating and controlling iconic images [3]. Further, the lack of this ability not only may hinder a person's vocational pursuits but his/her creative thinking potential [4,5]. Visuo-spatial understanding is described as the ability to juxtapose, manipulate, and orient an object mentally and to create structures in the mind from written and verbal directions. The phenomenon has further been subdivided into two separate factors, one having to do with the awareness or appreciation of spatial relations and image constancy (spatial orientation) and the other with the mental manipulations into other visual patterns (spatial visualization).

Visuo-spatial aptitude has been strongly linked to obtaining academic mastery of several science disciplines. For example, Siemankowski and MacKnight [6] found that science students who were mostly physics majors, possessed more highly developed visualization skills than non-science students. Pallrand & Seeber investigated and found spatial aptitude in successful students of physics [7]. Baker & Talley, and McIntosh, made a similar studies for chemistry students and found similar results [8,9]. In the same way, Lord found similar results for biology students [10].

Since researchers state that visuo-spatial ability is an important cognitive operation for success in science, it would be very helpful if it could be

improved in the population. While some researchers think that this can be achieved through practice [10,11], others believe that spatial ability is an innate phenomenon and cannot be learned [12]. Thomas R. Lord investigated the problem in detail and found results supporting those researches that claim visuo-spatial aptitude can be enhanced through teaching [10].

Pallrand & Seeber investigated the relationship between visuo-spatial ability, mathematical skills of students and achievement in science courses (especially physics) [7]. They were also interested in finding the influence of visuo-spatial abilities and mathematical skills on the high attribution rate characteristics of many introductory college-level science courses. They obtained pre and post measures of visuo-spatial abilities in the areas of perception, orientation, and visualization of three sections of introductory college level physics and one non-science liberal arts section. The study found that there exists a correlation between the visuo-spatial ability and achievement in science courses, and that taking physics improves visuo-spatial abilities.

Traditionally it is believed that there is a significant relationship between mathematical skills and physics achievement. The observations on the relationship between mathematical skills and physics achievement have been proved by various researchers [1,13,14,15,16,17,18]. Studies conducted on the effect of mathematical skills on physics achievement found significant correlations between mathematics and physics [15,18,19]. Some other studies found that mathematical skills can serve as a predictor for the physics courses [13,17,20, 21].

The purpose of the present study is to see the combined contribution of mathematics and spatial ability to achievement in secondary school physics.

## 2. METHOD

Three instruments (Physics Achievement Test, Mathematical Skills Test and Spatial Ability Tests) were used during the study. These instruments were administered to 68 students in two science classes in a high school in Ankara, Turkey. The administration was done in the first week of the spring semester of 1995-96 school year. The PAT was administered again just after the units "Electrostatic" and "Electric Current" were taught.

### 2.1 Instruments

Information about the instruments used to gather data is supplied below.

#### 2.1.1 The Physics Achievement Test (PAT)

The Physics Achievement Test (PAT) covers - the unit of "Electrostatic and Electric Current". The test was prepared from a wide range of sources. The selection of the proper questions for the test, the order and number of questions was determined in coordination with high school physics teachers. More than 250 questions were examined one by one and 25 questions were selected and put in order so as to be parallel with the subjects taught.

The test was given to all physics and mathematics teachers at the high school for determining the weaknesses. The critics and proposals of the teachers were taken into account. After the modifications, the test was administered in order to perform its psychometric properties.

#### 2.1.2 The Mathematical Skills Test (MST)

To see the effect of mathematical skills of students on physics achievement, a Mathematical Skill Test (MST) was developed by the researchers. The MST investigates the ability of students in six major subjects in mathematics, which are

required for learning electrostatic and electrical current in physics. These subjects are (1) numbers (natural, rational and decimal numbers), (2) algebraic expressions, (3) ratios and geometrical properties, (4) equations and formula, (5) functions and graphs, and (6) trigonometry. The reliability estimate of the instrument was done according to the Kuder-Richardson 21 formula. For the MST a reliability coefficient of 0.77 was found. The test was designed so as to investigate the relation between physics achievement and mathematical skills and included 25 multiple choice type questions. For selecting the questions following criteria were considered: The advises and suggestions of the high school science and math teachers, after careful examination of the test, were taken into consideration in establishing the content related evidence for the validity of the test.

#### 2.1.3 The Spatial Ability Tests (SAT)

The Spatial Ability Tests (SAT) were used to establish visuo-spatial abilities in the areas of spatial orientation and spatial visualization. The spatial ability of students can be broken down to two factors, which are spatial orientation and spatial visualization. Spatial orientation (rotation) is the ability to rotate solid figures in all planes and to orient spatially with respect to a given object or scene. Spatial visualization is the ability to determine what a given pattern or configuration would be if it were altered so that the parts occupied a different relationship to one another. The tests used were taken from "Manual for the kit of factor referenced cognitive tests" prepared by Ekstrom et al., [22]. The tests used for this study are:

Spatial Orientation (Rotation) Tests:

1. Card Rotation Test (CRT) having a reliability coefficient of 0.80
2. Cube Comparison Test (CCT) having a reliability coefficient of 0.84

**Spatial Visualization Tests:**

1. Paper Folding Test (PFT) having a reliability coefficient of 0.84
2. Surface Development Test (SDT) having a reliability coefficient of 0.82

The score of the spatial ability is obtained by the summation of the four tests. The score for the spatial orientation is the summation of the scores obtained by CRT and CCT. The score for the spatial visualization is the summation of the scores obtained by PFT and SDT. All tests were translated into Turkish by the researchers.

**3. DATA ANALYSES**

The results of the Pearson product-moment correlation of the three measures, spatial ability, mathematical skills and physics achievement are represented in Table I. As it can be seen, spatial ability and mathematical skills made both significant correlation with physics achievement. Moreover, mathematical skills and spatial ability correlate with each other at a significant level. This result shows that the spatial ability and mathematical skills measure almost 13% of the same mental structures of the students.

**Table I.** Correlation of Test Scores Used in the Study

	Mathematical Skills	Spatial Ability
Physics Achievement	.4589 P= .000	.4535 P= .000
Mathematical Skills		.3578 P= .005

To see the combined effect, a multiple regression analysis was performed between the dependent variable, namely physics achievement and the independent variables, i.e spatial ability and mathematical skills. Analysis revealed that F-value for the full regression model was significant at the  $p < 0.05$  level. As it can be seen from Table II, the combination of two predictor variables (mathematical skills and spatial ability) account for 30.66 % of the variance in the physics achievement as measured by the Physics Achievement Test. Mathematical skills and spatial ability made both a significant contribution to the variation in the physics achievement. Mathematical skills account for 21.06% of the variance in the physics achievement, spatial ability for 9.60% of the variation.

**Table II.** Regression of Physics Achievement on Mathematical Skills and Spatial Ability.

Multiple R	.55370
R Square	.30658
Adjusted R Square	.28182
Standard Error	3.16883
F=12.37985, P<0.05	

**Variables in the Equation**

Variable	Beta	R2 Total	R2 Change	T	P
MST	.340164	.2106	.2106	2.855	.0060<0.05
SAT	.331824	.3066	.0960	2.785	.0073<0.05
(Constant)		.3066		.815	.0000

#### 4. DISCUSSION AND CONCLUSION

As stated earlier, the studies have shown that mathematical skills is a factor influencing the success in learning physics. The present study found similar results for the relation between mathematical skills and physics achievement. Analyses of the data showed that there is a significant correlation between mathematical skills and physics achievement. Moreover multiple regression analyses of MST and SAT scores with PAT scores yielded a significant contribution of mathematical skills and spatial ability to physics achievement. Accordingly students' mathematical skills could explain about 21% of the variance in physics achievement when it enters a regression equation with spatial ability. In the present study we have found that mathematical skills of students have a primary importance and/or contribution to variance in physics achievement.

The findings of the present study not only brings a predictability to physics achievement but it also helps to reason why some of the students do better in physics than others. In the light of these results, students who can not apply basic mathematical skills should not be expected to take high grades from physics tests including mathematical operations. However, there are students that are perfectly capable at mathematics but unable to do well in physics. There may be also students who can not function well in mathematics but still do well in physics. But this is possible only if the student can reason on a conceptual level. This brings us to the conclusion that neither mathematics nor spatial ability are sufficient as alone to do well in physics. Both variables effect the performance independently. In summary, the result of the study indicated that students mathematical skills had a significant predictive power on physics achievement which was harmonious with our expectations and the findings of previous studies.

The results of the current study emphasized that visuo-spatial ability was another important cognitive operation for success in physics courses

and that there exists a significant relationship between students' spatial ability and the physics achievement of students. The scores made significant correlations with each other and with the scores obtained from physics achievement test. This finding points to a direct influence of spatial ability on physics achievement. In the regression equation with the mathematical skills, spatial ability explained about 10% of the variance in physics achievement. This finding is congruent with the findings of earlier studies. Pallrand & Seeber had also found strong relationship between visuo-spatial aptitude and physics achievement [7]. Some of the previous studies [7,10] investigated if science or special courses could develop such abilities. Although these studies found results in the favor of the thought that these abilities could be developed, it is still not settled. It was not the purpose of this study to find an answer for this problem. Therefore, we could not make any conclusions on that point. As a result we can say that students' problems in dealing with subjects including orientation or visualization such as analyzing graphs and resolving vector diagrams influence the students success in physics courses. These students lack abilities to recognize patterns and relationships as well as to isolate components or aspects of an overall pattern. These abilities as found in the current study are required in physics courses but are not addressed in counseling or other programs. Therefore, physics teachers need to consider the broad range of cognitive skills of students in their courses.

The question aimed to be answered by the present study was whether or not the two measures, mathematical skills and spatial ability of secondary school physics students, were tapping mental structures and, if so, what is the relative importance of these measures in the final physics grade distribution. The results indicated that mathematical skills and spatial ability are both important factors effecting students secondary school physics performance. It was assumed that the real impact of these variables could be obtained by the

combination of the measures. It is obvious that there are a variety of factors influencing the physics achievement. Some of these factors are cognitive such as the ones defined in this study; some others have nothing to do with mental structures of students. The present study found that the combination of the variables have significant influence on physics achievement. The study found more than this, according to multiple regression analyses between these two variables, mathematical ability of students seems to be the primary factor influencing physics achievement. In the multiple regression with spatial ability, mathematical skills contribute to the regression equation as the primary factor. Therefore, it seems safe to say that mathematical skills of students have the greatest importance among the measures.

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