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The Acquisition of Logical Thinking Abilities among Rural Secondary Students of Sabah

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ABSTRACT

The science curriculum in Malaysia emphasizes the acquisition of scientific skills, thinking skills, and the inculcation of scientific attitudes and noble values. Besides that, the acquisition of scientific and technological knowledge and its application to the natural phenomena and students' daily experiences are also equally emphasized. The purpose of this study was to gauge the acquisition of logical thinking abilities, namely, conservational reasoning, proportional reasoning, controlling variables, combinatorial reasoning, probabilistic reasoning, and correlational reasoning among Form 4 students in the Interior Division of Sabah, Malaysia. This study was also aimed to ascertain if there is any significant difference in students' acquisition of logical thinking abilities based on students' gender and science achievement at lower secondary level. This was a non-experimental quantitative research and sample survey method was used to collect data. In this study, samples were selected by using a two-stage cluster random sampling technique. Independent sample *t*-test and one-way ANOVA were used to test the stated null hypotheses at a predetermined significance level, $\alpha = .05$. Research findings showed that rural secondary students' acquisition of logical thinking abilities was low. The average item mean for all the subscales, except conservational reasoning, were lower than the overall average item mean. This research also surprisingly revealed that up to 98 percent of the respondents were categorized at the concrete operational stage whereas only 2 percent were categorized at the transitional stage. This study also found no significant difference in the mean of logical thinking abilities, except conservational reasoning, based on students' gender, but a significant difference based on students' science achievement at lower secondary level was found. These research findings bring some meaningful implications to those who are involved directly or indirectly in the development and implementation of secondary science curriculum, especially at the rural secondary schools of Sabah, Malaysia.

Keywords: Combinatorial reasoning, conservational reasoning, controlling variables, correlational reasoning, logical thinking abilities, probabilistic reasoning, proportional reasoning

BACKGROUND OF THE STUDY

The development of thinking abilities is well-discussed in the world of education. Cohen (1980) stated that the higher the ability of a person to think in an abstract way, the higher the ability of the person will function effectively in the society. Hence, the improvement of formal reasoning and thinking abilities among students is one of the aims of science education at all levels of schooling.

Cognitive Development Theory, a well-known theory proposed by Jean Piaget has

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conceptualized four different stages in the cognitive development of a person i.e. sensory motor (0 - 2 years), preoperational (2 - 7 years), concrete operational (7 - 11 years), and formal operational (11 - 16 years). The main difference among these stages of cognitive development is the mode of thinking involved. Children at formal operational stage can think logically about abstract propositions and test hypotheses systematically. At the same time, they become concerned with the hypothetical, the future, and ideological problems. Researchers (e.g., Inhelder and Piaget, 1958; Lawson, 1982b: 1985; Linn, 1982) had identified five different modes of formal operational reasoning i.e., proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning which are determinants of students' success in advanced science and mathematics courses at secondary level (Wilson and Wilson, 1984).

PROBLEM STATEMENT

The fundamental function of the schooling system in the United States of America was outlined by the Educational Policies Commission in 1961. The Commission stressed the importance of logical thinking abilities in education as stipulated by the following statement:

> *The purpose which runs through and strengthens all other educational purposes - the common thread of education is the development of the ability to think. (Renner and Philips, 1980, p.193)*

Renner and Philips (1980) strongly believed that students should be given opportunities to develop their thinking abilities as a base for intellectual development. In relation to this, Lawson (1985) stressed that schooling system is not meant for the teaching of facts and concepts which are specific to a particular knowledge domain but more importantly to assist students in acquiring thinking skills.

As stipulated in the Integrated Curriculum for Secondary School (ICSS) science curriculum, the aims of the science curriculum in Malaysia are to provide students with the knowledge and skills in the science and technology and enable them to solve problems and make decisions in everyday life based on scientific attitudes and noble values. Via the science curriculum, it is hoped that students will be able to acquire scientific skills (i.e., science process skills and science manipulative skills), thinking skills (i.e., creative and critical thinking skills), and apply knowledge and skills in a creative and critical manner for problem solving and decision-making (*Pusat Perkembangan Kurikulum, Kementerian Pelajaran Malaysia*, 2001).

Based on the Cognitive Development Theory proposed by Jean Piaget, Malaysian Form 4 students are at the formal operational stage whereby they can think logically about abstract propositions and test hypotheses systematically. At the same time, they also become concerned with the hypothetical, the future and ideological problems. As pointed out by Wilson and Wilson (1984), formal operational reasoning was determinant of students' success in advanced science and mathematics courses at secondary level.

Previous researchers (e.g., DeLuca, 1981; Hernandez, Marek and Renner, 1984; Howe and Shayer, 1981; Meehan, 1984; Shemesh, 1990) had found a significant difference in logical thinking abilities between male and female students. Male students have shown better performance in Piagetian formal reasoning tasks as compared to their counterparts. However, other researchers did not find any significant difference (e.g., Keig and Rubba, 1993; Michael Liau, 1982; Roadrangka, 1995). On the other hand, previous researches (e.g., Bitner, 1991; Roadrangka, 1995; Siti Hawa Munji, 1998) suggested that formal reasoning abilities are closely related to science achievement.

However, there are not many researches conducted to gauge secondary students' logical thinking abilities, especially in the Malaysian rural secondary schools context. Hence, due to the scarcity of research in this area, the main aim of this study is to gauge the logical thinking abilities among Form 4 students in the Interior Division of Sabah, Malaysia. This study is also aimed to identify if there is any significant difference in rural students' logical thinking abilities based on their gender and science achievement at lower secondary level.

RESEARCH OBJECTIVES

The objectives of this study are:

1. To gauge the logical thinking abilities among Form 4 students in the Interior Division of Sabah, Malaysia.
2. To investigate if there is any significant difference in rural secondary students' logical thinking abilities based on their gender and science achievement at lower secondary level.

RESEARCH HYPOTHESES

This study was guided by the following hypotheses:

Ho_1: There is no significant difference in the acquisition of logical thinking abilities based on students' gender.

Ho_2: There is no significant difference in the acquisition of logical thinking abilities based on students' science achievement at lower secondary level.

RESEARCH DESIGN

This was a non-experimental quantitative research and a sample survey method was used to collect data. The samples were selected by using a two-stage cluster random sampling technique. Univariate analysis which includes independent sample t-test and One-way Analysis of Variance (ANOVA) were used to test the stated null hypotheses at a predetermined significance level of .05.

CONTEXT OF THE STUDY

This study was conducted in 18 Form 4 classes from nine secondary schools in the Interior Division of Sabah, Malaysia. The distribution of schools and Form 4 classes according to four districts in the Interior Division of Sabah, Malaysia is shown in Table 1.

POPULATION AND SAMPLING

The population of this study was Form 4 students, from 22 secondary schools in the Interior Division of Sabah, who took the Integrated Curriculum for Secondary School (ICSS) Science as one of their compulsory learning subjects in school. Population size is approximately 3,500 students. The average age of the population is 16 years old. Sample size of this study was determined based on the formula suggested by Krejcie and Morgan (1970) and power analysis (Miles and Shevlin, 2001). Krejcie and Morgan suggested that for a

TABLE 1
Distribution of schools and Form 4 classes according to four districts in the interior division of Sabah, Malaysia

District	No. of schools	No. of Form 4 classes
Tambunan	2	4
Keningau	4	8
Tenom	2	4
Nabawan	1	2
Total	9	18

population between 3,000 and 3,500, a minimum sample size of 341-346 is acceptable. Thus, the sample size of this study is adequate compared to Krejcie and Morgan's recommendation.

To be specific, two-stage cluster random sampling was used to identify schools and Form 4 classes to be involved in this study. At stage one, systematic sampling was used to identify nine secondary schools from four districts in the Interior Division of Sabah, Malaysia. Once the schools have been chosen, simple random sampling method was used to select any two Form 4 classes from each chosen school by using the random number table. All the students in the chosen classes were automatically taken as samples of the study. The combination of sampling techniques is to ensure the representativeness of the samples used in the study.

RESEARCH INSTRUMENT

Group Assessment of Logical Thinking (GALT) is a paper-and-pencil test which consists of 21 items to measure students' logical thinking abilities. The distribution of items according to six different modes of logical thinking abilities is shown in Table 2.

Instrument used in this study is a modified and translated Malay version from the instruments i.e. 'Group Assessment of Logical Thinking' (GALT) (Roadrangka et al., 1983) and 'Test of Logical Thinking' (TOLT) (Tobin and Capie, 1981). These instruments were developed to measure students' modes of Piagetian cognitive reasoning abilities i.e. conservational reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning.

Double-multiple-choice response format for alternatives and justifications of answers were used in this instrument. Students were posed with a problem and asked to choose the best answer, from 2 to 5 possible answers available, for each problem. Following that, students were asked to choose the best justification for the chosen answer from a list of 2 to 5 possible justifications. On the other hand, pictorial presentation was used to enhance students' better understanding of the items (Roadrangka et al., 1983).

Validity and Reliability of the Instrument

The researcher had examined all the items in the original GALT and TOLT instrument and found that most of the items were suitable to be used in the Malaysian context. Efforts have been devoted to ensure the content and face validity of the modified and translated version of the instrument. In this matter, all the items were translated into Malay language so that the respondents can understand the items and choose their best answers and justifications without any semantic distortion. The Cronbach's alpha reliability coefficient of the instrument was found at .52 which is considered moderate for its use in the study.

TABLE 2
Distribution of GALT items according to six different modes of logical thinking

Subscales	Item	No. of items
Conservational reasoning	1,2,3,4	4
Proportional reasoning	5,6,7,8,9	5
Controlling variables	10,11,12	3
Probabilistic reasoning	13,14,15	3
Correlational reasoning	16,17,18	3
Combinatorial reasoning	19, 20, 21	3
Total		21

DATA COLLECTION

Before administering the instrument, formal permission from the school principals involved was sought and obtained. The instrument was then administered by the researcher. Students were gathered in the school hall and the instrument was administered to the students concurrently. The students were told about the nature of the instrument and how the instrument should be answered. The students were given ample time of approximately 2 hours to answer all the questions in the instrument.

DATA ANALYSIS

Students' answers on the instrument were checked and scored by the researcher to ensure consistency in the scoring. There were two answers for the first 18 items in the instrument. One point will be given for both correct answers. If only part of the answers is correct, zero point will be given. The last three items in the instrument were used to gauge students' combinatorial reasoning ability. One point will be awarded if all the correct combinations of answers are listed in the space provided. Likewise, zero point will be given if only part of the answers is correct. Possible minimum score for this instrument is zero whereas the maximum score can reach 21. According to Lawson (1995), students' performance in GALT instrument can be used to categorize students into empirical-inductive thinking pattern (score 0 to 15) or hypothetical-deductive thinking pattern (score 16 to 21). On the other hand, students can also be categorized into three levels of cognitive development i.e. concrete operational (score 0 to 8), transitional operational (score 9 to 15), and formal operational (score 16 to 21) stage.

Descriptive statistics which include measures of central tendency (mean, average item mean) and measures of variability (range, standard deviation, and average item standard deviation) were used to gauge the acquisition of logical thinking abilities among Form 4 students in the Interior Division of Sabah, Malaysia. After the assumptions of using parametric tests were met, univariate analysis such as independent sample *t*-test and one-way ANOVA were used to test the stated null hypotheses at a specified significance level, $\alpha = .05$.

Independent Sample t-Test

Independent sample *t*-test was used to determine if there is any significant difference in the acquisition of logical thinking abilities based on students' gender. Independent sample *t*-test was used to compare the overall mean of logical thinking abilities as well as the scale mean of logical thinking abilities i.e. conservational reasoning, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning.

One-way Analysis of Variance

One-way ANOVA was used to ascertain if there is any significant difference in the acquisition of logical thinking abilities based on students' science achievement at lower secondary level (low, medium, high). One-way ANOVA was used to compare the overall mean of logical thinking abilities as well as the scale mean of logical thinking abilities. If there is a significant difference, Post-Hoc multiple comparison test i.e., Tukey's HSD (Honestly Significant Difference) will be used to identify which levels of science achievement show significant difference in terms of logical thinking abilities.

RESEARCH FINDINGS AND DISCUSSIONS

Logical Thinking Abilities among Rural Secondary Students

Table 3 shows the overall mean and standard deviation of logical thinking abilities among Form 4 students in the Interior Division of Sabah, Malaysia.

Descriptive statistics in Table 3 and *Fig. 1* showed that the overall mean of logical thinking abilities among Form 4 students in the Interior Division of Sabah is 3.191 (average item mean = .152) with a standard deviation of 2.158 (average item SD = .103). The average item mean

TABLE 3
Mean and standard deviation of logical thinking abilities
(n = 549)

Subscales	No. of items	Mean	SD	Average item mean[a]	Average Item SD	Range
Conservational reasoning	4	1.384	1.084	.346	.271	0 - 4
Combinatorial reasoning	3	.424	.619	.141	.206	0 - 3
Controlling variables	3	.368	.582	.123	.194	0 - 3
Correlational reasoning	3	.330	.582	.110	.194	0 - 3
Proportional reasoning	5	.516	.749	.103	.150	0 - 4
Probabilistic reasoning	3	.169	.463	.056	.154	0 - 3
Overall	21	3.191	2.158	.152	.103	0 - 12

[a]Average item mean = Scale mean divided by the number of items in each scale

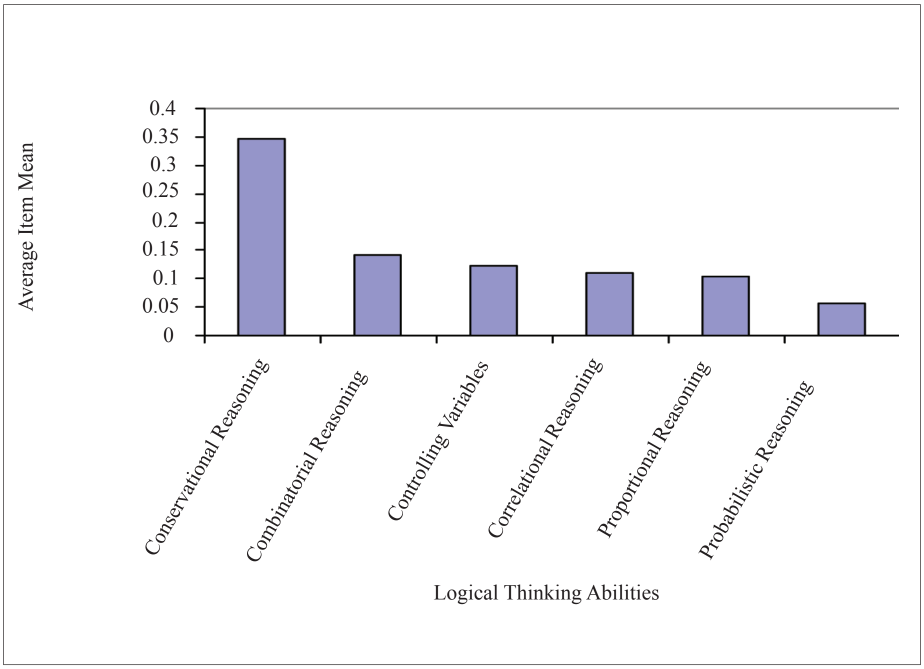

Fig. 1: Average Item Mean of Logical Thinking Abilities (n=549)

according to different modes of logical thinking abilities in descending order are: conservational reasoning (average item mean = .346, average item SD = .271), combinatorial reasoning (average item mean = .141, average item SD = .206), controlling variables (average item mean = .123, average item SD = .194), correlational reasoning (average item mean = .110, average item SD = .194), proportional reasoning (average item mean = .103, average item SD = .150), and probabilistic reasoning (average item mean = .056, average item SD = .154).

These research findings revealed that the acquisition of logical thinking abilities among Form 4 students in the Interior Division of Sabah was low with the average item mean in the range of .056 to .346. Average item mean for all the subscales (except conservational reasoning) were lower than the overall average item mean of logical thinking abilities. Further analysis, based on Lawson's categorization of cognitive development, surprisingly found that 98 percent of the respondents are categorized at the concrete operational stage whereas only 2 percent are categorized at the transitional operational stage. According to Lawson (1995), students can be categorized into three levels of cognitive development i.e. concrete operational, transitional operational, and formal operational based on their performance in GALT instrument.

As shown in Table 3, average item mean according to different modes of logical thinking in descending order are conservational reasoning, combinatorial reasoning, controlling variables, correlational reasoning, proportional reasoning, and probabilistic reasoning. This finding was supported by a model of hierarchical relationships between Piagetian modes of cognitive reasoning and integrated science process skills as proposed by Yap (1985) and Yeany *et al*. (1986). In the proposed model, probabilistic reasoning is situated at a higher hierarchy as compared to proportional reasoning, controlling variables, combinatorial reasoning, and conservational reasoning which are placed at a lower hierarchy of the model.

Students' low logical thinking abilities might be due to the education system which is more examination-oriented. Hence, less emphasis is given to the teaching and use of logical thinking skills. Science teaching and learning strategies are aligned to objectivism with the aim to cover the syllabus within the allotted time without 'investing' adequate time to nurture thinking skills among students. Furthermore, school evaluation system which only emphasizes the acquisition of content knowledge could contribute to low logical thinking abilities among students. Syed Anwar Aly and Merza Abbas (2000) reported that the evaluation of students' science achievement does not give equal emphasis on the process and product component of scientific skills. Almost 100 percent of the evaluation focused on the science product component i.e., concepts, theories, and formulae. Hence, high achievers in science are students who can explain the related concepts and theories and solve routine problems by using related formulae.

In relation to this, logical thinking abilities among students in local higher learning institutions were also reported as low. Syed Anwar Aly (2000) found that only 19 percent of matriculation college students possess high scientific reasoning abilities, 66 percent at medium stage whereas 15 percent possess low scientific reasoning abilities. In the same study, Syed Anwar Aly (2000) reported that only 19 percent of Malaysian students with average age of 19 years old possess high scientific reasoning abilities as compared to 22 percent of American students with average age of 16 years old.

Mean Difference in the Acquisition of Logical Thinking Abilities based on Students' Gender

Independent sample t-test results (Table 4 and *Fig. 2*) showed that there is no significant difference in the overall mean of logical thinking abilities based on students' gender ($t = -1.721$, $df = 483.410$, $p = .086$). Thus, the first null hypothesis which stated that there is no significant difference in the acquisition of logical thinking abilities based on students' gender is failed to be rejected.

Although male students ($M = 3.367$, $SD = 2.373$) scored higher than female students

TABLE 4
Independent sample t-test results for mean difference in logical thinking abilities based on gender (n = 549)

Subscales	Gender	n	Mean	SD	Mean difference	Effect size	t	df	p
Conservational reasoning	Male	251	1.498	1.201	.209	.193	-2.222*	477.331	.027
	Female	298	1.289	.966					
	Overall	549	1.384	1.084					
Proportional reasoning	Male	251	.582	.777	.122	.163	-1.893	515.368	.059
	Female	298	.460	.720					
	Overall	549	.516	.749					
Controlling variables	Male	251	.387	.612	.035	.060	-.684	547	.495
	Female	298	.352	.557					
	Overall	549	.368	.582					
Probabilistic reasoning	Male	251	.163	.440	-.012	-.026	.281	547	.779
	Female	298	.175	.482					
	Overall	549	.169	.463					
Correlational reasoning	Male	251	.339	.627	.017	.029	-.331	547	.741
	Female	298	.322	.542					
	Overall	549	.330	.582					
Combinatorial reasoning	Male	251	.398	.601	-.048	-.078	.903	547	.367
	Female	298	.446	.635					
	Overall	549	.424	.619					
Overall	Male	251	3.367	2.373	.323	.150	-1.721	483.410	.086
	Female	298	3.044	1.949					
	Overall	549	3.191	2.158					

* $p < .05$
The effect size is the mean difference divided by the pooled standard deviation

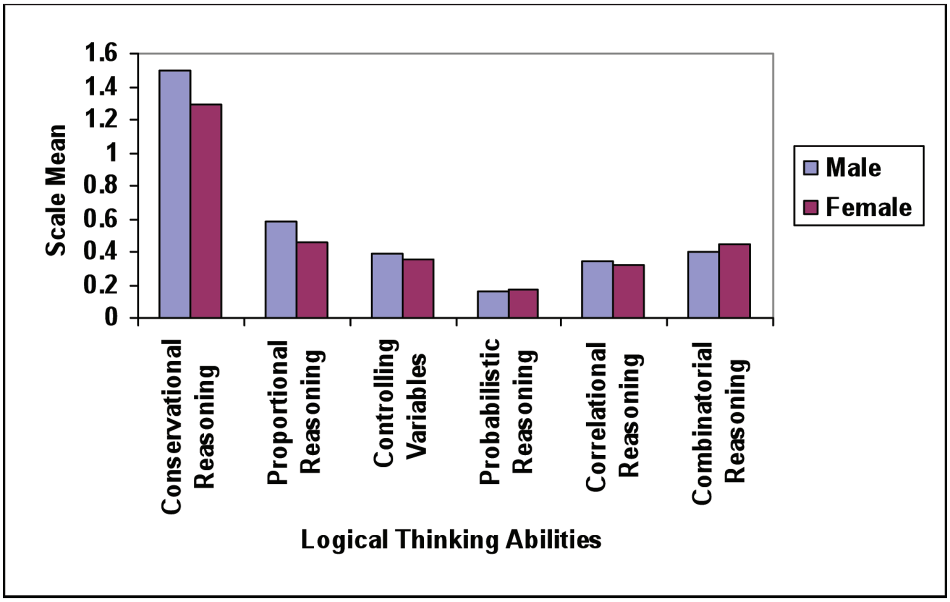

Fig. 2: Mean difference in logical thinking abilities based on gender (n = 549)

(M = 3.044, SD = 1.949), but at t = -1.721 and p = .086, the mean difference is insignificant. However, further analysis showed that male students (M = 1.498, SD = 1.201) scored significantly higher than female students (M = 1.289, SD = .966) in conservational reasoning at t = -2.222, df = 477.331 and p = .027.

The finding of this study also surprisingly revealed that up to 97.2 percent of male respondents and 98.7 percent of female respondents are categorized at concrete operational stage whereas the remaining are categorized at transitional operational stage. Hence, there is no significant difference in the acquisition of logical thinking abilities based on gender. This finding was found to be consistent with the findings of Keig and Rubba (1993), Michael Liau (1982), and Roadrangka (1995). As an example, Michael Liau (1982), in his research to investigate primary school students' ability in conservation of length via three Piagetian experiments, he found that there is no significant difference in the ability of conservation of length between male and female students. However, this finding was contradicting with previous researchers (DeLuca, 1981; Hernandez, Marek, and Renner, 1984; Howe and Shayer, 1981; Meehan, 1984; Shemesh, 1990). Previous researches had found a significant difference in logical thinking abilities between male and female students. Male students performed better in Piagetian formal reasoning tasks as compared to their female counterparts.

Mean Difference in the Acquisition of Logical Thinking Abilities based on Students' Science Achievement at Lower Secondary Level

One-way ANOVA results in Table 5 showed that there is a significant difference in the overall mean of logical thinking abilities according to students' science achievement at lower secondary level (F(2, 496) = 64.614, p<.0005). This finding successfully rejected the second null hypothesis which stated that there is no significant difference in the acquisition of logical thinking abilities according to students' science achievement at lower secondary level. On the other hand, one-way ANOVA revealed that there is a significant difference in the mean of conservational reasoning (F(2, 496) = 35.156, p<.0005), proportional reasoning (F(2, 496) =

TABLE 5
One-way ANOVA results for mean difference in logical thinking abilities based on students' science achievement at lower secondary level (n = 499)

Subscales	Sources of Variation	SS	df	MS	F	p
Conservational reasoning	Between group	70.785	2	35.393	35.156*	< .0005
	Within group	499.339	496	1.007		
	Overall	570.124	498			
Proportional reasoning	Between group	20.605	2	10.302	19.497*	< .0005
	Within group	262.085	496	.528		
	Overall	282.689	498			
Controlling variables	Between group	9.149	2	4.574	13.983*	< .0005
	Within group	162.266	496	.327		
	Overall	171.415	498			
Probabilistic reasoning	Between group	4.260	2	2.130	10.608*	< .0005
	Within group	99.600	496	.201		
	Overall	103.860	498			
Correlational reasoning	Between group	.295	2	.147	.435	.648
	Within group	168.146	496	.339		
	Overall	168.441	498			
Combinatorial reasoning	Between group	10.804	2	5.402	14.380*	< .0005
	Within group	186.318	496	.376		
	Overall	197.122	498			
Overall	Between group	474.691	2	237.345	64.614*	< .0005
	Within group	1821.934	496	3.673		
	Overall	2296.625	498			

* p < .05

19.497, p<.0005), controlling variables (F(2, 496) = 13.983, p<.0005), probabilistic reasoning (F(2, 496) = 10.608, p<.0005), and combinatorial reasoning (F(2, 496) = 14.380, p<.0005) based on students' science achievement at lower secondary level.

Post-Hoc Tukey's HSD multiple comparison results (Table 6 and *Fig. 3*) showed that students with better achievement in science scored significantly higher than students with medium and low achievement in science for conservational reasoning, proportional reasoning, controlling variables, probabilistic reasoning, combinatorial reasoning, and logical thinking abilities as a whole.

These mean differences might be due to the existence of possible relationships between logical thinking abilities and students' science achievement as pointed out by Lawson (1982b) and Roadrangka (1995). Logical thinking abilities play an important role in the understanding and learning of abstract science

TABLE 6
Post-Hoc Tukey's HSD comparison results for mean difference in logical thinking abilities based on students' science achievement at lower secondary level (n = 499)

Subscales	Science achievement at lower secondary level	n		Low	Medium	High
			M	1.0444	1.2119	1.9048
Conservational reasoning	Low	180	1.0444	-		
	Medium	151	1.2119	-.1675 (p = .285)	-	
	High	168	1.9048	-.8603* (p< .0005)	-.6928* (p< .0005)	-
			M	.3278	.4172	.7917
Proportional reasoning	Low	180	.3278	-		
	Medium	151	.4172	-.0894 (p = .505)	-	
	High	168	.7917	-.4639* (p< .0005)	-.3744* (p< .0005)	-
			M	.2556	.3179	.5655
Controlling variables	Low	180	.2556	-		
	Medium	151	.3179	-.0623 (p = .585)	-	
	High	168	.5655	-.3099* (p< .0005)	-.2476* (p< .0005)	-
			M	.0944	.1126	.2976
Probabilistic reasoning	Low	180	.0944	-		
	Medium	151	.1126	-.0181 (p = .929)	-	
	High	168	.2976	-.2032* (p< .0005)	-.1850* (p = .001)	-
			M	.3000	.3907	.6429
Combinatorial reasoning	Low	180	.3000	-		
	Medium	151	.3907	-.0907 (p = .372)	-	
	High	168	.6429	-.3429* (p< .0005)	-.2521* (p = .001)	-
			M	2.3222	2.7881	4.5595
Overall	Low	180	2.3222	-		
	Medium	151	2.7881	-.4659 (p = .071)	-	
	High	168	4.5595	-2.2373* (p< .0005)	-1.7714* (p< .0005)	-

* p < .05

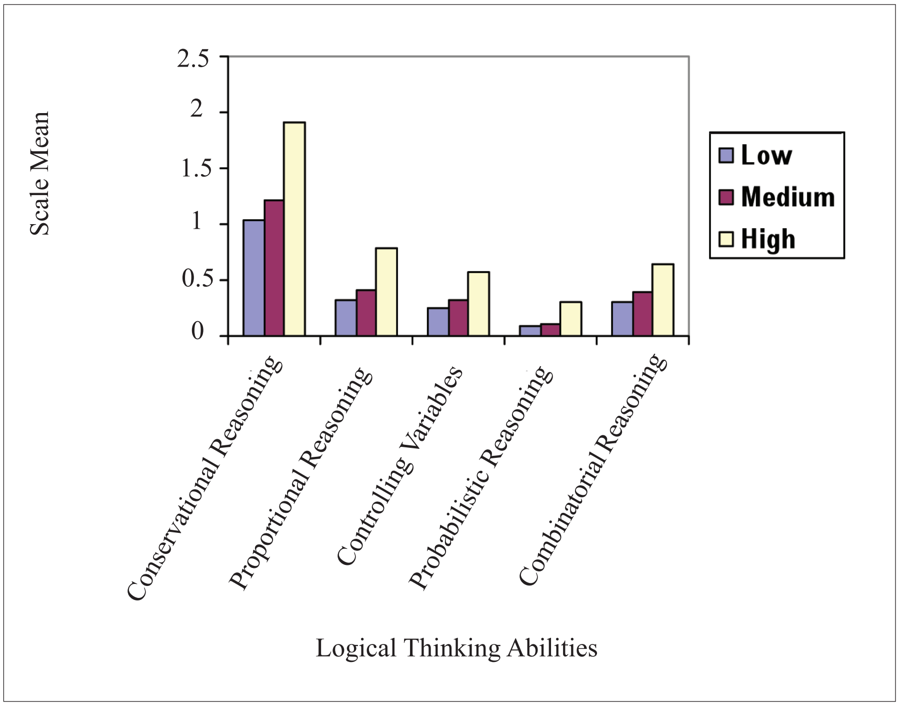

Fig. 3: Mean difference in logical thinking abilities based on students' science achievement at lower secondary level (n= 499)

concepts at secondary level and this is translated into better science achievement among students (Lawson, 1982b, 1985; Linn, 1982).

Previous research studies (e.g., Bitner, 1991; Boulanger and Kremer, 1981; Hofstein and Mandler, 1985; Howe and Durr, 1982; Keig and Rubba, 1993; Krajcik and Haney, 1987; Lawson et al., 1975; Lawson, 1982a, b; Marek, 1981; Mitchell and Lawson, 1988; Piburn, 1980; Piburn and Baker, 1989; Roadrangka, 1995; Siti Hawa Munji, 1998; Staver and Halsted, 1985) suggested that formal reasoning abilities are closely related to science achievement. For instance, Lawson (1982b) showed that students' score in 'Lawson Classroom Test of Formal Reasoning' (Lawson, 1978) was correlated with their achievement in school subjects i.e., social studies, science, and mathematics. This finding provides concrete evidence that formal reasoning abilities can also be related to students' general performance, not only to science and mathematics.

On the other hand, Roadrangka (1995) found that there is a relationship between formal operational reasoning abilities and students' achievement in biology, physics, and chemistry. Students at formal operational stage scored significantly higher in biology, physics, and chemistry tests compared to those at concrete operational stage. Students at formal operational stage were also found to obtain significantly higher score in physics and chemistry tests than students at transitional operational stage. Concrete thinkers are unable to develop the understanding of abstract concepts. Conversely, formal thinkers are able to develop the understanding of concrete and abstract concepts (Inhelder and Piaget, 1958). Hence, students' success in science will be guaranteed by using different modes of formal operational reasoning (Lawson, 1982b, 1985; Linn, 1982; Tsaparlis, 2005; Tai et al., 2005; Lewis and Lewis, 2007). For instance, Lewis and Lewis (2007) emphasized the need to include a focus on the development of formal thought as well as a content review in the efforts to help at-risk students in general chemistry.

IMPLICATIONS OF THE STUDY

In the effort to develop students' logical thinking abilities, some changes in the evaluation system and science teaching and learning strategies need to be seen more intentionally. In relation to this, different subjects such as planning and developing instructional programs, classroom activities, laboratory activities, teaching materials, measurement-assessment methods, and pre-service teacher education strategies need to be considered for the purpose of developing students' cognitive thinking abilities (Schneider and Renner, 1980; Moshman and Thompson, 1981; Akdeniz, 1993; Çepni and Özsevgeç, 2002; Özsevgeç, 2002).

The importance of logical thinking abilities in our education system as emphasized by Renner and Philips (1980, p.193): "The purpose which runs through and strengthens all other educational purposes – the common thread of education is the development of the ability to think" needs to be fully understood by all the relevant parties (e.g. Curriculum Development Centre, schools, science teachers) who are involved directly and indirectly in the planning and implementation of science curriculum in this country. As pointed out by Renner and Philips (1980), students should be given more opportunities to develop their thinking abilities for intellectual development via various approaches. In relation to this, Yaman (2005) has shown that problem-based learning (PBL) approach was effective in the development of logical thinking skills. On the other hand, the creative and critical thinking based laboratory method was also found effective in developing creative and logical thinking abilities (Koray and KÖKSAL, 2009).

Hence, logical thinking abilities should be given new emphasis in the teaching and learning of science in the effort to improve students' science achievement at all levels of schooling. Lawson (1985) stressed that the schooling system is not meant for the teaching of facts and concepts which are specific to a particular knowledge domain, but to assist students in acquiring thinking skills.

REFERENCES

Akdeniz, A.R. (1993). The implementation of a new secondary physics curriculum in Turkey: An exploration of teaching activities. Unpublished Doctoral Dissertation, University of Southampton, UK.

Bitner, B.L. (1991). Formal operational reasoning modes: Predictors ofcritical thinking abilities and grades assigned by teachers in science and mathematics for students in grades nine through twelve. *Journal of Research in Science Teaching*, *28*(3), 265 - 274.

Boulanger, F. D. and Kremer, B.K. (1981). Age and developmental level as antecedents of science learning. *Journal of Research in Science Teaching*, *18*(4), 371 - 384.

Çepni, S. and Özsevgeç, T. (2002). *Science teachers' assessment tools and their relation with students' cognitive development.* Education: Changing Times, Changing Needs, First International Conference on Education, Faculty of Education Eastern Mediterranean University, May 8 - 10, Gazimagusa, Turkish Republic of Nothern Cyprus.

Cohen, H.G. (1980). Dilemma of the objective paper-and-pencil assessment within the Piagetian framework. *Science Education*, *64*(5), 741 - 745.

DeLuca, F.P. (1981). Application of cluster analysis to the study of Piagetian stages of intellectual development. *Journal of Research in Science Teaching*, *18*(1), 51 - 59.

Hernandez, L.De., Marek, E.A. and Renner, J.W. (1984). Relationships among gender, age, and intellectual development. *Journal of Research in Science Teaching*, *1*(4), 365 - 375.

Hofstein, A. and Mandler, V. (1985). The use of Lawson's Test of Formal Reasoning in the Israeli science education context. *Journal of Research in Science Teaching*, *22*(2), 141 - 152.

Howe, A.C. and Durr, B.P. (1982). Analysis of an instructional unit for level of cognitive demand. *Journal of Research in Science Teaching*, *19*(3), 217 -224.

Howe, A. C. and Shayer, M. (1981). Sex related differences on a task of volume and density. *Journal of Research in Science Teaching*, *18*(2), 169 -175.

Inhelder, B. and Piaget, J. (1958). *The Growth of Logical Thinking: From Childhood to Adolescence*. New York: Basic Books, Inc.

Keig, P.F. and Rubba, P.A. (1993). Translation of representation of the structure of matter and its relationship to reasoning, gender, spatial reasoning, and specific prior knowledge. *Journal of Research in Science Teaching*, *30*(8), 883 - 903.

Koray, Ö. and KÖKSAL Mustafa Serdar. (2009). The effect of creative and critical thinking based laboratory applications on creative and logical thinking abilities of prospective teachers. *Asia Pacific Forum on Science Learning and Teaching*, *10*(1). Retrieved January 1, 2009 from http://www.ied.edu.hk/apfslt/v10_issue1/koksal/index.htm#con.

Krajcik, J.S. and Haney, R.E. (1987). Proportional reasoning and achievement in high school chemistry. *School Science and Mathematics*, *87*(1), 25 - 32.

Krejcie, R.V. and Morgan, D.W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, *30*(3), 607 - 610.

Lawson, A.E. (1978). The development and validation of a classroom test of formal reasoning. *Journal of Research in Science Teaching*, *15*(1), 11-24.

Lawson, A.E. (1982a). The relative responsiveness of concrete operational seventh grade and college students to science instruction. *Journal of Research in Science Teaching*, *19*(1), 63 - 77.

Lawson, A.E. (1982b). Formal reasoning, achievement, and intelligence: An issue of importance. *Science Education*, *66*(1), 77 - 83.

Lawson, A.E. (1985). A review of research on formal reasoning and science teaching. *Journal of Research in Science Teaching*, *22*(7), 569 - 617.

Lawson, A.E., Nordland, F.H. and DeVito, A. (1975). Relationship of formal reasoning to achievement, aptitudes, and attitudes in preservice teachers. *Journal of Research in Science Teaching*, *12*(4), 423 - 431.

Lewis, S.E. and Lewis. J.E. (2007). Predicting at-risk students in general chemistry: Comparing formal thought to a general achievement measure. *Chemistry Education Research and Practice*, *8*(1), 32 - 51.

Linn, M.C. (1982). Theoretical and practical significance of formal reasoning. *Journal of Research in Science Teaching*, *19*(9), 727 - 742.

Marek, E.A. (1981). Correlations among cognitive development, intelligence quotient, and achievement of high school biology students. *Journal of Research in Science Teaching*, *18*(1), 9 - 14.

Meehan, A.M. (1984). A meta-analysis of sex differences in formal operational thought. *Child Development*, *55*, 1110 - 1124.

Liau, T.L. (1982). Three Piagetian experiments: An investigation into the ability of Malaysian primary school children from a school with an urban character and from a school with a rural character to conserve length. Unpublished Master Dissertation, Universiti Sains Malaysia, Penang.

Miles, J. and Shevlin, M. (2001). *Applying Regression and Correlation. A Guide for Students and Researchers*. London: Sage Publications.

Mitchell, A. and Lawson, A.E. (1988). Predicting genetics achievement in nonmajors college biology. *Journal of Research in Science Teaching*, *25*(1), 23 - 37.

Moshman, D. and Thompson, P.A. (1981). Hypothesis testing in students: Sequences, stages, and instructional strategies. *Journal of Research in Science Teaching*, *18*(4), 341 - 352.

Özsevgeç, T. (2002). Determination of the relationships between middle school students' profiles and their cognitive development levels in the selected science topics. Unpublished Master Dssertation, Karadeniz Technical University, Turkey.

Piburn, M. (1980). Spatial reasoning as a correlate of formal thought and science achievement for New Zealand students. *Journal of Research in Science Teaching*, *17*(5), 443 - 448.

Piburn, M. D. and Baker, D. R. (1989). Sex differences in formal reasoning ability: Task and interviewer effects. *Science Education*, *73*(1), 101 - 113.

Pusat Perkembangan Kurikulum, Kementerian Pendidikan Malaysia. (2001). *Huraian Sukatan Pelajaran Sains KBSM Tingkatan Empat.* Kuala Lumpur: Kementerian Pendidikan Malaysia.

Renner, J. W. and Philips, D. G. (1980). Piaget's developmental model: A basis for research in science education. *School Science and Mathematics*, *80*, 193 - 198.

Roadrangka, V. (1995). *Formal operational reasoning ability, cognitive style and achievement in Biology, Physics, and Chemistry concepts of Form 4 students in Penang, Malaysia.* SEAMEO Regional Centre for Education in Science and Mathematics, Penang.

Roadrangka, V., Yeany, R.H. and Padilla, M.J. (1983). The construction of a group assessment of logical thinking (GALT). Paper presented at the *56th annual meeting of the National Association for Research in Science Teaching*, Dallas, Texas, April 5 – 8, 1983.

Shemesh, M. (1990). Gender-related differences in reasoning skills and learning interests of junior high school students. *Journal of Research in Science Teaching*, *27*(1), 27 - 34.

Schneider, L.S. and Renner, J.W. (1980). Concrete and formal teaching. *Journal of Research in Science Teaching*, *17*(6), 503 - 518.

Siti Hawa Munji. (1998). Cognitive styles, intelligence, level of cognitive development, study habits and academic achievement of university students. Unpublished Doctoral thesis, University Malaya, Kuala Lumpur.

Staver, J. R. and Halsted, D. A. (1985). The effects of reasoning, use of models, sex type, and their interactions on posttest achievement in chemical bonding after constant instruction. *Journal of Research in Science Teaching*, *22*(5), 437 - 447.

Syed Anwar Aly. (2000a). Hypothetico-deductive reasoning and concept acquisition: Implications for strategies in the Malaysian smart schools. Kertas dibentangkan dalam *Simposium Pendidikan Sains dan Teknologi*, Pulau Pinang, 30 March – 2 April, 2000.

Syed Anwar Aly and Merza Abbas. (2000b). Penyerapan kemahiran saintifik dalam proses pengajaran dan pembelajaran kimia di tahap menengah. Kertas dibentangkan dalam *Seminar Pendidikan Sains dan Matematik*, UiTM Shah Alam, 2 – Oktober, 2000.

Tai, R.H., Sadler, P.M. and Loehr, J.F. (2005). Factors influencing success in introductory college chemistry. *Journal of Research in Science Teaching*, *42*, 987 - 1012.

Tobin, K.G. and Capie, W. (1981). The development and validation of a group test of logical thinking. *Educational and Psychological Measurement*, *41*, 413 - 423.

Tsaparlis, G. (2005). Non-algorithmic quantitative problem-solving in university physical chemistry: A correlation study of the selective cognitive factors. *Research in Science and Technological Education*, *23*, 125 - 148.

Wilson, A.H. and Wilson, J.M. (1984). The development of formal thought during pretertiary science courses in Papua New Guinea. *Journal of Research in Science Teaching*, *21*(5), 527 - 535.

Yaman, Suleyman. (2005). Effectiveness on development of logical thinking skills of problem based learning skills in science teaching. *Journal of Turkish Science Education*, *2*(1), 31 - 33.

Yap, K.C. (1985). Validation of hierarchical relationships among Piagetian cognitive modes and integrated science process skills for high school students with different cognitive reasoning abilities. Unpublished Doctoral dissertation, University of Georgia.

Yeany, R. H., Yap, K. C. and Padilla, M. J. (1986). Analyzing hierarchical relationships among modes of cognitive reasoning and integrated science process skills. *Journal of Research in Science Teaching*, *3*(4), 277 - 291.