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The Effectiveness of Teaching Critical Thinking Skills on Students' Academic Achievement in Mathematics and Science: A Study in Timss Framework

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Abstract

The present study, conducted in Timss 2007 framework, aimed to examine the effectiveness of teaching critical thinking on students' academic achievement in mathematics and science. Research design was Quasi-experimental. Research sample (With available sampling method) included two classes of third grade students in Eghbal middle school in Baharestan, Tehran, Iran in 2014-15 randomly assigned to experimental and control groups. Afterwards, the experimental group received critical thinking instruction for 12 sessions, while the control group received no training during this period. The data were gathered using parallel forms of Timss 2007 framework, which were implemented in three periods. The data were analyzed through Analysis of Covariance (ANCOVA), and t-test. Results showed that critical thinking teaching could considerably improve students' performance in mathematics and science in domains of reasoning and applying; however, no significant relationship was revealed between critical thinking teaching and students' performance in the domain of knowing. Findings of the follow up test, in addition, indicated a significant decrease in applicants' scores of the experimental group. It can be concluded that critical thinking teaching should be brought into sharper focus in syllabuses of middle schools as its principles could not only resolve students' problems in academic issues but they would also result in improving performance of students in the domains of mathematics and science.

Keywords: Academic achievement, Critical thinking, Timss study

Introduction

Academic achievement is considered as one of the key points in education which has been brought into sharper focus from the points of view of parents and officials in recent years (Tulbure, 2012). Ward, Stoker, and Murray-Ward (1996) defined academic achievement as a tool in education for measuring the amount of success or achievement of any individual in a specific field or area of accomplishment. Zhang (2010) also argued that academic achievement represents the extent to which a society has been successful in obtaining its objectives and fostering educational system.

Arizi, Abedi, and Taji (2010) reported mathematics and science as two challenging courses for students in middle schools. Therefore, psychologists, education officials, mathematics and science experts have paid closer attention to learning styles and behaviors in addition to cognitive elements such as intelligent (Ertekin, Dilmac, & Yazici, 2009). In his research on the

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role of mathematics and science in professional life, Daneshravayi (2007) has concluded that many individuals have lost the opportunity of getting a good job due to the fact that they were feared of mathematics and science.

Meyers (1986) considered lack of critical thinking as a serious problem which is to be urgently addressed by officials; also, it is necessary that educationalists make a big change in syllabuses through inserting the principles of critical thinking in schools. Facion (2010) states that "we understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual con- siderations upon which that judgment is based" (p. 27).

Critical thinking is an urgent skill which emphasizes logical interpretation as well as able to learn lifelong; so, it helps students in two aspects of 1) everyday life which includes reasonable learning and contribute them to be lifelong learners as well as 2) academic life which requires them to practice themselves to systematically think (Santiprasitkul, Sithivong, & Polnueangma, 2013). Many researchers (Barlow et al., 2008; Botvin, Barker, Renik, Filazzola, & Botvin, 1984; Gonzalez, 2003; Kazemi et al., 2011; Lam et al., 2008; Moghadam et al., 2006; Pentz, 1980; Rolin & Darylm, 2002) proved that critical thinking can be made into practice through experience and instruction, which in turn improve personal and social life.

Nowadays, schools have mainly focused on knowledge and information transmission rather than training critical thinkers (Shabani, 2011). Thus, it seems of crucial significance for officials in educational system to consider critical thinking as an inalienable part of curriculum development. In fact, it is very necessary to bring critical thinking as a main objective of education system into a sharper focus because the courses are exposed to change and development during the time (Meyers, 1986).

A number of researches have shown the effectiveness of critical thinking teaching on academic achievement in social sciences, sociology, mathematics, English, etc. (Abasi, 2001; Bayat, 2010; Law & Kaufhold, 2009; Muhammmadi, 1999). In addition, De Koning, Hamers, Sijtsma, and Vermeer (2002) examined the impact of reasoning teaching and Hashemian Nejad (2001) studied the aspects and methods in teaching critical thinking.

Reports by Timss and Pirls show that Iranian students, compared to those in other countries, possessed lower average scores in cognitive and content domains of mathematics and science in fourth and eighth grades (Karimi, 2008). Ranjbar and Esmaili (2006) attributed this issue to the fact that some elements of critical thinking including reasoning is not addressed in Iranian education system as Timss requires students to use high level of thinking (based on Bloom taxonomy). The present research aims to answer this question that whether teaching critical thinking can improve students' academic achievement in mathematics and science in third grade of middle school.

Method

Participants

The research population included all third-graders male students of middle schools in district 2 of Baharestan region, Tehran in 2014-15. To get the sample, one school was selected through convenient method, among the six classes of which two classes were randomly selected and assigned to experimental and control groups (each of which included 30 applicants).

Instruments

Three parallel forms of Timss (2007), each of which included 24 questions in three domains of knowing, applying and reasoning (8 questions for each domain). Also, parallel forms were homogenized with regard to level of difficulty, questions, content and cognitive areas. It is to be mentioned that forms A and B were mixed to each other because there were a few number of questions in Timss 2007. It should be noted that the TIMSS exam questions are standard and, for this reason, it can be said that the question of the parallel forms used in this study have Validity and reliability.

Critical Thinking Teaching Package which was a researcher-made package designed through various sources. The package includes some topics about critical thinking and some tasks which are designed for teaching in 12 sessions. To measure the content validity, the questionnaire was assessed by five experts and professors in Shahid Beheshti University and The Institute for Educational Research (IER) in Tehran. Reassessing the questionnaire based on their points of view, the internal consistency of instrument was 5.83 (df =7.21) which reported significance at the level of 0.001, indicating that experts unanimously confirmed the questionnaire appropriateness in teaching critical thinking.

Procedure

The design of this study was quasi-experimental. Dividing the applicants into control and experimental groups, the researchers implemented the pretest; afterwards, the experimental group received the treatment for critical thinking in 12 sessions which lasted for three months whereas the control group received no

treatment. Then two groups were provided with a posttest, three months after which a follow up test was performed. The data, finally, were analyzed through descriptive statistics methods (such as mean and standard deviation) and inferential statistics methods (such as Analysis of Covariance (ANCOVA) and T-test. Furthermore, the Statistical Package for Social Science (SPSS) was used to perform statistical procedures.

Findings

To assess the impact of teaching critical thinking on all applicants' academic achievement in mathematics and science, the Timss measure was employed in pre- and posttest as well as follow up test. Table 1 shows the results of descriptive statistics in details.

Table 1.
Mean and standard deviation for experimental and control groups in pretest, posttest and follow up

Group		Reasoning		Applying		Knowing		Total	
		M	SD	M	SD	M	SD	M	SD
Experimental	Pretest	2.77	1.18	3.13	1.33	3.25	1.174	9.16	3.16
	Posttest	3.83	1.19	4.29	1.62	3.93	1.39	12.06	3.49
	follow up	3.56	1.10	3.72	1.39	4.08	1.43	11.37	3.14
Control	Pretest	3.06	1.59	3.17	1.63	3.62	1.45	9.85	3.94
	Posttest	3.07	1.15	3.30	1.42	3.89	1.39	10.27	3.48
	follow up	3.06	1.24	3.31	1.53	3.56	1.44	9.92	3.65

Also, Analysis of Covariance (ANCOVA) was used to compare students' scores of both groups in mathematics and science in pre- and posttest. Before the main analysis, assumptions of covariance analysis (normality, homogeneity of variance and random independent samples) were examined, and the results showed that there has been no violation of the assumptions. The results of Analysis of Covariance (ANCOVA) are shown in Table 2.

Table 2.
Results of ANCOVA for testing the effect of teaching critical thinking on students' academic achievement in mathematics and science

Sources of variation	Sum of squares	df	F	Sig	η^2
Pretest	498.26	1	137.83	.0001	.707
Group	82.69	1	22.87	.0001	.286
Error	206.06	57			
Total	8228.56	60			

As shown in Table 2, the value of F=22.87 (df =57.2) is significant at the level of P=0.0001. Therefore, it can be concluded that teaching critical thinking would enhance students' academic achievement in mathematics and science. In addition, eta squared value (0.286) shows that teaching critical thinking had been effective in boosting learners' achievement in two courses.

To assess the effectiveness of teaching critical thinking on students' academic achievement in domain of reasoning for mathematics and science, the scores in pre-and posttest were compared through ANCOVA, the results of which are shown in Table 3.

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Table 3.
Results of ANCOVA for the effectiveness of teaching critical thinking in domain of reasoning for mathematics and science

Sources of variation	Sum of squares	df	Mean square	F	Sig	η^2
Pretest	46.98	1	46.98	81.56	.0001	.589
Group	13.13	1	13.13	22.78	.0001	.286
Error	32.84	57	.58			
Total	804.32	60				

As shown in Table 3, the value of F=22.78 (df =57.2) is significant at the level of P=0.0001. Therefore, it can be concluded that teaching critical thinking would enhance students' academic achievement in domain of reasoning for mathematics and science. In addition, eta squared value (28.6%) indicates that teaching critical thinking has been effective in boosting learners' achievement in reasoning domain for these two courses.

Moreover, to assess the impact of teaching critical thinking on students' academic achievement in domain of applying for mathematics and science, the scores in pre-and posttest were compared through ANCOVA, the results of which are represented in Table 4.

Table 4.
Results of ANCOVA for the effectiveness of teaching critical thinking in domain of applying for mathematics and science

Sources of variation	Sum of squares	df	Mean square	F	Sig	η^2
Pretest	44.028	1	44.09	27.57	.0001	.326
Group	15.34	1	15.34	9.602	.003	.144
Error	91.03	57	1.60			
Total	1014.31	60				

As shown in Table 4, the value of F=215.336 (df =57, df=2) is significant at the level of P=0.0001. Consequently, it can be inferred that teaching critical thinking would enhance students' academic achievement in domain of applying for mathematics and science. In addition, eta squared value (14.4%) indicates that teaching critical thinking was reported effective in improving learners' achievement in applying domain for the courses of mathematics and science.

Furthermore, to evaluate the effectiveness of teaching critical thinking on students' academic achievement in domain of knowing for mathematics and science, the scores in pre-and posttest were compared through ANCOVA, the results of which are representedin Table 5.

Table 5.
Results of ANCOVA for the effectiveness of teaching critical thinking in domain of knowing for mathematics and science

Sources of variation	Sum of squares	df	Mean square	F	Sig	η^2
Pretest	41.512	1	41.512	33.592	.000	.371
Group	1.168	1	1.168	.945	.335	.016
Error	70.440	57	1.236			
Total	1030.438	60				

As represented in Table 5, the value of F=0.945 (df =57, df=2) is not significant at the level of P=0.335. Consequently, it can be concluded that teaching critical thinking would not improve students' academic achievement in the domain of knowing for mathematics and science.

In addition, to assess the effectiveness of teaching critical thinking on students' academic achievement in mathematics and science, the follow up test was performed three months after posttest, the results of which were analyzed through t-test and presented in Table 6.

Table 6.
Results of independent t-test for scores of posttest and follow up test in experimental and control groups

	Mean	SD	Std. Error	T	df	Sig
Posttest	11.16	3.57	0.46			
follow up test	10.64	3.45	0.44	3.084	59	0.003

As the Table shows, the t-value of 3.084 and significance of 0.003 indicate that the mean differences in posttest and follow up are significant. Regarding the scores in posttest and follow up test, therefore, it can be inferred that the scores of follow up test have decreased compared to those in posttest. This means that the effectiveness of teaching critical thinking has gradually faded away.

Discussion and Conclusion

The findings of the present research revealed that teaching critical thinking could significantly enhance students' academic achievement in mathematics and science, which is in line with the results of the study conducted by Muhammadi (1999) which showed that critical thinking would dramatically improve students' performance in schools. In addition, the results are consistent with studies of Abasi (2001) and Law and Kaufhold (2009) who found that teaching critical thinking skills would have a crucial impact on students' academic performance.

Findings are also in line with those of Kitot et al. (2010) who found that teaching critical thinking skills was effective in students' learning of history (also reported by Amir, 2009; Arsalan et al., 2009; Ataollahi, 1996; Baba Muhammadi & Khalili, 2004; Badri Gargari, 2008; Hartman & Strenberg, 2008; Hartman & Sternberg , 2008; Zhang, 2002). Other researchers (for example, Arsalan et al., 2009; Koning et al., 2002; Shafiyi et al., 2004; and Zaman et al., 2011) have found in their studies some evidences showing that teaching critical thinking as well as reasoning skills would be effective in students' learning of academic materials in mathematics.

The results can be attributed to this fact that traditional methods in teaching (say memorization or drills) have failed to help students reach top educational objectives, so enhancing their performance requires the educational system to consider thinking as the main effective element in learning (Ghasempour Moghadam, 2010). Talebzade et al., (2009) argued that overemphasizing on memorization in Iranian schools has posed a growing threat on educational system, thus teachers and officials are to bring critical thinking and mental improvement into focus of attention.

Bakhtiar Nasrabadi et al. (2011) cited Conerly (2006) as believing that learning critical thinking skills encourage students to express their points of view in a clear way; in addition, they would adopt a more logical method in dealing with problems, which enables them to obtain a considerable academic achievement.

Therefore, it is necessary to consider critical thinking in students' curriculum in middle schools; also, using self-regulation is suggested to monitor one's cognitive activities by applying skills in analysis, and evaluation to one's own inferential judgments with a view toward questioning, confirming, validating, or correcting either one's reasoning or one's results (Facione, 2010, p. 6).

Furthermore, Barraza and Bodenhorn (2012) emphasize that strong critical thinkers can be described in terms of how they approach specific issues, questions, or problems. In addition, such individuals possess some characteristics as clarity in stating the question or concern, orderliness in working with complexity, diligence in seeking relevant information and care in focusing attention on the concern at hand (Facione, 2010, p. 11). Stylianides et al. (2013), in examining the challenges that students and teachers face with in classrooms, discuss that the activity of reasoning-and-proving is at the heart of mathematical sense making and is important for all students' learning as early as the elementary grades. They concluded that overcoming the

obstacles to teaching reasoning-and-proving would help elementary teachers and students make significant progress in courses. Furthermore, marginal place of reasoning-and-placing in elementary school can be attributed to the fact that elementary teachers have weak mathematical knowledge about this issues as well as counterproductive beliefs in teaching (ibid). Arguing that teaching by inquiry is touted for its potential to encourage students to reason scientifically, Dolan and Grady (2010) continue that even when inquiry teaching is practiced, complexity of students' reasoning may be limited or unbalanced. Their research results revealed points when students' reasoning was quite complex and occasions when their reasoning was limited by the curriculum, instructional choices, or students' unprompted prescription (p. 1).

Teachers of critical thinking, on the other hand, are to bear in mind that environment and method of teaching are very crucial; therefore, academic achievement, learning environment, social structure and teaching methods play a greatly crucial role in enhancing critical thinking in students (Amir, 2009). Consequently, learners are to be encouraged towards learning motivation and curiosity in order to implement their experiences and internalize critical thinking principles in their educational life and help them expresses his/her feelings, opinions, dreams, impressions, and experiences because critical thinking is an active and organized mental process that aims at interpreting ourselves by implementing our acquired knowledge through being aware of our own thought processes and taking into consideration that of others as well as the events taking place around us (Cüceoğlu, 1993, as cited in Ulas et al., 2012, p. 369).

Moreover, students are to be provided with opportunities to practice the principles of critical thinking in the framework of their minds, which per se enables them to explore the issues and resolve the problems in a thoughtful manner. Generally, learners can open their minds to new opportunities of learning experiences and try hard to widen the gap of his understanding of one topic and to be informed more about what one learns gives more rational reasons (Hajhoseini, 2012).

Nevertheless, the relationship between critical thinking and academic achievement in the domain of knowing of mathematics and science was not reported significant. This can be attributed to this fact that Timss is designed as an assessment of mathematics and science which tries to compare the academic performances of different countries in mathematics and science for benefiting from teaching-learning process (Karimi, 2008). Bloom (as cited in Dehghani et al., 2011) related the critical thinking to the top levels of cognitive development (analysis, interpretation, assessment). It can be, thus, inferred that critical thinking is a high level of thinking that enables individuals to ask some questions about presuppositions and concepts, also resolve problems through reasoning and logical thinking (Delioglu et al., 2011). In fact, Bloom (1956) defined critical thinking as the ability to gain knowledge through the exploration of ideas concerning the following six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Knowledge and comprehension belong to the low level of thinking skills, while the other elements belong to the higher level of thinking skills (Xu, 2011, p. 136).

Since the domain of knowing is not related to the high level of cognition, it can be said that critical thinking is in direct relationship with high levels of cognitive development. It is worth mentioning that the applicants in experimental group had no progress in their knowledge because critical thinking basically does not increase or change the level of knowledge of students, rather it is a tool to adopt a self-regulation process which contribute students to practice mental activities. However, the possible increase in learners' knowledge can be attributed to some clinical factors like planning, self-regulation and metacognition through which they learned how to study more effectively and enhance their information.

Results also showed that the scores of applicants in follow uptest significantly decreased, compared to those in posttest, which indicates that teaching critical thinking was not effective for a long-term period. This issue can be attributed to the fact that the outcomes of critical thinking process would not appear in a short-term period; rather they can be expected in a long-term by constant practice and teaching (Altintas & Ozdemir, 2012).

Since the fundamental concepts of learning mostly relied on memorizing for students, the strategy of asking them to memorize rules, procedures and materials are not regarded fairly practical. In fact, although memorization definitely has many valuable uses, fostering critical thinking is not among them. Critical thinking, conversely, emphasizes on reasoning, decision-making, the nature of thought, planning, metacognition, and self-regulation which are taught through team work, questioning and real tasks for effective learning. It can be claimed, consequently, that teaching critical thinking would considerably enhance students' academic achievement in mathematics and science and contribute to their learning due to the fact that it equips learners with skills, by the use of which they can shift their learning approach and boost their learning though applying the academic skills of thinking.

One of the limitations of this research is the non-use of the experimental research design and the absence of other follow-up tests at longer times. According to the results, it is suggested that the components of critical thinking should be included in the curriculum (from elementary to higher levels), and to educate the teachers in this regard; To test the impact of critical thinking training on students' academic performance, researchers use experimental research designs. It is also suggested that researchers should be considered in the preparation of critical thinking tool for students (for younger ages) in future studies.

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