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The Relationship between Scientific Process Skills and Science Achievement: A Meta-Analysis Study

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ABSTRACT One of the main challenges in science education is interpreting existing studies to improve scientific process skills. The main purpose of this study is to bring together the quantitative findings obtained on the relationship between scientific process skills and academic achievement in science education, to highlight the relevant gaps in 5838 samples, and to interpret the overall effect size. The bibliographic research was carried out through the ERIC and ProQuest databases, especially in the Science Education Research category. Two hundred thirty-four articles published between 2005 and 2020 were obtained. Following the application of the inclusion criteria, 18 articles were selected according to the random-effects model, resulting in an average effect size of 0.56. Two moderator variables with a significant correlation between science achievement and scientific process skills were analyzed ($Q = 417.082$; $df = 17$; $p < .05$; $I2 = 95.22$). The percentage of the moderator variables explaining the relationship was interpreted by meta-regression analysis. Educational inferences have shown a requirement for further research at the high school and university levels on the relationship between science method skills and scientific achievement.

Keywords Meta-analysis, Scientific process skills, Science achievement, Science

1. INTRODUCTION

Concepts are at the center of science education (Enger & Yager, 2001). Rather than defining their meanings, science courses require questioning the underlying reasons for these concepts. Why does hot air rise, for instance? How does sound move in the atmosphere? (NCERT, 2005). Because it is not enough to just transfer the existing knowledge to students and provide them with problem-solving skills that they cannot use in their daily lives (Rillero, 1998). One of the main points of the literature on the necessity of acquiring science education through inquiry is the development of scientific process skills.

Science educators argue in the literature that the development of scientific process skills directly affects science achievement and science literacy. Scientific process skills constitute a large part of the science literacy of individuals. Many studies claim that science literacy must be supported by scientific process skills acquired from an early age (Kirch, 2007; Limatahu & Prahani, 2018; Meador, 2003; Martin, Sexton & Gerlovich, 2001). Another group of authors concluded that students' academic achievement increased as a result of the activities carried out to develop scientific process skills in the science course (Aktamis & Ergin, 2008; Ardaç & Mugaloğlu, 2002; Geban, 1990; Turpin, 2000). Also, the main goal of national and international science teaching programs is to develop the conceptual understanding and the skills that will enable students to become science literate in the future (AAAS, 1998; TMoNE, 2006; TmoNE, 2019; TMoNE, 2020). Science literate individuals have decision-making and problem-solving skills and can learn and think creatively and logically. That keeps them one step ahead throughout their lives (National Research Council, 1997; cited: Çakır & Sarıkaya, 2010). Also, science-literate individuals conduct research, ask questions, solve problems, and are open to criticism (Afacan, 2016; Sadler, 2004; Fettahoğlu, 2012). For all these reasons, scientific process skills should be reconsidered and interpreted for different variables for science literacy and success.

Science education programs implemented in Turkey also stress that developing scientific process skills is important. However, it has been observed that student success is low in examinations in which these skills are measured at the international level (PISA 2015 and PISA

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2018, TIMSS 2015, TIMSS, 2018). In national examinations, student success is generally low to measure science achievement (Bakanlığı, 2019). For this reason, the barriers and variables in the development of scientific process skills need to be rethought. Also, the national literature is not sufficient to meet this need. It is possible to find many studies on scientific process skills in the literature. It has been observed that scientific process skills help students develop their creativity by making them think like scientists (Lind, 2002; Meador, 2003; Ozdemir & Dikici, 2017; Setiani, Surasmi & Tresnaningsih, 2020; Yoo & Kang, 2015). Also, it has been stated in some studies that the effective use of scientific process skills is critical in the formation and development of scientific literacy (Anderson, 2002; Colvill & Pattie, 2002; Handayani, Adisyahputra & Indrayanti, 2018; Kaya, Bahceci, & Altuk, 2012; Keil, Haney & Zoffel, 2009). In some studies, it has been demonstrated that active use of scientific process skills in lessons has developed students' attitudes (Bilgin, 2006; Juhji & Nuangchalerm, 2020; Movahedzadeh, 2011; Zeidan & Jayosi, 2015), reasoning ability (Oloyede & Adeoye, 2012; Markawi, 2013; Settlage & Southerland, 2007), and critical thinking skills (Darmaji, Astalini & Kuswanto, 2020; Ješková et al., 2016; Jatmiko et al., 2018; Tanti, Indica, Kuswanto, Utami, & Wardhana, 2020). The application of various methods and techniques in the lessons has been shown to help the development of scientific process skills (Ika & Doa, 2021; Mulyeni, Jamaris, & Supriyati, 2019; Setiawan, Suwondo & Syafii, 2021; Sholahuddin, Yuanita, Supardi, & Prahani, 2020). There are also studies on the use of science process skills by teachers in the teaching process and to determine their level of knowledge on the subject (Al-Rabaani, 2014; Chabalengula, Mumba, & Mbewe, 2012; Gultepe, 2016; Setyowati, 2020; Turkmen & Kandemir, 2018). Also, Irwanto, Rohaeti & Prodjosantoso (2019) stated that scientific process skills increase students' ability to absorb scientific knowledge; and develop critical thinking, decision making, and problem-solving skills.

When the relational studies conducted on scientific process skills were examined, it was seen that its relationship with the academic achievement variable was mostly examined. It has been determined that training aimed at developing scientific process skills in the science course increases students' academic success (Aktamis & Ergin, 2008; Ardaç & Mugaloğlu, 2002). Likewise, there is a similar trend abroad (Geban, 1990; Nasir, Fakhrunnisa & Nastiti, 2019; Turpin, 2000). In relational studies conducted between scientific process skills and academic achievement, a positive relationship was observed (Doğan, Doğan, Atılgan, Batçıoğlu & Demirci, 2002; Feyzioğlu, 2009; Harlen, 1999; Jackson, 2000; Koray, Köksal, Özdemir & Presley, 2007; Özdemir, 2004; Saat, 2004; Sittirug, 1997; Unutkan, 2006). The importance of this relationship has been proven. Still, there is a need to bring together all adhering studies' findings and rethink moderator variables in national and international literature. The effort to see the whole is important to capture and interpret the relevant gaps.

On the other hand, the studies conducted are numerous and well-established to allow meta-analysis. Since there is no meta-analysis study on scientific process skills in science, it is thought that this study will contribute to the literature. The teaching level and scale type, which were supposed to affect the data obtained from primary studies, were selected as moderator variables. It is necessary to gain scientific process skills gradually. It aims to acquire basic process skills at the primary school level and integrated skills at secondary and higher levels (Akgün, Özden, Çinici, Aslan & Berber, 2014). In addition, it is important whether there is a difference between the data collection tools whose validity and reliability have been provided before and the data collection tools developed by THE researchers themselves. In this study, within the scope of the general question "how do teaching strategies, methods and techniques support the development of science process skills?" the following questions were sought:

1. What is the general effect size of the relationship between scientific process skills and academic achievement?
2. Is there a significant difference between the effect sizes of the studies according to the teaching level and the type of scale used in the studies (moderator variables)?
3. To what extent do the moderator variables explain the relationship between scientific process skills and academic achievement?.

2. METHOD

The meta-analysis method was used in this study to examine the relationship between scientific process skills and academic achievement. Meta-analysis is a statistical analysis method that helps one to have a common judgment by bringing together various quantitative research results (Lipsey & Wilson, 2001) to reach larger results (Büyüköztürk et al., 2014) and allow the results to be evaluated with a larger sample. Meta-analysis takes place through a statistical combination of quantitative research results and does not include qualitative research results. This study brought examples and results of relational studies examining the relationship between scientific process skills and academic achievement.

2.1 Data Collection and Analysis

To find answers to the questions of the research, articles and theses between 2005 and 2020 examining the relationships between scientific process skills and academic achievement were scanned. Four databases were used: ProQuest, ERIC, Google Scholar. Articles and theses were searched with the keywords "scientific process skills" and "science process skills." According to Lipsey & Wilson (2001), studies included in meta-analysis should be included within certain limits. In this context, inclusion criteria were determined while selecting all the studies included in this larger study:

a. Conducted between 2005–2020
b. Studies examining the relationship between scientific process skills and academic achievement
c. Containing the correlation coefficient (*r*) value
d. A specified number of samples
e. Availability of full text
f. Being a master's/ doctoral thesis or an article published in scientific journals.

Within the scope of the research, 234 studies were determined by considering the above criteria. Later, when the studies were examined in detail, studies with qualitative research findings and no r and *p* values were not included. As a result, 18 studies were analyzed using the Comprehensive Meta-Analysis v3.0 statistics program. Demographic information about the studies included in the analysis is presented in Table 1

The effect sizes were taken as a basis for the interpretation of the analyses. The correlation value was converted to Fisher's *z*-value. The analyses were carried out with these values because Fisher's z is a value that considers the sample size. Effect sizes based on Cohen, Manion & Marrison's (2007) correlation are interpreted depending on the direction of the relationship. Concerning this, the correlation coefficient is used as the effect size based on the order of the relationship. Interpretation of effect sizes based on the correlation coefficient: Very weak if between ± 0.00 and ± 0.10; weak if between ± 0.10 and 0.30; medium if between ± 0.30 and 0.50; strong if between ± 0.50 and 0.80; powerful effect if ± 0.80 and above. As the moderator variable, the scale type and the education level in which the study was conducted were considered.

2.2 Validity and Reliability Studies

To conduct meta-analysis studies, the studies should not cause publication bias, and the effect sizes should show normal distribution. Therefore, it is necessary to examine the publication bias of each study to identify studies that have a heavy impact on the overall effect size and adversely affect the normal distribution of the data. Publication bias is one of the most important factors affecting meta-analysis results.

First, a funnel plot was examined to determine whether the publication bias of the studies was due to the general effect size. In this graph, publication bias is interpreted according to the line in the middle. In the absence of publication bias, the individual effect size of each study is expected to be around this line and within the funnel (Dinçer, 2014). The distribution of the effect sizes of the studies included in this study is presented in Figure 1.

As shown in Figure 1, the oval shapes representing the effect size of each study included in the meta-analysis were gathered symmetrically around the middle line expressing the general effect size. According to the funnel scatter plot, it can be said that 18 studies whose common effect sizes

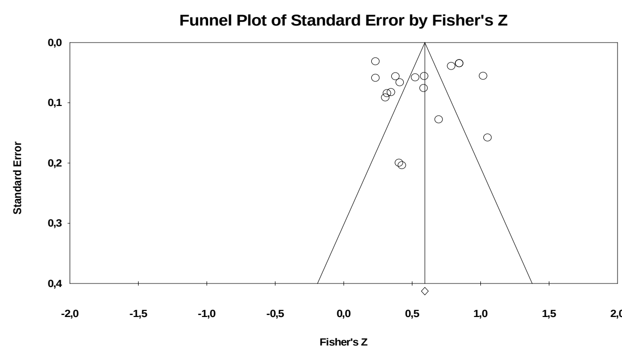


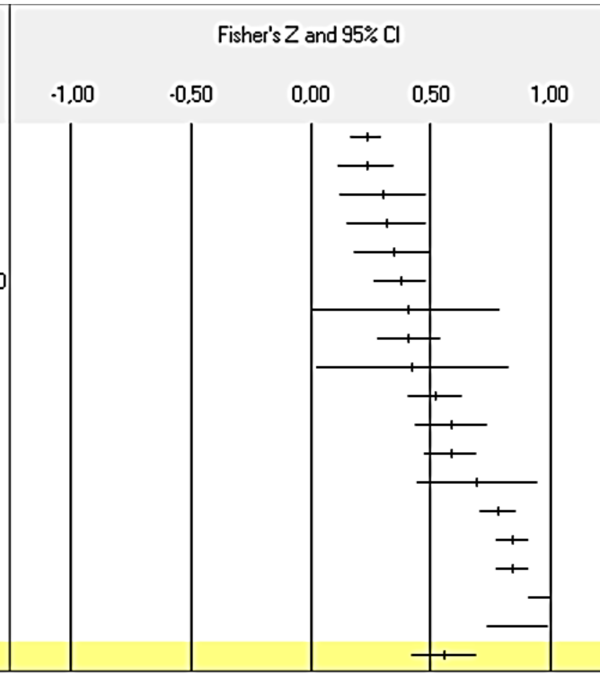
Figure 1 Funnel Scatter Plot

Table 1 Demographic Characteristics of Studies Included in the Meta-Analysis

Author	Year	Education level	Scale Type
Aktaş & Ceylan, 2016	2016	University	Okey, Wise and Burns (1982)
Aktaş, Aktaş & Kalaycı, 2020	2020	Secondary school	Smith and Welliver (1994)
Karar & Yenice, 2012	2012	Secondary school	Okey, Wise and Burns (1982)
Durmaz & Mutlu, 2014	2014	Secondary school	Smith and Welliver (1994)
Hırça, 2013	2013	University	Others
Raj & Devi, 2014	2014	High school	Others
Jeon & Park, 2014	2014	Secondary school	Others
Aydoğdu & Buldur, 2013	2013	University	Others
Sinan & Uşak, 2011	2011	University	Others
Irwanto, 2018	2018	University	Others
Öztürk, 2008	2008	Secondary school	Others
Aydoğdu,2006	2006	Secondary school	Okey, Wise and Burns (1982)
Güler, 2010	2010	Secondary school	Others
Tan, 2010	2010	High school	Others
Arslan, 2019	2019	Secondary school	Aydaoğdu et al. (2012)
Longo, 2012	2012	Secondary school	Others
Öztürk, Tezel & Acat, 2011	2011	Secondary school	Others
Delen & Kesercioğlu, 2012	2012	Secondary school	Aydaoğdu et al. (2012)

Table 2 Effect Sizes, Weights, and General Effect Size of the Studies Examined within the Scope of the Research (Fisher's *Z*)

Fisher's Z	p-Value	Weight (Random) Relative weight	Study name	Model
0,234	0,000	6,08	Raj & Devi,2014	
0,234	0,000	5,89	Delen & Kesercioğlu,2012	
0,306	0,001	5,55	Tan,2010	
0,318	0,000	5,64	Aydoğdu & Buldur,2013	
0,347	0,000	5,66	Aktaş & Ceylan,2016	
0,380	0,000	5,92	Aktaş, Aktaş & Kalaycı,2020	
0,406	0,042	4,05	Hırça,2013	
0,412	0,000	5,83	Longo,2012	
0,427	0,036	4,00	Sinan & Uşak,2011	
0,524	0,000	5,90	Irwanto,2018	
0,586	0,000	5,73	Aydoğdu,2006	
0,590	0,000	5,92	Arslan,2019	
0,696	0,000	5,08	Jeon & Park, 2014	
0,788	0,000	6,04	Karar & Yenice,2012	
0,846	0,000	6,07	Öztürk, 2008	
0,846	0,000	6,07	Öztürk, Tezel & Acat,2011	
1,020	0,000	5,92	Güler, 2010	
1,053	0,000	4,65	Durmaz ve Mutlu, 2014	
0,557	0,000			Random



were examined within the scope of meta-analysis did not have publication bias. However, since not all of the individual effect sizes of the studies were in the funnel, more than one confidence test showing the status of publication bias was conducted, and the results were also examined. When the test results are examined, it is revealed that Rosenthal's fail-safe N test results are statistically significant (Z = 36,126, $p \leq 0.01$, number of missing studies that would bring the *p*-value to> α = 7155). Seven thousand one hundred fifty-five studies are needed to eliminate the significance of the meta-analysis result. For the Classic fall-safe N-Rosenthal's Safe N test, the higher the number of studies, the lower the publication bias. Few studies examine the relationship between scientific process skills and academic achievement. For this reason, since it does not seem possible to reach this number, it is interpreted as an indication that there is no publication bias. Since $p \geq 0.05$ according to Begg and Mazumdar rank correlation (Tau=0.98; *z*-value for tau= 0.57; *p*-value (1-tailed): 0.28; *p*-value (2-tailed)=0.57) and Egger's regression intercept (t value= 0.56; df:16; *p*-value (1-tailed): 0.29; *p*-value (2-tailed) = 0.58) test results, we can say that publication bias does not exist at the rate of 95%.

To determine the analysis model, whether the effect size is homogeneously distributed is tested. According to this result, if the effect size is not fixed to homogenous, the use of the random effects model is appropriate (Borenstein, Hedges, Higgins & Rothstein, 2013). The fact that the studies used in this study are based on social sciences research carried out at different educational levels and varied in terms of the scale indicates that the random-effects model is more suitable. The Q value obtained due to the homogeneity test is statistically significant (Q = 417, 082, $p = 0.000$). This value is larger than the critical value, and having $p \leq 0.05$ indicates heterogeneous effect size distribution. On the other hand, to determine whether heterogeneity between studies exists I^2, the (95, 224) value has been checked. According to this value, it can be said that there is a 95%-high level of heterogeneity.

3. RESULTS AND DISCUSSION

Findings on the sub-problems of the research are given here. First of all, the effect size of the studies examined within the scope of meta-analysis and meta relation is presented. Then, the findings related to the effect sizes of the study group's level type and scale type variables and metaregression scores were presented.

3.1 Findings Regarding the General Effect Size of the Relationship Between Scientific Process Skills and Academic Achievement

The analysis results for the sub-problem "What is the general effect size of the relationship between scientific and academic process skills?" are shown below. Data on the effect sizes, upper and lower limits, *z*–*p* values, and weights of the studies are presented.

In Table 2, the effect size value for the relationship between scientific process skills and academics is 0.557 according to the random-effects model. Accordingly, the effect size value indicates a strong relationship (Cohen, Manion & Morrison, 2007). Therefore, as the scientific process skills increase or decrease, the level of academic achievement increases or reduce strongly. All of the studies examined have a positive effect. Within the scope of meta-analysis, information on the effect sizes, weights, Fisher's

Table 3 Effect Size and Metarelation Analysis Test Results According to the Education Level of the Study Group Examined within the Scope of the Research

Moderator		*N*	Effect Size	Standard error	Alt Limit	Upper limit	sd	Q_B	R^2	p
Level	Middle School	11	0.126	0.142	0.151	0.404				
	High School	2	0.320	0.194	0.702	0.060				
	University	5	0.184	0.158	0.494	0.127				
Total		18	0.588	0.114	0.366	0.811	3	8.78	0.27	0.032

Table 4 Effect Size and Metarelation Analysis Test Results According to the Scale Type Used in the Studies

Moderator Scale type	*N*	Effect Size	Standard error	Lower Limit	Upper limit	sd	*Q*	R^2	p
Okey,Wise, & Burns	4	0.043	0.1951	0.339	0.425				
Smith & Welliver	2	0.141	0.2362	0.321	0.604				
Aydoğdu et al.	2	0.122	0.2259	0.565	0.319				
Others	10	0.086	0.2014	0.307	0.481				
Total	18	0.535	0.1037	0.332	0.738	4	1.04	0.0	0.90

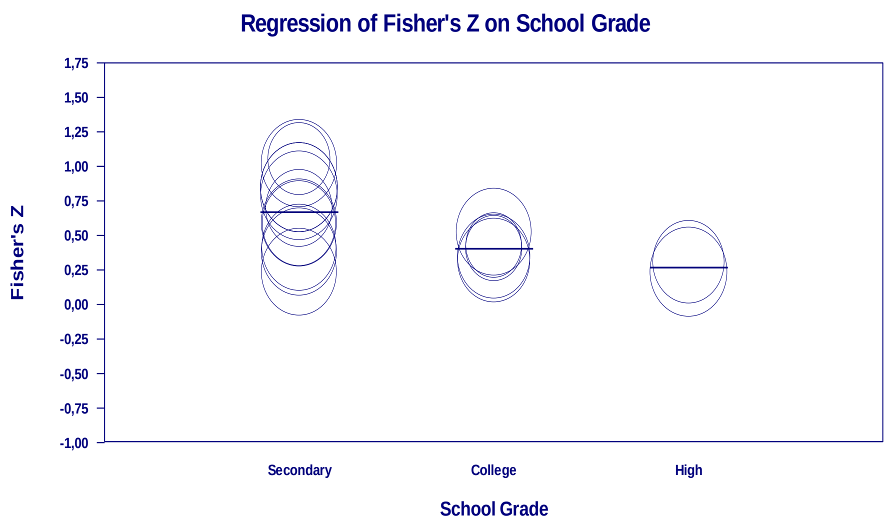


Figure 2 Meta -regression scatter plot according to the type of teaching level

Z, and *p* values of the studies included in this study are provided. The study with the most significant effect size is 1.053 by Durmaz & Mutlu (2014), and the study with the smallest effect size is the study of Raj and Devi (0.234). When examined in terms of weight, the study with the highest weight is Raj and Devi (6.08), and the one with the least weight is 4.00 Sinan & Muhammet (2011).

3.2 Findings Regarding the Effect Size According to the Education Level and Meta-regression Analysis as the Moderator Variable

The results of subgroup and meta-regression analysis made according to the random-effects model to determine the effect of the study group included in the meta-analysis on the total effect size are given in Table 3.

According to the findings, it was noted that there was a statistically significant difference between the effect sizes of the groups according to the type of education level addressed in the studies [Q = 8.78; $p \leq .05$]. It is seen that the largest effect size is in the high school group (0.320), and the lowest effect is in the middle school group. On the other hand, this moderator variable explains 27% of the relationships between scientific process skills and science achievement [R^2 analog = 0.27, Q = 8.78, df = 3, *p* = 0.0323]. The scatter plot of the moderator type is given in Figure 2. According to the Fisher's Z regression scatter plot, the explanation percentage according to the scientific process skills and science achievement learning level type mostly affected the answers of middle school students.

3.3 Findings Regarding Effect Size and Metarelation Analysis According to the Scale Type Used in Studies as Moderator Variable

The results of subgroup and meta-regression analysis made according to the random-effects model to determine

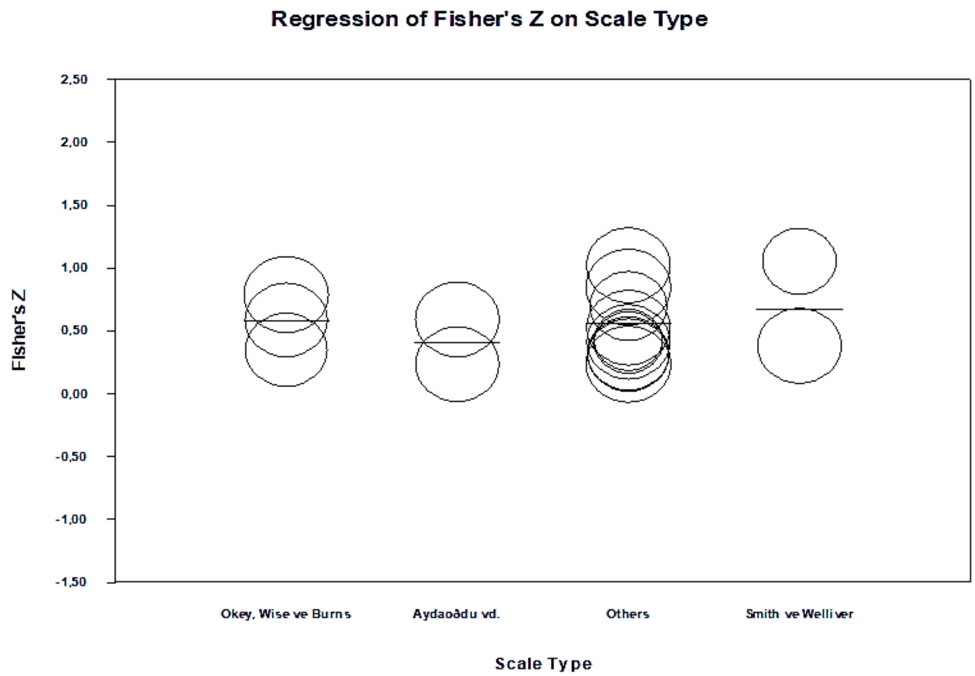


Figure 3 Meta-regression scatter plot according to the level of education

the effect on the total effect size according to the type of scale used in the studies are given in Table 4.

According to the findings obtained, it was observed that there was no statistically significant difference between the effect sizes of the groups according to the type of scale used in the studies [Q = 1.40; $p \geq .05$]. Therefore, there is no need to interpret the regression situation. Scale type effect size scores are close to each other. The scatter plot of the moderator type is given in Figure 3.

When the relationship between scientific process skills and science achievement was examined according to the type of scale based on the Fisher's Z regression scatter plot, the researchers mostly used the scales they developed themselves.

CONCLUSION

In this meta-analysis study, which examines the relationship between scientific process skills and academic achievement, individual effect sizes and overall effect sizes of 18 studies (sample numbers = 5838) were calculated in accordance with the selection criteria. Also, it was determined whether there is a difference between the effect sizes of the studies examining the relationship between scientific process skills and academic achievement depending on the moderator variables (teaching level, scale type).

Rosenthal's fail-safe N test, Begg and Mazumdar Rank Correlations, and Egger's Linear Regression Method were used to determine the validity and publication bias of the study. As a result of the reliability tests, it was decided that there was no publication bias. After calculating the individual effect sizes of the studies included in the meta-analysis, the random-effects model was used due to the heterogeneity test performed to calculate the overall effect size by combining these effect sizes. According to the random-effects model, the combined effect size has been found as.55 (at a 95% confidence level. Between 56 and 61).

The first finding obtained from the researchers determined that there is a moderate and positive relationship between scientific process skills and academic achievement. According to this finding, as the use of scientific process skills increases, their academic success also increases. Each study examining the relationship between scientific process skills and academic achievement yielded a significant effect size. When these effect sizes are combined according to the random-effects model, it has been observed that the overall effect size is significant as a result of the calculated Z test ($p < .05$). The variables that have the greatest effect on students' acquisition of scientific process skills are academic competence and cognitive development (Germann, 1994). Feyzioğlu (2009), who was not included in the study because of not meeting the selection criteria, examined the relationship between scientific process skills and academic achievement separately as basic skills and combined skills. He found a positive relationship between basic and integrated scientific process skills and academic achievement.

Similarly, Aydoğdu, Yıldız, Akpınar & Ergin (2006) stated that there is an important relationship between scientific process skills and academic achievement at the secondary school level. Also, Aktamis & Ergin (2008) stated that science courses based on scientific process skills are important in increasing student success. Their higher scientific process skills can explain students' success in science lessons at school (Karatay, 2012; Meriç & Karatay, 2014; Sittirug, 1997; Tezcan, 2011).

The study's second finding revealed a significant difference between the effect sizes of the studies examining the relationship between scientific process skills and academic achievement, depending on the teaching level among the moderator variables. In other words, it creates a significant difference between effect sizes calculated to determine the relationship between scientific process skills and academic achievement. While the greatest effect on the education level where the studies are applied is at the high school level (.320), the lowest impact level is at the secondary school level (.126). The teaching level also explains around 27% of the relationship between scientific process skills and academic achievement. In this 27% slice, according to the Fisher's Z regression scatter plot, the meta-analysis results mostly include middle school students' answers. Scientific process skills that should be acquired from an early age (Kirch, 2007; Limatahu & Prahani, 2018) are proportional to students' cognitive capacities (Ferreira, 2004). Using these findings, it can be said that there is a gap in the study of high school and university-level scientific process skills. Also, another finding obtained was that the type of scale used in the studies was not a significant moderator variable. Accordingly, scale type does not significantly differ between effect sizes calculated to determine the relationship between scientific process skills and academic achievement. While the largest effect size among scale types was the scale developed by Smith (1994), the smallest effect size was the scale developed by Burns, Okey, & Wise (1982). When looking at the scales used, the time frame between the development dates is quite broad. Although all of them measure the same feature, both the characteristics of the individuals and the constantly evolving conditions presently have changed during this period. Based on this, a significant difference can be created among effect sizes by using scales based on gaining current competencies in today's conditions. As a result, this study has analyzed the subject and the literature and emphasized the points that need to be improved to develop scientific process skills.

LIMITATIONS

The study has some limitations. The sample chosen for this study includes ERIC, ProQuest, and Google Scholar publications. The research category includes health correlational studies within the scientific framework. As a result, we assume that we missed some unpublished studies in our sample. The level of relationship between scientific process and achievement is weak in studies included in the meta-analysis (Raj & Devi, 2014); The difference in the medium (Longo, 2012) and strong level (Öztürk, 2008) is related to similar effects. This limitation shows that we represent the field even though we have a sample, and it demonstrates that there is no publication bias. Also, studies included in the meta-analysis are limited to inclusion criteria and studies conducted between 2005 and 2020.

RECOMMENDATIONS

In future studies, the relationship between sub-dimensions of scientific process skills and academic achievement can be examined with the help of meta-analysis. In addition, the effect of different moderator variables on the relationship between scientific process skills and academic achievement can be examined.

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