Effects of the Inquiry-Based Learning Method on Students' Achievement, Science Process Skills and Attitudes towards Science: A Meta-Analysis Science

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ABSTRACT

The effectiveness of inquiry-based learning method was discussed for a long time. However, inquiry-based learning method was not discussed and compared with traditional learning before in terms of students' academic achievement, science process skills and attitudes towards science in a meta-analysis study. This study aimed to cover the effects of the inquiry-based science education on students' academic achievement, science process skills and attitudes towards science comparing with traditional learning. The study reviews the findings of the studies on the effectiveness of the inquiry-based science education comparing with traditional learning. In other words, meta-analysis method was used to combine statistically the numerical data of the studies and to reach a general conclusion using the results of these studies. The study reviewed a total of nineteen studies (37 comparisons in terms of achievement, science process skills and attitudes towards science) about the effects of the inquiry-based science education on the students' academic achievement, science process skills and attitudes towards science comparing with traditional learning carried out in Turkey between 2005 and 2015. Meta-analysis results showed that the inquiry-based science education had a positive and higher levels of effects of students' academic achievement (Cohen's d=1.029). It was also found that this specific teaching and learning method had a positive and medium level of effect on their science process skills (Cohen's d=0.742) and attitudes towards science (Cohen's d=0.558). It was found that the inquiry-based learning method used in science education had much more significant effects on student achievement rather than on their science process skills and their attitudes towards science in contrast to the traditional teaching method.

Keywords: Academic achievement, attitudes towards science, inquiry, meta-analysis, science process skills.

INTRODUCTION

Improvements in science and technology have significant effects on science education like in other fields. Therefore, given that science education has become an important field the educational systems of different countries aimed at educating individuals who are scientific literacy. Countries have tried to improve the science course and to make it possible to educate individuals who can reach the necessary information, interpret the newly acquired information

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based on experiences and have problem-solving skills (AAAS, 1990; NRC, 1996, 2000; MEB 2013). The national educational program for the course of science which became effective in 2013 has the major goal of "educating scientifically literate individuals" (MEB, 2013). The program makes use of the inquiry-based method as a primary learning and teaching method for educating scientifically literate individuals. Similarly, National Research Council (NRC) published a series of standards and reported that inquiry is the basis for science education (NRC, 1996; 2000). The inquiry-based learning method is a student-centered method in which students discover everything in their near environment, develop strong arguments about the natural and physical world surround them based on strong justifications, become those individuals who are aware of the significance of science, and construct information about doing, living and thinking (MEB, 2013; Wallace, 1997; Wood, 2003).

Although inquiry-based science teaching commonly could not be identified by scientists, scientists determine common characteristics of inquiry-based science teaching for participants. National Research Council (1996) expressed national science standards to define inquiry-based teaching in different aspects (content, process skills or instructional strategies). In 2000, Inquiry and the national science education standards declared five main characteristics of inquiry-based science teaching without any classification (NRC, 2000; Tatar, 2006; Ulu, 2011);

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.

Using of traditional teaching cause to rote learning of science topics. Traditional teaching is concerned with the teacher being the controller of the learning environment. Power and responsibility are held by the teacher and they play the role of instructor (in the form of lectures) and decision maker (in regards to curriculum content and specific outcomes). They regard students as having knowledge holes that need to be filled with information. In short, the traditional teacher views that it is the teacher that causes learning to occur (Novak, 1998). In the eyes of reformers, traditional teacher-centered methods focused on rote learning and memorization must be abandoned in favor of student-centered and task-based approaches to learning. In recent years, reforms in science education proposed methods which are not based on route memorization, and encourage students' mental and scientific reasoning skills. These methods are strongly based on inquiry and aimed to improve their interest in science (NRC, 1996; 2000). In numerous studies, it was found that the inquiry-based teaching is much more efficient in improving student performance than traditional teaching methods (Gabel, Ruba & Franz, 1977; Hal & McCurdy, 1990; Geban, Askar & Ozkan, 1992; Gencturk & Turkmen, 2007; Celik & Cavas, 2012), their laboratory skills or science process skills (Tobin & Capie, 1982; Matheis & Nakayama, 1988; Basaga, Geban & Tekkaya, 1994; Ergul et al., 2011; Ozdemir & Isık, 2015; Yalcın, 2014), their ability to remember the content of the course (Schneider & Rener, 1980), gender (Gencturk & Turkmen, 2007; Inaltekin & Akcay, 2012) and their attitudes towards science or their scientific activities (Gabel, Ruba & Franz, 1977; Shepardson & Pizini, 1992; Turkmen, 2009; Arslan et al., 2014). Ergul, Simsekli, Calıs, Ozdilek, Gocmencelebi and Sanlı (2011) carried out the study with elementary students about how inquiry-based science learning change their science process skills and attitudes towards science and had reached the conclusion that

inquiry-based science learning significantly influenced on their science process skills and attitudes towards science.

Although there are plenty of studies to investigate about the effect of inquiry-based science learning on students' achievement, science process skills and attitudes towards science, there is no clear conclusion about whether inquiry-based science learning influence students achievement, science process skills and attitudes towards science positively or negatively compared with traditional learning. In all these studies, there seems to be no consistent conclusion. Some studies showed a result that inquiry-based science learning increased students' science process skills, achievement and attitudes towards science and technology than traditional learning (Celik & Cavas, 2012; Hickey et al., 1999; Hickey, Wolfe & Kindfeld, 2000; Hmelo-Silver, Duncan & Chinn, 2007; Guthrie et al., 2004; Langer, 2001; Lynch et al., 2005; Tatar, 2012; Wu & Tsai, 2005) with statistical significance, whereas others found that there is no statistical effect of inquiry-based science learning on students' science process skills, achievement and attitudes towards science and technology compared with traditional learning (Bagcaz, 2009; Yıldırım & Berberoğlu; 2012).

Such studies may or may not reach different conclusions. Given that the number of studies has been increasing, it is hard to access the information needed. Therefore, a comprehensive research approach should be used in order to make use of the findings of these studies. One of such comprehensive research approaches is meta-analysis (Hedges & Olkin, 1985; Borenstein et al., 2009). There are both national and international studies about the use of the inquiry-based teaching method in science education. However, in these studies, the correlations among the variables which have significant effects on inquiry-based teaching method in science education generally have not been fully revealed. Therefore, a meta-analysis is needed to reveal the effects of these variables in science education.

This study aimed at covering the effects of the inquiry-based science education on students' academic achievement, science process skills and attitudes towards science comparing with traditional learning. In addition, the study reviewed the findings of the studies on the effectiveness of the inquiry-based science education comparing with traditional learning. In other words, it contains a meta-analysis which is a method to combine statistically the numerical data of the studies and to reach a general conclusion using the results of these studies. According to the aim of the study, the following research questions try to be answered. In contrast to traditional teaching methods:

1) At which level does the inquiry-based learning method affect students' academic achievement?
2) At which level does the inquiry-based learning method affect students' science process skills?
3) At which level does the inquiry-based learning method affect their attitudes towards science?

METHODS

a) Research Design

In the study, meta-analysis method was employed to cover the effects of the inquiry-based learning method on students' academic achievement, their science process skills and their attitudes towards science comparing with traditional learning in science education. Meta-analysis is a method to combine statistically the numerical data of the studies which were carried out on the same topic and to reach a general conclusion using the results of these studies (Lipsey & Wilson 2001; Saglam & Yuksel, 2007; Kablan, Topan & Erkan, 2013). In general, meta-analysis is carried out in the following three steps: 1) identification and selection of eligible studies, 2) the coding of the data of studies and calculation of effect size

and 3) statistical analysis of the effect size and interpretation of the findings of the studies (Hoffler & Leutner, 2007).

b) Data Collection Tools

The studies were reviewed if they contained a comparison between traditional teaching methods and the inquiry-based learning method used in science education in terms of the effects on students' academic achievement, their scientific process skills and their attitudes towards science. More specifically, the following criteria were employed in selecting the studies to be reviewed (Camnalbur & Erdogan, 2008; Springer, Stanne & Donovan, 1999; Topcu, 2009; Kablan, Topan & Erkan, 2013):

Publication dates: Those studies which were carried out between 2005 and 2015 were included in the study.

Publication type: Master theses, Ph.D. theses, articles published in scientific journals or in e-journals, databases (ERIC, YOK thesis catalog, Google scholar, Springer, Science Direct) were reviewed in the study.

Method employed in the studies: In order to establish the effect size of each method, namely traditional teaching method and the inquiry-based learning method, those studies which included both an experimental group and a control group were selected. In addition, the traditional method should be implemented in the control groups and the inquiry-based method should be employed in the experiment groups. The study data included statistics that could be transformed in an effect size. The study was available in Turkish or English. The sample was from Turkey only.

Use of the appropriate teaching method: In the study, it was required that the inquiry-based method was employed in the experiment groups and traditional learning was implemented in the control groups.

Sufficient numerical data: In meta-analysis, the effect size should be covered. Therefore, descriptive numerical data about the control group and the experiment group are needed to reveal the effect size. Therefore, those studies which contained the data on the number of the sample, mean and standard deviation for the control group and the experiment group were included in the study.

In order to find all potential studies for inclusion in the quantitative synthesis, a comprehensive systematic search strategy was used. These articles published in international journals and national journals, which met the criteria given above, were accessible through the YOK theses catalog, and proceedings were reviewed. The stems of following identifiers or keywords in the title or abstract were used in the separate or combined searches: (In Turkish) Sorgulama, Araştırma, Sorgulamaya Dayalı Öğretim, Araştırmaya Dayalı Öğretim, (In English) Inquiry, Inquiry-based, Inquiry-based Teaching. At the end, a total of 58 studies were identified.

Then, these studies were reviewed in terms of containing the control group and the experiment group. Those with no such sampling design were excluded from the study. Those studies with no numerical data were also excluded. When it was clear that multiple sources (e.g., dissertations and journal manuscript) reported about the same data set, the source with more information was included in the analysis. After these reviews, a total of nineteen studies were included in the sample of the study.

c) Coding of the Data

In the study, the data collected were grouped into two categories. In the first category, there were eight sub-categories which are all about the publication information and the content of the studies. These sub-categories were the author(s), publication date, type of the

publication, academic semester, materials used in the study, dependent variables, target educational level and type of the course. The second category includes information about sampling size, arithmetical mean, and standard deviation. In order to establish the reliability of the coding, the data were coded by the authors for two times independently.

Dependent variables: The dependent variables of the study were the effects of the inquiry-based learning method on the students' academic achievement, their science process skills and their attitudes towards science comparing with traditional learning. The effect size is a standardized value for the data analysis tools used in each study (Bernard et al., 2004).

d) Data Analysis

The data collected in the study were analyzed using treatment effectiveness meta-analysis. This method is reported to be employed when the arithmetical means of the dependent variables was found using different data collection tools (Camnalbur & Erdogan, 2008). The statistical data obtained in different studies should be transformed into a common form which is called the effect size.

The calculation of the effect size was realized using the Standardized Mean Difference (SMD) also known as Cohen's d in the literature and in the statistical analyses the significance was set at 95%. To calculate SMD and to get possible moderators, the following information was extracted from each study: sample size (experiment and control groups), the title of participants (traditional and inquiry-based science education attendance) and quantitative data to calculate effect sizes (r, t, F statistics and X2), p values, or means and standard deviations. Calculations were based on fixed and random effect model. However, in social studies, random was recommended (Cumming, 2012). Heterogeneity of effect sizes was assessed using Q and I2 statistics. When these statistics indicate the lack of homogeneity, the meta-analytic procedures are repeated in the moderator sub-groups. Therefore, in the study the effect size classification developed by Cohen (1992) was used. In the meta-analysis, the effect size is interpreted using a coefficient classification. This classification states that if the effect size is between .20 and .50 it is small-size. If it occurs between .50 and .80, it is called medium effect size and if it is higher than .80, it is called large effect size. In the study, the CMA and the Microsoft Excel 2010 Office program were used for the group comparisons.

Publication Bias

Publication bias is mostly stated in the studies which contain positive and statistical significance. However, it is rarely stated in the studies which contain negative and no statistical significance. Publication bias at a certain level affects the mean effect size and makes it larger than its actual size (Kıs & Konan, 2014). In the study in order to control the effect of publication bias on the effect size the funnel plot and Orwin's Fail-Safe N value were employed.

A funnel plot is a graph designed to check the existence of publication bias. It shows standard error in the study on the Y axis and effect size on the X axis. Those studies with smaller standard error occur at the top of the funnel and near to the line of the effect size. Those studies with higher standard error occur at the bottom of the funnel (Dincer, 2013). Because those studies with smaller sampling rate have a larger sampling variance than the expectation of effect size. Publication bias was controlled for each dependent variable independently below.

RESULTS

a) Descriptive Data

In the study, a total of nineteen studies comparing the traditional method and the inquiry-based method used in the secondary school science education were reviewed.

These studies were carried out on 1521 students, 778 of whom were in the experiment groups and 743 of whom were in the control groups. The following table shows the type of the studies, publication dates, and the dependent variables included:

Table 1. *Included Studies*

Included Studies	Academic Achievement		Science Process Skill		Attitudes Towards Science	
	Article	Thesis	Article	Thesis	Article	Thesis
Celik & Cavas, 2012	X		X		X	
Bagcaz, 2009		X				X
Kula, 2009		X		X		X
Kaya, 2009		X				
Akpullukcu & Gunay, 2013	X				X	
Fansa, 2012		X		X		X
Gencturk & Turkmen, 2007	X					
Colak, 2014		X		X		
Koksal & Berberoglu, 2012	X		X		X	
Karamanoglu, 2006		X				
Taskoyan, 2008		X				X
Yildirim, 2012		X		X		
Ulu, 2009		X		X		
Tatar, 2006		X		X		X
Sahin & Saglamer Yazgan, 2013	X					
Parim, 2009		X		X		
Turkmen, 2009					X	
Yalcın, 2013				X		
Ergul et al., 2011			X		X	
Total (n=19)	5	11	3	8	5	5

The studies reviewed were categorized into three groups: the effects of the inquiry-based learning method on students' academic achievement, the effects of the inquiry-based learning method on students' science process skills and the effects of the inquiry-based learning method on students' attitudes towards science (Table 1). It was found that there were eleven theses and five articles on the effects of the inquiry-based learning method on students' academic achievement. There were eight theses and three articles on the effects of the inquiry-based learning method on students' science process skills. There were five theses and five articles on the effects of the inquiry-based learning method on students' attitudes towards science. On the other hand, these studies were also found to be related to the effects of other variables which were not included in the study.

b) Effects of the Inquiry-Based Learning Method on Students' Academic Achievement Based on the Random Effects Model

As given in Table 2, the results of the random effects models about the effects of the traditional teaching model and the inquiry-based learning method on the student achievement used in the studies reviewed.

Table 2. *Effectiveness of inquiry-based learning method according to random effects model*

Model Type	N	Z	Q	ES	95% confidence interval	
					Lower	Upper
Random Effects Model	16	6.488	87.358	1.029	.718	1.340

As can be seen in Table 2, there is a large effect size on student achievement. Therefore, it can be argued that the students' academic achievement in the groups where the inquiry-based learning method is employed is much higher than in the groups where the traditional learning method is employed.

The results of the z test which was employed for statistical significance purposes showed the following z value: z= 6.488. It is statistically significant with p= 0.000 (p<0.05).

In the chi-square table, the critical value is stated to be nearly 24.996 with a significance level of 95% and a degree of freedom of 15. Given that Q value found in the study is 87.358 and that it is higher than the critical value of 24.996, the hypothesis of homogeneity about the distribution of the effect size was used in the random effects model.

In the study, the effect size was found as 1.029. As can be seen in Figure 1 the effect sizes of the studies reviewed are symmetrically distributed on two sides of the vertical axis and they are all near to this axis. The Orwin's Fail-Safe N analysis showed that the effect size of 1.029 could only be near to zero if 848 studies were included in the meta-analysis. However, there were only sixteen studies which met the necessary inclusion criteria. In short, it can be argued that there was no publication bias in the studies reviewed.
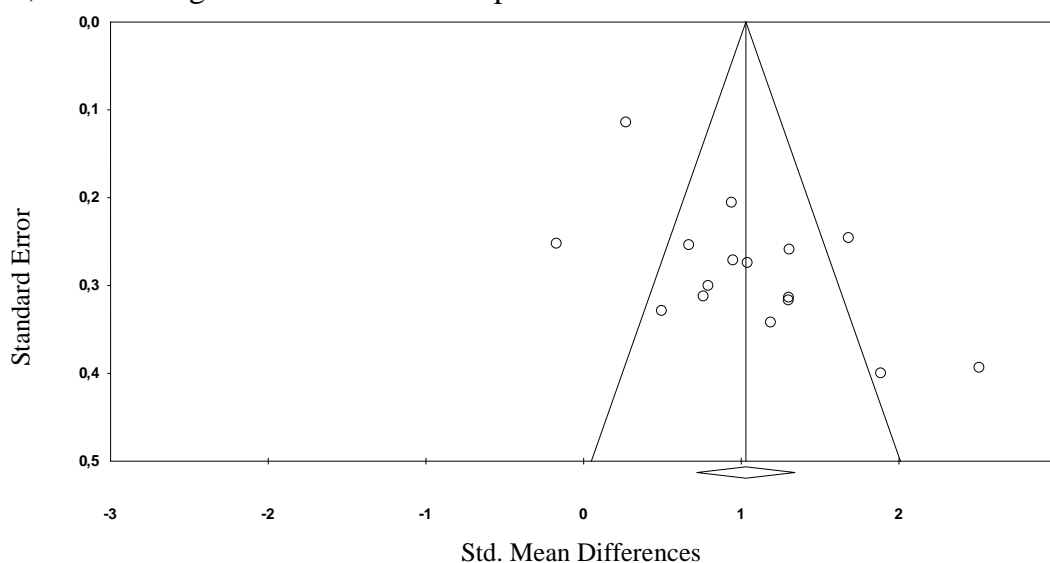

Figure 1. *Funnel plot for effectiveness of inquiry-based learning on academic achievement*

c) Effects of the Inquiry-Based Learning Method on Students' Science Process Skill Based on the Random Effects Model

As given in Table 3, the results of the random effects models about the effects of the traditional teaching method and the inquiry-based learning method on students' science process skills used in the studies reviewed.

Table 3. *Effectiveness of inquiry-based learning method according to random effects model*

Model Type	N	Z	Q	ES	95% confidence interval	
					Lower	Upper
Random Effects Model	11	5.074	37.816	.742	.455	1.028

As it can be seen in Table 3, the effect size is at the medium level according to the classification developed by Cohen (1988). It is safe to argue that the students' science process skill in the groups where the inquiry-based learning method is employed is much better than in the groups where the traditional teaching method is employed.

The results of the z test which was employed for statistical significance purposes showed the following z value: z= 5.074. It is statistically significant with p=0.000 (p<0.05).

In the chi-square table, the critical value is stated to be nearly 18.31 with a significance level of 95% and a degree of freedom of 10. Given that Q value found in the study is 37.816 and that it is higher than the critical value of 18.31, the hypothesis of homogeneity about the distribution of the effect size was used in the random effects model.

In the study, the effect size was found as 0.742. As can be seen in Figure 2, the effect sizes of the studies reviewed are symmetrically distributed on two sides of the vertical axis and they are all near to this axis. The Orwin's Fail-Safe N analysis showed that the effect size of 0.742 could only be near to zero if 266 studies were included in the meta-analysis. However, there were only eleven studies which met the necessary inclusion criteria. In short, it can be argued that there was no publication bias in the studies reviewed.
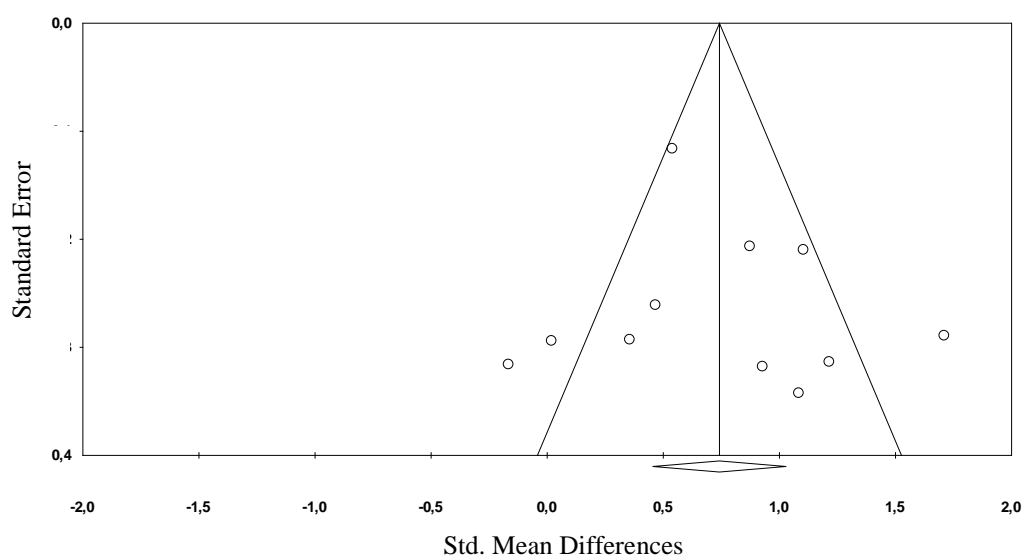

Figure 2. *Funnel plot for effectiveness of inquiry-based learning on science process skills*

d) Effects of the Inquiry-Based Learning Method on Students' Attitudes Towards Science Based on the Random Effects Model

Table 4 shows the results of the random effects models about the effects of the traditional teaching model and the inquiry-based learning method on students' attitudes towards science used in the studies reviewed.

Table 4. *Effectiveness of inquiry-based learning method according to random effects model*

Model Type	N	Z	Q	ES	95 % confidence interval	
					Lower	Upper
Random Effects Model	10	3.832	36.631	.558	.273	.843

As it can be seen in Table 4, the effect size is at the medium level according to the classification developed by Cohen (1988). It is safe to argue that the students' attitude towards science in the groups where the inquiry-based learning method is employed is much more positive than in the groups where the traditional teaching method is employed.

The results of the z test which was employed for statistical significance purposes showed the following z value: z= 3.832. It is statistically significant with p=0.000 (p<0.05).

In the chi-square table, the critical value is stated to be nearly 16.92 with a significance level of 95% and a degree of freedom of 9. Given that Q value found in the study is 36.631 and that it is higher than the critical value of 16.92, the hypothesis of homogeneity about the distribution of the effect size was used in the random effects model.

In the study, the effect size was found as 0.558. As can be seen in Figure 3 the effect sizes of the studies reviewed are symmetrically distributed on two sides of the vertical axis and they are all near to this axis. The Orwin's Fail-Safe N analysis showed that the effect size of 0.742 could only be near to zero if 127 studies were included in the meta-analysis. However, there were only ten studies which met the necessary inclusion criteria. In short, it can be argued that there was no publication bias in the studies reviewed.
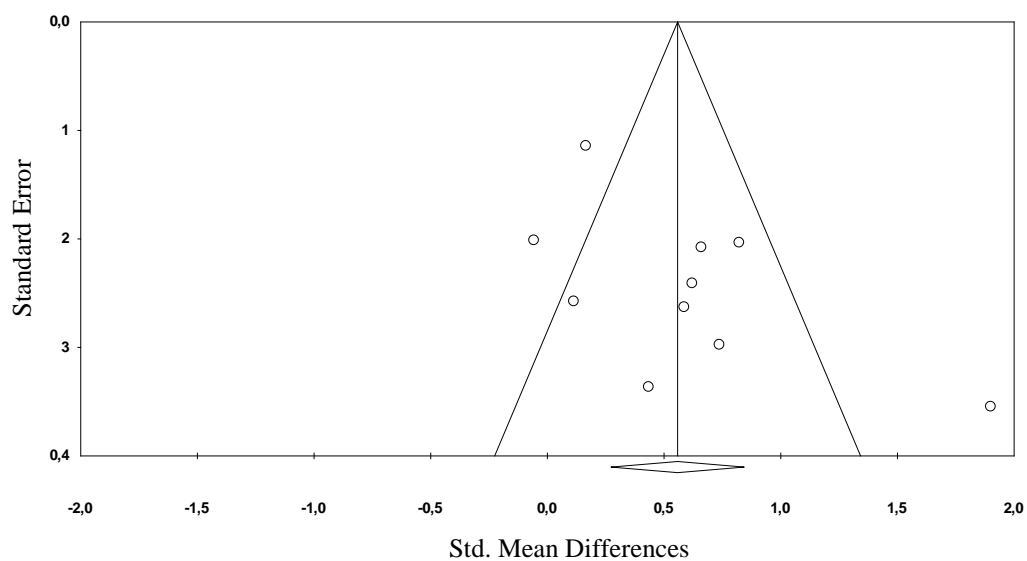

Figure 3. *Funnel plot for effectiveness of inquiry-based learning on attitudes towards science*

DISCUSSION and CONCLUSION

Discussion

In the study, a total of nineteen studies were reviewed in terms of the effects of the traditional teaching method and the inquiry-based learning method on student achievement, their science process skills and their attitudes towards science in the context of primary education science courses.

Of these nineteen studies, sixteen studies compared the effects of the traditional teaching method and the inquiry-based learning method on students' academic achievement. The meta-analysis showed that in fifteen studies there was a positive effect size in favor of the inquiry-based learning method. The national findings (Timur & Kincal, 2010) about the effects of the inquiry-based learning method are mostly consistent with the international findings (Schroeder et al., 2007). Minner, Levy & Century (2009) reviewed a total of 138 studies on the effects of the inquiry-based learning method used in science education on student achievement and their conceptual comprehension. These studies were published between 1984 and 2002. They found that the inquiry-based learning method used in science education had significant effects on the students' academic achievement and their conceptual comprehension. On the other hand, based on the findings of the current meta-analysis and the previous findings it is safe to argue that the inquiry-based learning method used in science education had significant effects on the primary education students' academic achievement in contrast to the traditional teaching method (Celik & Cavas, 2012).

In the current meta-analysis, eleven studies were reviewed in terms of the effects of the traditional teaching method and the inquiry-based learning method on students' scientific process. Of these eleven studies in ten studies, the inquiry-based learning method was found to have much more positive effects on students' science process skills in contrast to the traditional teaching method. In the previous studies carried out in Turkey about the effects of the inquiry-based learning method on primary education students' science process skills inconclusive findings were found. For instance, Yıldırım and Berberoglu (2012) concluded that the inquiry-based learning method had no significant effect on the eight-grade students' academic achievement and science process skills in regard to the unit of force and movement. However, Yasar and Duban (2009) concluded that the science activities which were carried out using the inquiry-based learning method increased the number and type of the science process skills used by the fifth-grade students. Based on the findings of the current meta-analysis it is possible to argue that the inquiry-based learning method improved the use of the science process skills by primary education students in terms of the number of these skills.

Among ten studies reviewed in eight studies the inquiry-based learning, method was found to have much more positive effects on the attitudes of the students towards science in contrast to the traditional teaching method. Similarly, Gibson and Chase (2002) concluded that the attitudes of the students towards science who were taking courses in an inquiry-based learning method. Duban (2008) also argued that the inquiry-based learning method used in science education has positive and significant effects on student achievement, their science process skills and their attitudes towards science.

Conclusion

Experimental studies were included to meta-analysis study so results should be interpreted according to nature of experimental studies. In experimental studies, it was possible that variables out of the independent variables influence on dependent variables. Especially, when participants' attitudes toward being involved in a study affect the way

they behave, a Hawthorne effect has occurred. When participants are given increased attention and recognition because they are participating in a study, their responses may be affected. This is known as the Hawthorne effect, some changes in teaching method by researchers cause that participants can give different responses unusually (Fraenkel & Wallen, 2006). Therefore, experimental groups can take higher scores than control groups. Sometimes teachers and researchers can be influenced by Hawthorne effect. For this reason, it can be said that increasing of academic achievement could not be resulted from only inquiry-based science teaching in experimental studies.

In the current study, it was found that in contrast to the traditional teaching method the inquiry-based learning method used in science education had much more significant effects on student achievement rather than on their science process skills and their attitudes towards science.

Recommendations

Therefore, it can be suggested that the inquiry-based learning method should be preferred in primary education science courses in order to improve student achievement, science process skills and attitudes towards science.

Future studies may also employ the meta-analysis technique to reveal the effects of the inquiry-based learning method used in science education on misconceptions and on students' future careers.

In the study only quantitative studies were reviewed. Therefore, future studies may review the qualitative studies. Another limitation of the current study is that it reviewed those studies carried out in Turkey. Future studies may review other studies carried out in different countries. Such studies will provide an opportunity to make comparisons at a larger scale.

Given that the studies on the inquiry-based learning method have become common, similar meta-analysis based studies should be made to make comparisons in terms of the effect size.

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