INVESTIGATING STUDENTS' LOGICAL THINKING ABILITIES: THE EFFECTS OF GENDER AND GRADE LEVEL

CİNSİYET VE SINIF DÜZEYİNİN ÖĞRENCİLERİN MANTIKSAL DÜŞÜNME YETENEKLERİNE ETKİSİ

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ABSTRACT: The purpose of this study was to investigate the effect of gender and grade level on students' logical thinking abilities. A total of 174 sixth, seventh, and eighth-grade students participated in the study. Test of Logical Thinking (TOLT) was administered to determine students' reasoning abilities. A two-way multivariate analysis of variance (MANOVA) was conducted to determine the effect of grade level and gender on five reasoning modes. Results revealed a statistically significant effect of grade level and gender on reasoning ability.

Keywords: logical thinking ability, gender, grade level

ÖZET: Bu çalışmanın amacı cinsiyet ve sınıf düzeyinin öğrencilerin mantıksal düşünme yeteneği üzerine etkisini araştırmaktır. Çalışmaya toplam 174 altı, yedi ve sekizinci sınıf öğrencisi katılmıştır. Öğrencilerin mantıksal düşünme yeteneğini Mantıksal Düşünme Yetenek Testi (TOLT) ile ölçülmüştür. Cinsiyet ve sınıf farkının mantıksal düşünme yeteneği üzerindeki etkisini olçmek için iki yönlü çoklu varyans analizi (MANOVA) kullanılmıştır. Sonuçlar, hem sınıf düzeyinin hem de cinsiyetin mantıksal düşünme yeteneği üzerinde anlamlı bir fark yaratttığını göstermiştir.

Anahtar Sözcükler: mantıksal düşünme yeteneği, cinsiyet, sınıf düzeyi

1. INTRODUCTION

Throughout the courses taught in elementary and middle school, 'science' is the one requiring intellectual skills to collect and analyze data to solve problems. In fact, science process skills taught in elementary grades such as observing, classifying and collecting data act as prerequisites for integrated processes usually taught in middle school grades like hypothesizing, controlling variables and defining operationally (Tobin and Capie, 1982). Such processes require high levels of reasoning ability. According to Wood (1974), there is a direct link between formal thought and integrated processes such as identifying and controlling variables, and hypothesizing (cited in Tobin and Capie, 1982). It is reported that formal reasoning ability was the strongest predictor of process skill achievement and retention. (Tobin and Capie, 1981)

The relationship between various variables and formal reasoning has been received a special attention in science education research for many years. For example, five formal operational reasoning modes, namely proportional reasoning, controlling variables, probability reasoning, correlational reasoning and combinational reasoning, have been identified as essential abilities for success in school science and mathematics courses (Bitner 1991). Considering this importance, some other authors have urged that the development of formal reasoning ability should be a major priority in science education (DeCarcer, Gabel, & Slaver, 1978; Lawson, 1982). In fact, proportional reasoning, for example, is important in many quantitative aspects of science. Without access to proportional reasoning an understanding of the derivation and use of a vast number of functional relationships in science is not attainable. This applies especially in the construction and interpretation of tabulated data and graphs. Hence, proportional reasoning leads to a good understanding of derivation and use of functional relationships in science. Similarly, correlational reasoning is central to scientific investigation at all

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levels. It is an important in formulation of hypothesis which considers potential relationships between variables. It is also important in the interpretation of data where the potential relationships between variables are considered. Controlling variables is important in planning, implementation and interpretation. The interpretation of data from investigations, observations, or experimentation often requires probabilistic reasoning. And lastly, combinational reasoning occurs in the formulation of alternative hypothesis to test the effects of selected variables on a responding variable. However, most of the elementary grade students do not bear this type of thinking (Garnett and Tobin, 1984). In line with this idea, Johnson and Lawson (1998) investigated the relative effects of reasoning ability and prior knowledge on biology achievement in expository and inquiry classes. They found that reasoning ability explained a significant portion of variance in final examination score in both instructional methods. Moreover, reasoning ability was found to be the best predictor of students' achievement in solving genetics problems (Cavallo 1996; Mitchel and Lawson, 1988). What is more, Lawson (1982) found out substantial correlation between formal reasoning and biology achievement. Similarly, Chandran, Treagust and Topin (1987) showed that formal reasoning ability and prior knowledge were significant predictors of performance on chemical calculations, laboratory applications, and chemistry content knowledge. Also, Ehindore (1979) reported that the brightness defined by students' performance on the biology tests was significantly related to the cognitive developmental precocity.

In addition, Huppert and Lazarowitz (2002) investigated the computer simulation's impact on students' academic achievement and on their mastery of science process skills in relation to their cognitive stages. Their results indicated that concrete and transition operational students in the experimental group achieved significantly higher achievement than their counterparts in the control group. Recently, Sungur and Tekkaya (2003) investigated the effect of gender and reasoning ability on the human circulatory system concepts achievement and attitude toward biology. The results revealed that although there was no statistically significant mean difference between boys and girls with respect to achievement and attitude toward biology, there was statistically significant mean difference between concrete and formal students with respect to achievement and attitude toward biology.

Moreover, Oliva (2003) investigated the effect of reasoning ability on changing the alternative conceptions related to mechanics. The results showed that the students with the highest level of formal reasoning changed their alternative conceptions more easily when these display a higher level of initial structuralization. Moreover, the study conducted by Lawson and Thompson, (1988) showed that formal reasoning patterns are necessary for elimination of some biological misconceptions.

However, the cross-age study carried out by Valanides (1996) indicated substantial deficiencies in the development of student reasoning abilities, and only ninth-graders had significantly better performance than seventh-graders which was related to proportional reasoning problems. In his study, no gender difference was found. In a separate study, Valanides (1997) examined the reasoning abilities and 12^{th}-grade Cypriot student with respect to gender. Results revealed that students' performance was higher on proportional reasoning and controlling variables items. Concerning gender difference, findings indicated that boys had significantly superior performance than girls on probabilistic reasoning items. Regarding students' achievement, the results revealed that girls had significantly higher achievement than boys. Vass, Schiller and Nappi (2000) analyzed reasoning skills of undergraduate college students majoring in education, specifically in the areas of proportional, probabilistic, and correlational reasoning which are essential for literacy in science and mathematics. The results demonstrated the lack of proficiency in formal reasoning by undergraduate education majors in the areas of proportional, probabilistic, and correlational reasoning.

In this study the effect of gender and grade level on elementary students' reasoning abilities was investigated. The following questions guided the study:

1. Is there a difference between mean scores of students attending 6^{th}, 7^{th} and 8^{th} grade on reasoning abilities related to five reasoning modes on TOLT: proportional reasoning, controlling variables, probability reasoning, correlational reasoning and combinational reasoning?

2. Is there a difference between mean scores of boys and girls on reasoning abilities related to five reasoning modes?

2. METHOD

2.1. Sample

A total of 174 students (109 boys and 65 girls) participated in the study. Of 174 students, 62 were sixth-grade, 58 were seventh-grade and 54 were eighth-grade students (Table 1). The mean age of students ranged from 11 to 13.

Table 1. Distribution of sample with respect to gender and grade level

Variables	N
Gender	
Male	109
Female	65
Grade level	
6	62
7	58
8	54
Total	174

2.2. Instrument

In this study, the Test of Logical Thinking (TOLT), originally developed by Tobin and Capie (1981), was used to determine the formal reasoning ability of students. The psychometric characteristics of TOLT have been well-documented by the developers. This test was translated and adapted into Turkish by Geban, Aşkar, and Özkan (1992) and its reliability was found as .81. The test consists of 10 items designed to measure controlling variables (items 1 and 2), proportional (items 3 and 4), probabilistic (items 5 and 6), correlational (items 7 and 8), and combinational (items 9 and 10) reasoning. Students select a response from among five possibilities and then they are provided with five justifications among which they choose from. The correct answer is the correct choice plus the correct justification. Students' performance on TOLT was used both as a measure of formal reasoning abilities and as a means to categorize them in the stages of cognitive development based on Piagetian criteria. Test scores from 0-1, 2-3, 4-7, and 8-10 were used as a basis for classifying the subjects as concrete, transitional, formal, and rigorous formal, respectively (Valanides, 1997).

2.3. Procedure

In each class, students are informed about the purpose of the questionnaire, and the procedure for completing it. After this short explanation, the answer sheets are distributed, and students are asked to complete the personal background information on the answer sheet. They were instructed to think about each question and answer it as it applies to them. Then, the tests were distributed and students were asked to complete the questions on their own. It took about 40 minutes for students to complete the test.

2.4. Data Analysis

Statistical analysis included tabulation of frequency distribution of students' responses to TOLT and two-way Multivariate Analysis of Variance (MANOVA). The independent variables were grade level and gender while the modes of reasoning ability (proportional reasoning, controlling variables, probability reasoning, correlational reasoning and combinational reasoning) constituted the dependent variables of the study. Prior to examining multivariate effects, multivariate normality and homogeneity of variance and covariance matrices assumptions of MANOVA were checked Since multivariate normality assumption can be detected by examining univariate normality of observations on each variable, Shapiro-Wilk test was conducted (Stevens, 2002). Results revealed that dependent variables were normally distributed and the nonsignificant *F* tests from Box's M statistics were the sign of homogeneity of variance and covariance matrices ($p > 0.05$). All analyses were conducted at the 0.05 level of significance.

3. RESULTS

Descriptive statistics for the gender and grade level with respect to five modes of the test of logical thinking ability is presented in Table 2 and Table 3. According to Table 2, students attending higher grade levels have higher scores on TOLT. Sixth-grade students appeared to be more successful in proportional reasoning although still they had the lowest mean score compared to students at other grade levels. Similarly, seventh-grade students appeared to be more successful in combinational reasoning with a mean score of 0.50 which is higher than that of sixth-grade students but lower than that of eighth-grade students. Eighth-grade students appeared to be more successful in controlling variables compared to other reasoning modes.

Table 2. Descriptive statistics for the gender and grade level with respect to five reasoning modes

	Reasoning Mode										
	prop.		contr. var.		prob.		corr.		comb.		
	M	SD	M	SD	M	SD	M	SD	M	SD	Total
Gender											
Male	0.45	0.71	0.41	0.74	0.37	0.66	0.26	0.53	0.47	0.76	0.39
Female	0.26	0.56	0.49	0.73	0.20	0.50	0.33	0.61	0.35	0.62	0.32
Total	0.38	0.66	0.44	0.74	0.31	0.61	0.29	0.56	0.42	0.71	0.36
Grade Level											
Grade 6	0.24	0.46	0.09	0.29	0.20	0.48	0.16	0.41	0.09	0.34	0.15
Grade 7	0.34	0.66	0.37	0.67	0.37	0.67	0.36	0.58	0.50	0.73	0.38
Grade 8	0.54	0.81	0.90	0.91	0.35	0.67	0.37	0.68	0.72	0.85	0.57
Total	0.38	0.66	0.44	0.74	0.31	0.61	0.29	0.56	0.42	0.71	0.36

When the performances of boys and girls were compared with respect to the five reasoning modes, it is seen that boys have higher scores than girls on proportional, probabilistic and combinational reasoning, while girls have higher on controlling variables and correlational reasoning (Table 2). These are also supported by the data given in Table 3, which presents the performance of students according to each item on TOLT.

Table 3. Performance on TOLT with respect to Grade level and Gender

		Grade level (%)			Gender (%)	
Reasoning mode	Item	6^{th}	7^{th}	8^{th}	M	F
Proportional	1	17.7	20.7	35.2	28.4	16.9
Proportional	2	6.5	13.8	24.1	17.4	9.2
Controlling variables	3	8.1	19.0	46.3	22.9	24.6
Controlling variables	4	1.6	19.0	44.4	18.3	24.6
Probabilistic	5	11.3	25.9	16.7	22.9	9.2
Probabilistic	6	9.7	12.1	18.5	14.7	10.8
Correlational	7	8.1	13.8	20.4	12.8	15.4
Correlational	8	8.1	22.4	16.7	13.8	18.5
Combinational	9	8.1	31.0	44.4	28.4	24.6
Combinational	10	1.6	19.0	27.8	18.3	10.8

A two-way multivariate analysis of variance (MANOVA) was conducted to determine the effect of gender and grade level on five modes of reasoning ability. A statistically significant difference was indicated by grade level; Wilks' $\Lambda = 0.731$, $F(2,168) = 5.555$, $p = .000$. The multivariate η^2 of 0.15 based on Wilk's Λ implied that 15 % of multivariate variance of the dependent variables was associated with the grade level. Since a significant MANOVA F was obtained for the collective dependent variables, univariate ANOVAs were conducted to further understand how the 6^{th}, 7^{th}, and 8^{th} grade students differed with respect to each of the dependent variable. The univariate ANOVAs for proportional reasoning (F (2,168) = 4.797, p = .009), controlling variables (F (2,168) = 22.481, p = .000), and combinational reasoning (F (2,168) = 12.629, p = .000) were significant with respect to grade level, while the univariate ANOVAs for probabilistic (F (2,168) = 1.053, p = .351) and correlational reasoning (F (2,168) = 2.154, p = .119) were not significant. These results indicated that there was significant effect of grade level on the three modes of reasoning ability; proportional reasoning, controlling variables and combinational reasoning. However, no statistically significant effect was found on probabilistic and correlational reasoning with respect to grade level. Follow-up Sheffe test was conducted to evaluate pairwise differences among the means. The results indicated that there was a significant difference between grades 6 and 8 concerning proportional reasoning (p=0.016), controlling variables (p=0.000), and combinational reasoning (p=0.000). Moreover it was found that there was a significant difference between grades 7 and 8 concerning controlling variables (p=0.000), and between grades 6 and 7 (p=0.005) concerning combinational reasoning.

The two-way MANOVA results also indicated a statistically significant difference in students' reasoning ability by gender Wilks' Λ = 0.928, F (1,168) = 2.547, p= .030. The multivariate η^2 of 0.07 based on Wilk's Λ implied that 7 % of multivariate variance of the dependent variables was associated with gender. The univariate ANOVAs for proportional reasoning was significant with respect to gender F (1,168) = 4.356, p = .038, while the univariate ANOVAs for controlling variables (F (1,168) = 0.260, p = .611), probabilistic (F (1,168) = 3.478, p = .064), correlational (F (1,168) = 0.619, p = .433) and combinational reasoning (F (1,168) = 1.543, p = .216) were not significant. These results indicated that there was a significant effect of gender on proportional reasoning. However, no statistically significant effect was found on controlling variables, probabilistic, correlational and combinational reasoning with respect to gender. Moreover, no interaction between gender and grade level (Wilks' Λ = 0.941, F (1,168) = 1.008, p= .436) was found.

In this study, students' performance on TOLT was also used as a means to categorize the subjects into stages of cognitive development based on Piagetian criteria as concrete, transitional, and formal. The formal stage is also subdivided into two substages, the formal stage and the rigorous formal stage (Valanides, 1997). Results are presented in Table 4.

Table 4. Percentages of Students at Different Stages of Cognitive Development with respect to Grade Level and Gender

	Cognitive Level				
	Concrete	Transitional	Formal	Rigorous formal	Total
Gender					
Male	62.4	16.5	15.6	5.50	100.0
Female	67.7	18.5	7.70	6.20	100.0
Grade Level					
Grade 6	80.6	17.7	1.60	0.00	100.0
Grade 7	62.1	17.2	15.5	5.20	100.0
Grade 8	48.1	16.7	22.2	13.0	100.0

As indicated in Table 4, only a small percentage of students have reached the formal operational stages. The percentages of students at the formal operational stage of cognitive development were 1.6%, 15.5%, and 22.2% for 6th, 7th, and 8th-grade students, respectively. Results showed that as the grade level increases, the number of students at formal stage increases, as expected. For example, the percentage of sixth-grades at concrete level (80.6%) is high when compared to seventh-grades (62.1%), and eighth-grades (48.1%). However, the percentages of all grades at transitional level are quite closer to each other (Table 4). Moreover, although only a small percentage of sixth-grades (1.6%) could reach the formal stage and even none of them could reach the rigorous formal stage, the percentage increases to 15.5% for seventh-grades and 22.2% for eighth-grades considering formal level, and it increases to 5.2% for seventh-grades and 13.0% for eighth-grades considering rigorous formal level. When the percentages of boys and girls are compared according to these levels, the number of girls at concrete, transitional and rigorous formal stages is more than the boys at these stages. However, boys at formal stage are more than the girls at the same stage (Table 4).

4. DISCUSSION

In this study, the effect of gender and grade level on students' reasoning abilities was investigated. Results showed that boys have higher scores than girls on proportional, probabilistic and combinational reasoning, while girls have higher scores on controlling variables and correlational reasoning. Gender difference was found to be statistically significant only for proportional reasoning in favor of boys. However, the results of Valanides' (1996) study showed that there were no significant differences between boys and girls with respect to five reasoning modes. In a separate study conducted by the same author regarding gender difference, it was found that boys had significantly higher performance on TOLT than girls on controlling variables and probabilistic reasoning. Boys and girls did not differ significantly on proportional, correlational and combinational reasoning. In addition, BouJaoude and Giuliano (1994) investigated the TOLT scores of male and female freshman. Scores of male students on TOLT were significantly higher than those of female students. As suggested by authors further investigation is needed to uncover the possible reasons behind these results through the use of qualitative research methods.

The results of the current study also revealed that students attending higher grade levels had higher scores on TOLT. The mean scores of students in four reasoning modes (proportional reasoning, controlling variables, correlational reasoning and combinational reasoning) increased as the grade level increased. MANOVA results showed that there was significant effect of grade level on the three modes of reasoning ability; proportional reasoning, controlling variables and combinational reasoning. However, no statistically significant effect was found on probabilistic and correlational reasoning with respect to grade level. Follow-up tests revealed that there was a significant difference between grades 6 and 8 concerning proportional reasoning, controlling variables, and combinational reasoning. Moreover it was found that there was a significant difference between grades 7 and 8 concerning controlling variables, and between grades 6 and 7 concerning combinational reasoning ($p<0.05$). The mean scores of seventh- and eighth-grade students on probabilistic and correlational reasoning were very close to each other, although, in general, there was an increase in the mean scores as grade level increases (Table 2). In fact, it was expected that as grade level increases, students' reasoning abilities increases. Because, according to Piagetian model, formal though begins to develop at age 11 or 12 and reaches equilibrium state at around age 15 or 16. Piaget's model of cognitive development indicates that by late adolescence, young adults should have reached the final stage of maturation. Therefore, middle school students should function at the formal operational level of cognitive development. However, as indicated in Table 4, only a small percentage of the students have reached the formal operational stage, while majority of them were still at the concrete level of intellectual development. Since these students were found to be unable to develop appreciable understanding of formal, abstract, concepts, it appears that for them a science course which deals with abstraction is inappropriate, such as atoms, electrons, photons, genes, and photosynthesis. The results suggest that a substantial portion of middle school science subject matter may not be suitable in terms of the intellectual level of the learner. Indeed Lawson and Renner (1975) reported that students defined as concrete operational encounter learning difficulties when they were asked to deal with concepts which require formal reasoning. Similarly, Yalvaç (2004) reported a negative correlation between learning difficulties in biology and reasoning ability. Therefore, teachers should be aware of the reasoning ability of their students and design the lesson accordingly. For example, concrete students can be instructed with instructional materials that provide first-hand experiences and concrete problems. To be able to promote meaningful learning, teachers should help students abstract key concepts, realize the interrelationships among the concepts, transfer and integrate what they learn in one course to another and to their daily lives. Thus, teachers should provide a rich learning environment for the students to deal with individual differences concerning reasoning abilities since lack of adequate formal reasoning among students is linked to their low achievement in science

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