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The effects of using analogy in science education on academic achievement: A meta-analysis study

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ABSTRACT

The aim of this study is to examine the effects of using analogy in science education in increasing academic achievement of students through meta-analysis method. While researching studies on analogy use in science education, a few key phrases (for example, Model 1: analogy and science education) were used in well-known data bases (for example, ERIC, EBSCO, Science Direct, Web of Science). Finally, 52 studies were included in this meta-analysis which examined the effects of using analogy in science education on academic achievement. All statistical data obtained from the studies were first placed in an Excel page and then transferred to comprehensive meta-analysis (CMA) statistics software to calculate Hedges's g values. As a result of the general effect size obtained as a result of the study (Hedges g =1.029), it was concluded that using analogy in science lessons had a positive high effect on academic achievement. It was found that as moderator variables, subject area and types of questions affected academic achievement of students, while level of education, the implementer and duration of implementation did not. In addition, it was found that using analogy alone or with another method did not affect academic achievement of students. In the light of the results found, it can be said that using analogy in science education is very effective in increasing academic achievement of students. The present study recommends conducting more research to explore studies including different data values.

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Introduction

Scientific literacy is widely recognized as a fundamental goal of science education. It encompasses individuals' ability to think critically, solve problems, collaborate, and communicate effectively, while also applying scientific knowledge to real-life contexts (MEB, 2018; NRC, 1996). Many countries emphasize fostering scientifically literate individuals who can relate scientific understanding to everyday life, contribute to scientific development, and engage meaningfully in societal advancement (Can & Çelik, 2020; Osborne, 2007).

One key dimension of scientific literacy is the understanding of core science concepts (Kavak, Tufan & Demirelli, 2006). However, students frequently struggle with science content due to its abstract and complex nature (Djudin & Grapragasem, 2019; Haider & Fölling-Albers, 2020), leading to the formation and persistence of misconceptions (Aymen Peker & Taş, 2020). Overcoming these misconceptions requires instructional strategies that support conceptual change and meaningful learning (Coştu, Ayas& Ünal, 2007; Çaycı, 2007; Yağbasan & Gülçiçek, 2003).

Among these strategies, analogies have received considerable attention for their effectiveness in facilitating students' understanding of unfamiliar and abstract science concepts. Analogies help bridge existing knowledge (source) and new concepts (target) by highlighting structural similarities, thus

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fostering deeper understanding and supporting conceptual change (Brown, 1994; Clement, 1993; Dagher, 1995; Gentner, 1983; Gentner & Holyoak, 1997; Treagust, Harrison, & Venville, 1998; Wong, 1993;).

Empirical research supports the effectiveness of analogy-based instruction in promoting academic achievement (Chiu & Lin, 2005; Duru, 2002), fostering conceptual change (Tsai, 1999), preventing misconceptions (Stavy, 1991; Bilgin & Geban, 2001), enhancing metacognitive abilities (Bryce & MacMillan, 2005), and improving students' interest, motivation, and creativity in science education (Aykutlu & Şen, 2011; Çalık & Kaya, 2012; Nworgu & Otum, 2013).

Despite the accumulated evidence, the effect of analogy-based instruction has not been comprehensively evaluated through a meta-analytic lens focusing specifically on science education. While previous meta-analyses have addressed analogy use across disciplines (Alfieri, Nokes-Malach & Schunn, 2013; Apthorp, Igel & Dean, 2012) and others have examined conceptual change strategies more broadly (Guzzetti, Snyder, Glass & Gamas, 1993; Öner Armağan, 2011), none has systematically analyzed the impact of analoges on academic achievement in science classes with respect to relevant moderators. This study aims to address this gap by conducting a meta-analysis to determine the overall effect of analogy-based instruction on students' academic achievement in science education. Additionally, the study explores the influence of potential moderator variables, including educational level, subject matter, intervention duration, instructor type, and assessment characteristics. Based on the theoretical framework and the accumulated empirical evidence, the present meta-analysis seeks to address the following research questions:

1. What is the overall effect of analogy-based instruction on students' academic achievement in science education?
2. How do moderator variables such as educational level, subject matter, intervention duration, instructor type, and assessment characteristics influence this effect?

Method

In this section, the systematic procedures employed for literature retrieval are described, the inclusion criteria for the meta-analysis are defined, the coding framework is outlined, and the statistical computation of effect sizes is explained. Measures were taken to ensure coding reliability, with particular emphasis on agreement between the authors and additional coders.

Literature search

Database and journal search

The data source of this study, which examined the use of analogy in science education on students' academic achievement, consisted of master's and doctoral theses. While searching for studies in which analogies were used in science education, the authors used a few key phrases from the abstracts (e.g., Pattern 1: science education and analogy; Pattern 2: science education and analogical reasoning; Pattern 3: science education and analogical thinking; Pattern 4: science education and analogue method) and conducted a review in well-known databases (e.g., EBSCO (319 papers), ERIC (57 papers), Science Direct (85 papers), Web Of Science (102 papers), Wiley Online Library Full Collection (666 papers), ProQuest Dissertations and Theses Global (74 papers), the Higher Education Council (HEC) Dissertations and Theses in Turkey (115 papers) and ULAKBİM (206 papers) and accessed a total of 1624 studies.

Inclusion criteria

The criteria for including studies in the meta-analysis were as follows: studies published between 01.01.2006 and 31.12.2020 were included in the process. The other criteria for including studies in the meta-analysis were sample group consisting of primary education, secondary education, high school and university students, the study having an experimental or quasi-experimental design, presence of pre-test and post-test values (sample, arithmetic mean, standard deviation, t and p values suitable for calculating effect size, the study examining the effects of using analogy in science lessons on students' academic achievement, the study being in Turkish or English, the study being a master's thesis, doctoral thesis or article, and preferring the thesis in case of reaching a study in the format of a thesis or article. As a result, 52 studies were included in the meta-analysis. The process of determining the studies included in the meta-analysis is shown in the PRISMA flow diagram (Moher et al., 2009) in Figure 1.

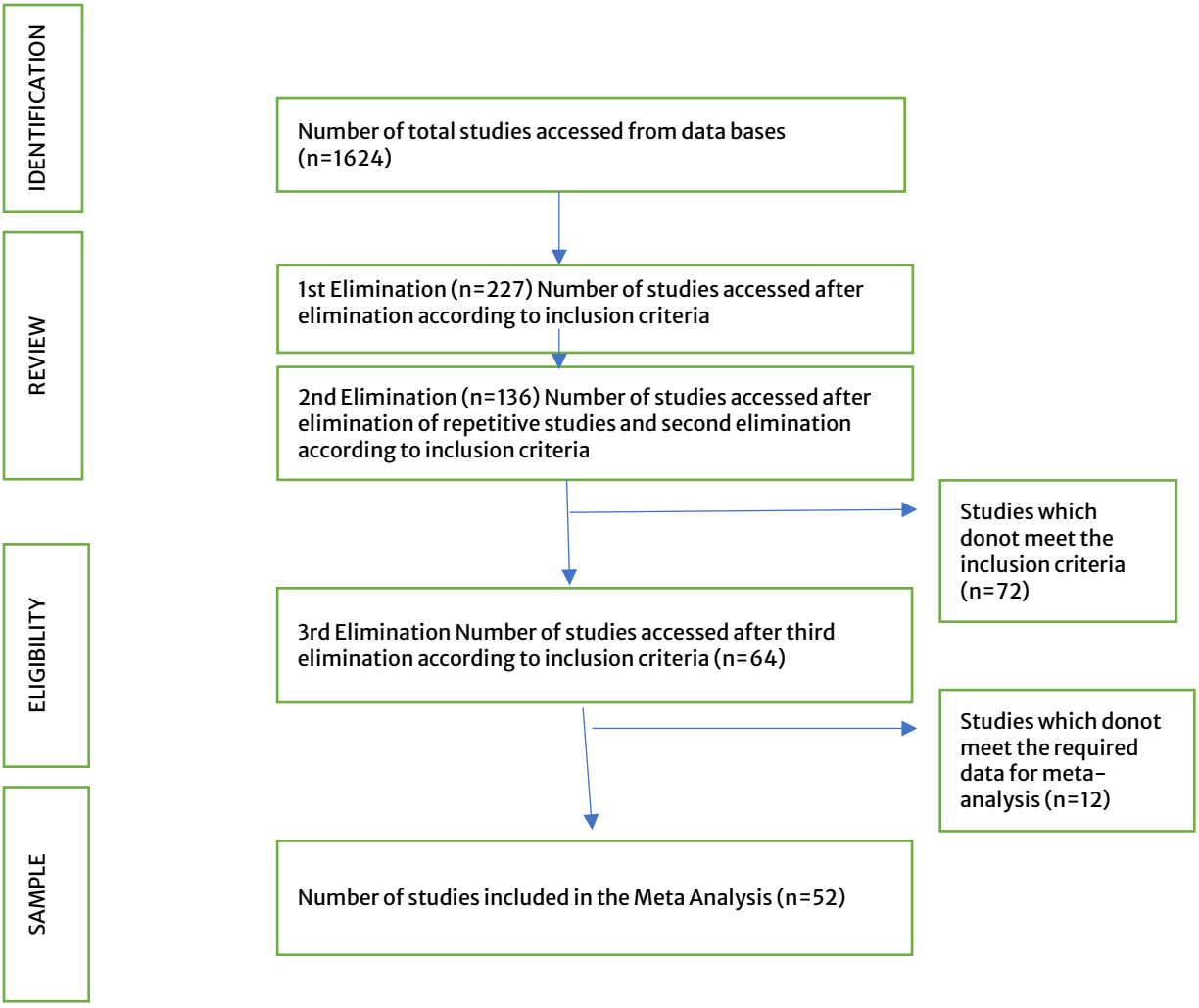

Figure 1. Flow chart of the determination process for studies included in the meta-analysis

Rosenthal (1991) defines study moderators as factors related with the effect size. Study moderators are independent variables which are determined by the researcher, which are thought to affect the meta-analysis and which are used to determine the size of this effect (Öner Armağan, 2011). Moderators of this meta-analysis were determined as study area, level of education, implementers of studies, implementation process of studies, way of using the analogy, researchers who developed the measurement instrument, types of questions used in measurement instruments. Table 1 shows the characteristics of the studies included in the meta-analysis.

Table 1. Characteristics of the studies included in the meta-analysis (52 studies)

Characteristics	Criteria	f	%
Publication year	2006-2010	22	42.31
	2011-2015	17	32.69
	2016-2020	13	25.00
Publication type	Article	18	34.61
	Master Dissertation	19	36.54
	Doctoral Dissertation	15	28.85
Grade	Primary education	1	1.92
	Secondary education	19	36.54
	High school	21	40.39
	University	11	21.15
Language	Turkish	30	57.70
	English	22	42.30
Country	National (Turkey)	39	75.00
	International	13	25.00
Subject Area	Science	21	40.38
	Physical	12	23.08
	Chemical	15	28.85
	Biology	4	7.69

Dataset construction

Coding method

The coding form used in this study was developed by the researchers within the context of research questions by examining the examples in literature (Bakioğlu and Özcan, 2016; Borenstein, Hedges, Higgins, & Rothstein, 2019; Dinçer, 2014; Nesbit and Adesope, 2006; Onuoha, 2007; Sommers, 2021). Each study included in the meta-analysis was coded in terms of the references in the coding form (descriptive characteristics (Table 1), subject area, level of education, the implementer, duration of implementation, the way the analogy is used, developer of the measurement tool, type of questions in the measurement tool, dependent and independent variables, and quantitative values- sample size, mean, standard deviation, p and t values. Interscorer agreement rate was calculated as 0.987 (Cooper, Hedge's & Valentine, 2009). Any dispute was resolved through negotiation.

Individual studies

If the study included in the meta-analysis has been studied with different sample groups or in case of two variables, the study should be coded twice (Dinçer, 2014). Since some of the studies included in this meta-analysis examined the state of academic achievement variable in different experimental groups, these studies were divided and coded as different studies. Therefore, the number of studies obtained as a result of this process and the number of studies included in the meta-analysis are different. This is shown in Table 2 below.

Table 2. Individual studies

Code of the study	Content
Aykutlu Çıldır (2009); Chan (2016); Çıray (2010); Demirci Güler (2007); Duymaz (2011); Karadoğu (2007); Kobal (2011); Köklü (2009); Lim (2007); Sıddıqui (2016); Şahin Pekmez (2010); Şendur et al. (2008); Weaver (2019); Yıldırım (2009)	Different groups
Naseriazar (2015); Karadoğu (2007)	Different measurement tools
Okur (2009); Cerit Berber (2008)	Different methods/techniques

When Table 2 is examined, since Şendur et al. (2008) and Aykutlu Çıldır (2009) coded studies were conducted in two different schools, they were approached as different groups and coded by dividing in two. Since Şahin Pekmez (2010) coded study was conducted in three different schools, it was divided into three, each divided study was evaluated as a different study and included in the meta-analysis. Since the studies coded Chan (2016), Çıray (2010), Demirci Güler (2007), Duymaz (2011), Karadoğu (2007), Kobal (2011), Köklü (2009), Lim (2007), Sıddıqui (2016), Weaver (2019), Yıldırım (2009) included different groups, they were included in the meta-analysis after they were divided. Karadoğu (2007) and Naseriazar (2015) coded studies used two different achievement tests to measure academic achievement. For this reason, the result obtained from each measurement tool was coded separately. In Okur (2009) and Cerit Berber (2008) coded studies, both analogy-oriented teaching was carried out and analogy was used with other methods. For this reason, while analogy-oriented implementation was coded separately, the implementations in which analogy was used with other methods were coded as separate studies.

Calculating the effect size

In this meta-analysis, Hedges' g was preferred for the calculation of effect size. First, all statistical data for the studies were put in an Excel page and then transferred to comprehensive meta-analysis (CMA) statistical software. Comprehensive Meta-Analysis (CMA) software was preferred for providing general effect by combining studies with different data types (Gürsoy, 2017).

The following studies were conducted to calculate Hedges's g value:

- 44 studies included sample size, mean scores and standard deviations for experimental and control groups.
- 7 studies included sample size, pre and post mean scores, matched groups t-value for experimental group.
- 1 study included sample size, pre and post mean scores, matched groups p-value for experimental group.

Thalheimer and Cook (2002)'s study was used to interpret effect sizes since a wider range of effect sizes was provided: $0.00 \leq d < 0.15$ (insignificant); $0.15 < d < 0.40$ (low); $0.40 < d < 0.75$ (moderate); $0.75 < d < 1.10$ (high); $1.10 < d < 1.45$ (very high); $1.45 < d$ (perfect).

Meta-analysis model

In this meta-analysis, general effect model was decided by conducting heterogeneity analysis for each of the sub-problems and by choosing according to p and Q values (Borenstein et. al., 2019). According to Table 2, p value was determined as "0.000" in heterogeneity test analysis. Since p value is <0.05, it can be said that individual studies have a heterogeneous structure. In addition, whether individual studies are heterogeneous should also be checked. This can be checked with Chi-square test. "Q-value" in heterogeneity values was calculated as 571.573 and from Chi-square table critical value for df(Q) = 69 was calculated as 87.928. Q value's being greater than the critical value is interpreted as the studies' having a heterogeneous structure. As a result of the calculations, it was found that individual studies had a heterogeneous structure and random effect model was used to calculate the general effect for individual studies (Borenstein et. al., 2019). In addition, subject area, level of education, the implementer, duration of implementation, the way of using analogies, developer of the measurement tool, type of questions in the measurement tool were defined as moderator variables that would answer the second research question. In other words, the variable of "subject area" covers science, physics, chemistry and biology; "level of education" variable covers primary education (grades 1-4), secondary education (grades 5-8), high school (grades 9-12) and university (undergraduate); the variable of "the implementer" covers the researcher and the teachers; the variable of "duration of implementation" covers 0-2 weeks, 3-4 weeks, 5-6 weeks, 7-8 weeks, 10 weeks and longer; the variable of "the way of using analogies" covers focusing on analogy and using analogy with another method; the variable of "developer of the measurement tool" covers the measurement tool developed by the researcher, the researcher and the teacher together and by another person; the variable of "type of questions in the measurement tool" covers 2-phase test, 3-phase test, multiple choice test, open-ended questions and mixed questions.

Table 3. The findings of heterogeneity test

Model	Number of studies	Effect size and 95% confidence interval					Test of null (2-tail)		Heterogeneity			
		Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	*P*-value	*Q*-value	df(Q)	*P*-value	I-squared
Fixed	70	0,941	0,032	0,001	0,879	1,003	29,833	0,000	571,573	69	0,000	87,928
Random	70	1,029	0,092	0,008	0,848	1,209	11,175	0,000				

Publication bia.

To detect publication bias in the current meta-analysis, a funnel plot was generated. The outcomes were cross-checked using the traditional fail-safe N statistic, which allowed for an objective evaluation of the evidence.

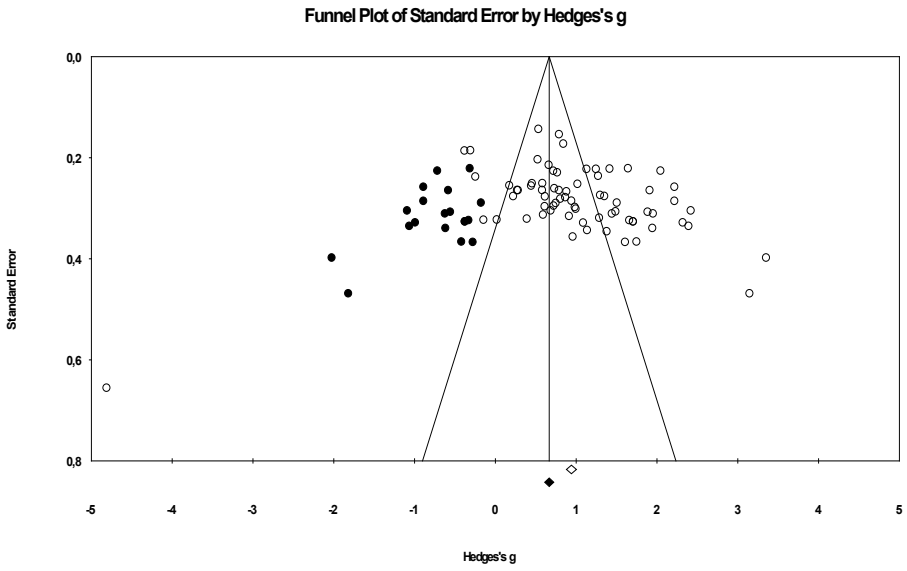

Figure 3. Funnel plot for publication bias

Figure 3 illustrates that the funnel plot is asymmetric (Vekli & Çalık, 2023). This asymmetry may initially suggest a potential publication bias, since several studies appear outside the funnel's boundaries. Nevertheless, the classical fail-safe N test clarifies this situation. The calculated fail-safe N value was 7022, meaning that an additional 7022 unpublished studies would be required to reduce the observed effect size to nearly zero (Üstün & Eryılmaz, 2014). Given that only 70 studies were analyzed in this meta-analysis, the

likelihood of such a large number of missing studies is unrealistic, suggesting that publication bias is not present.

Results

Research question 1: Overall effects of analogical instruction on academic achievement

To estimate the overall effectiveness of analogical instruction in science education, a meta-analysis was conducted with 70 effect sizes derived from 52 studies. A forest plot was generated to visualize the range and distribution of individual effect sizes. The values ranged from -4.808 to 3.355, showing considerable variability. Table 4 presents the individual effect sizes, standard errors, confidence intervals, and corresponding p-values.

Table 4. Effect sizes of the studies included in the study

Name of the Study	Effect size	Standard Error	Variance	Lower Limit	Upper Limit	Z-Value	p-Value
Sıddıqui (2016)	3.355	0.398	0.159	2.574	4.136	8.420	0.000
Ketenci(2019)	3.150	0.469	0.220	2.230	4.069	6.714	0.000
Çıray (2010)	2.423	0.305	0.093	1.825	3.021	7.939	0.000
Ayçiçek (2014)	2.394	0.336	0.113	1.736	3.052	7.132	0.000
Kobal (2011)	2.322	0.329	0.108	1.678	2.966	7.062	0.000
Uysal (2013)	2.220	0.258	0.067	1.714	2.726	8.598	0.000
Dilber and Düzgün (2008)	2.220	0.286	0.082	1.659	2.781	7.757	0.000
Yılmaz et al. (2006)	2.048	0.226	0.051	1.604	2.491	9.050	0.000
Sıddıqui (2016)*	1.954	0.311	0.097	1.344	2.564	6.282	0.000
Şeker (2012)	1.947	0.340	0.115	1.281	2.613	5.732	0.000
Okoronka and Wada (2014)	1.913	0.265	0.070	1.394	2.433	7.222	0.000
Naseriazar (2015)	1.889	0.308	0.095	1.286	2.492	6.138	0.000
Okur (2009)	1.750	0.367	0.134	1.032	2.469	4.775	0.000
Çetingül and Geban (2011)	1.708	0.327	0.107	1.067	2.348	5.225	0.000
Tamer (2006)	1.708	0.327	0.107	1.067	2.348	5.225	0.000
Şendur et al. (2008) *	1.661	0.324	0.105	1.025	2.296	5.123	0.000
Genç (2013)	1.646	0.222	0.049	1.211	2.080	7.426	0.000
Demirci Güler (2007) *	1.609	0.367	0.135	0.889	2.329	4.380	0.000
Naseriazar(2015)*	1.507	0.290	0.084	0.939	2.075	5.204	0.000
Cerit Berber (2008) *	1.491	0.307	0.094	0.890	2.093	4.857	0.000
Uğur (2009)	1.446	0.311	0.097	0.836	2.056	4.647	0.000
Köklü (2009)	1.418	0.222	0.049	0.982	1.853	6.375	0.000
Okur (2009) *	1.382	0.346	0.120	0.703	2.061	3.990	0.000
Kobal (2011) *	1.353	0.277	0.076	0.811	1.895	4.892	0.000
Al-Hınai and Al-Balushı (2015)	1.300	0.275	0.075	0.762	1.838	4.735	0.000
Şendur et al. (2008)	1.289	0.319	0.102	0.663	1.915	4.034	0.000
Köklü (2009) *	1.276	0.237	0.056	0.812	1.740	5.395	0.000
Dilber (2006)	1.249	0.223	0.050	0.812	1.686	5.603	0.000
Şahin Pekmez (2010) *	1.139	0.344	0.118	0.465	1.813	3.313	0.001
Özyilmaz Akamca (2008)	1.132	0.223	0.050	0.695	1.569	5.077	0.000
Arıcı (2018)	1.090	0.329	0.108	0.445	1.735	3.312	0.001
Zorluoğlu and Sözbilir(2016)	1.020	0.252	0.064	0.526	1.515	4.042	0.000
Kılıç (2007)	0.998	0.302	0.091	0.407	1.589	3.309	0.001
Karslı Baydere et al. (2020)	0.987	0.298	0.089	0.402	1.572	3.308	0.001
Demirci Güler (2007)	0.961	0.357	0.127	0.262	1.660	2.694	0.007
Şahin Pekmez (2010)	0.945	0.286	0.082	0.385	1.506	3.307	0.001
Yıldırım (2009) *	0.915	0.316	0.100	0.296	1.535	2.897	0.004
Şahin Pekmez (2010) **	0.883	0.267	0.071	0.359	1.407	3.305	0.001
Kuru (2012)	0.869	0.279	0.078	0.322	1.415	3.115	0.002
Ukoh and Adejimi (2018)	0.845	0.173	0.030	0.506	1.184	4.889	0.000
Cerit Berber (2008)	0.807	0.282	0.079	0.254	1.359	2.862	0.004
Vidak et al. (2018)	0.792	0.154	0.024	0.489	1.094	5.131	0.000
Duymaz (2011)	0.790	0.265	0.070	0.271	1.309	2.984	0.003
Sert Çıbık (2011)	0.769	0.230	0.053	0.319	1.219	3.350	0.001
Taşkara (2015)	0.751	0.290	0.084	0.182	1.320	2.586	0.010
Lim (2007)	0.733	0.261	0.068	0.221	1.245	2.807	0.005
Koyunlu Ünlü and Dökme (2011)	0.725	0.296	0.087	0.145	1.304	2.451	0.014

Samara (2016)	0.722	0.227	0.051	0.278	1.166	3.187	0.001
Kahraman Gökharman(2013)	0.688	0.305	0.093	0.091	1.286	2.257	0.024
Kayhan (2009)	0.664	0.215	0.046	0.243	1.085	3.093	0.002
Ünlü (2006)	0.617	0.277	0.077	0.074	1.161	2.226	0.026
Aykutlu Çıldır (2009)	0.613	0.297	0.088	0.032	1.195	2.067	0.039
Yıldırım (2009)	0.594	0.313	0.098	-0.021	1.208	1.894	0.058
Naseriazar et al. (2011)	0.586	0.251	0.063	0.094	1.078	2.333	0.020
Çoban (2019)	0.583	0.265	0.070	0.064	1.101	2.201	0.028
Ayanda et al. (2012)	0.537	0.144	0.021	0.255	0.818	3.731	0.000
Harman (2016)	0.527	0.204	0.042	0.127	0.927	2.583	0.010
Lim (2007) *	0.458	0.251	0.063	-0.035	0.950	1.822	0.069
Duymaz (2011) *	0.446	0.256	0.066	-0.056	0.948	1.743	0.081
Arslan Karakethüdaoğlu (2010)	0.393	0.321	0.103	-0.237	1.023	1.223	0.221
Karadoğu (2007) *	0.284	0.265	0.070	-0.236	0.803	1.070	0.284
Karadoğu (2007)	0.273	0.265	0.070	-0.246	0.792	1.030	0.303
Aykutlu Çıldır (2009) *	0.224	0.277	0.077	-0.318	0.767	0.811	0.418
Şenpolat et al. (2006)	0.176	0.255	0.065	-0.324	0.677	0.690	0.490
Chan (2016)	0.021	0.323	0.104	-0.612	0.654	0.065	0.948
Chan(2016)*	-0.143	0.323	0.105	-0.777	0.491	-0.442	0.658
Çıray (2010) *	-0.244	0.238	0.057	-0.710	0.223	-1.024	0.306
Weaver (2019) *	-0.305	0.186	0.035	-0.670	0.059	-1.641	0.101
Weaver (2019)	-0.378	0.187	0.035	-0.744	-0.013	-2.028	0.043
Cain (2016)	-4.808	0.656	0.430	-6.094	-3.522	-7.329	0.000

* Individual studies

Based on Hedges' g, the mean effect size was estimated at 1.029 with a standard error of 0.092. Referring to the categorization by Thalheimer and Cook (2002), this corresponds to a large effect. The test statistics were significant ($Z = 11.175$, $p < .001$), confirming that the use of analogy-based teaching strategies markedly enhances students' performance in science education.

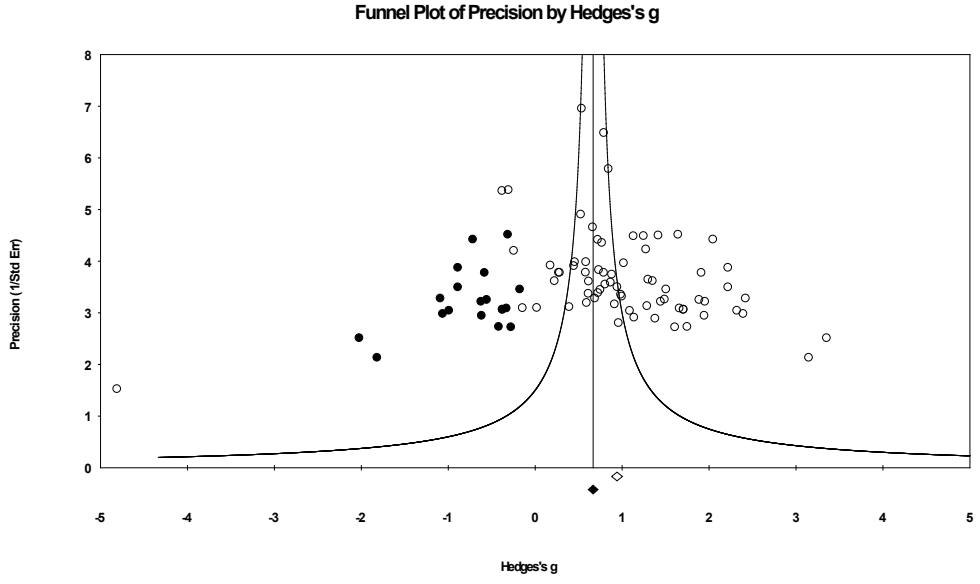

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Figure 4 Distribution funnel plot of effect sizes according to Hedges'g

To assess the risk of publication bias, a funnel plot was constructed (Figure 4). While visual inspection showed some asymmetry, the classic fail-safe N value was calculated as 7022. This suggests that more than 7000 unpublished studies with null effects would be needed to nullify the significant results observed, confirming the robustness of the findings.

Research question 2: Moderation effects on academic achievement

Moderator analysis was performed to examine whether the effect of analogical instruction varied according to the following variables: subject area, education level, implementation agent, intervention duration, type of analogy implementation, test developer, and test item format. The results are summarized in Table 5.

Table 5 The effects of moderator variables on academic achievement

		N	Point estimate	Standard error	Variance	confidence interval (95%)		Z-value	P-value	Q-value	df(Q)	P-value
						Low.lim1	Up.lim2					
Subject area	Biology	6	0.604	0.091	0.008	0.426	0.782	6.647	0.000			
	Science	27	0.911	0.175	0.030	0.569	1.253	5.219	0.000			
	Physics	16	1.045	0.203	0.041	0.647	1.443	5.142	0.000			
	Chemistry	21	1.270	0.139	0.019	0.997	1.543	9.114	0.000			
	T.betw.3									17.475	3	0.001
Level of education	Primary	1	1.090	0.329	0.108	0.445	1.735	3.312	0.001			
	Secondary	25	1.058	0.156	0.024	0.753	1.363	6.795	0.000			
	High school	30	1.213	0.121	0.015	0.975	1.451	9.998	0.000			
	University	14	0.551	0.238	0.057	0.085	1.017	2.319	0.020			
	T.betw.3									6.163	3	0.104
Implementer	Researcher	39	1.062	0.120	0.014	0.827	1.297	8.855	0.000			
	Teacher	29	0.996	0.147	0.022	0.708	1.284	6.785	0.000			
	T.betw.3									0.120	1	0.729
Duration of implementation	0-2 weeks	12	0.914	0.265	0.070	0.396	1.433	3.455	0.001			
	3-4 weeks	26	1.050	0.169	0.029	0.718	1.382	6.201	0.000			
	5-6 weeks	15	0.879	0.151	0.023	0.583	1.174	5.829	0.000			
	7-8 weeks	7	0.983	0.104	0.011	0.780	1.186	9.491	0.000			
	≥10 weeks	4	0.922	0.149	0.022	0.630	1.214	6.182	0.000			
	T.betw.3									0.892	4	0.926
Analogy use	UAOMT4	23	1.087	0.123	0.015	0.845	1.329	8.815	0.000			
	AOT5	47	0.998	0.122	0.015	0.758	1.237	8.179	0.000			
	T.betw.3									0.265	1	0.606
Developers of the	Researcher	65	1.002	0.094	0.009	0.817	1.187	10.620	0.000			
	RATT6	1	0.617	0.277	0.077	0.074	1.161	2.226	0.026			
	Others	4	1.577	0.429	0.184	0.737	2.417	3.680	0.000			
	T.betw.3									23.997	2	0.000
Type of questions in the measurement tool	2-phase test	13	0.971	0.200	0.040	0.579	1.362	4.859	0.000			
	3-phase test	4	1.124	0.456	0.208	0.229	2.018	2.463	0.014			
	Open-ended questions	1	0.284	0.265	0.070	-0.236	0.803	1.070	0.284			
	Multiple Choice Test	42	1.156	0.123	0.015	0.916	1.396	9.437	0.000			
	Mixed	10	0.625	0.197	0.039	0.239	1.012	3.169	0.002			
	T.betw.3									11.968	4	0.018

[1] : Lower limit, [2] : Upper limit, [3] : Total between, [4]: Use of Analogy and other methods together, [5]: Analogy oriented teaching, [6]: Researcher and Teacher together

- Subject Area: Statistically significant differences were found (Q = 17.475, df = 3, p < .01). Chemistry showed the highest mean effect size (g = 1.270), followed by physics (g = 1.045), science (g = 0.911), and biology (g = 0.604).
- Education Level: Although not statistically significant (Q = 6.163, df = 3, p > .05), all levels showed significant within-group effects. The highest effect was for high school students (g = 1.213), while university-level students had the lowest (g = 0.551)
- Implementation Agent: No significant difference was observed between teachers and researchers (Q = 0.120, df = 1, p > .05). Both groups produced significant effect sizes.
- Intervention Duration: No significant moderation effect was detected (Q = 0.892, df = 4, p > .05). However, all duration groups showed meaningful effect sizes, with the 3–4-week group having the highest (g = 1.050).
- Type of Analogy Implementation: The difference between analogy-only and analogy combined with other methods was not statistically significant (Q = 0.265, df = 1, p > .05). Both implementation types yielded high-level effects.
- Test Developer: Statistically significant differences were found (Q = 23.997, df = 2, p < .01). The highest effect was reported for tests developed by others (g = 1.577), followed by researcher-developed (g = 1.002) and jointly developed instruments (g = 0.617).
- Item Format: A significant moderation effect was detected (Q = 11.968, df = 4, p < .05). The highest effect sizes were associated with multiple-choice (g = 1.156) and three-tier tests (g = 1.124), while open-ended questions yielded the lowest (g = 0.284).

These findings indicate that the effectiveness of analogical instruction is particularly influenced by the subject area, test developer, and item format. Other variables such as education level and implementation duration exhibited variability but did not reach statistical significance in between-group comparisons.

Discussion and conclusion

Overall effectiveness of analogical instruction

This meta-analysis aimed to determine the overall effectiveness of analogy-based instruction in science education on students' academic achievement. The findings revealed a high-level mean effect size (Hedges' g = 1.029), suggesting that analogical instruction significantly enhances academic success in science-related subjects. This result supports the idea that analogies help concretize abstract scientific concepts, improving understanding and retention (Çalık, 2006; Dagher, 1995; Gentner, 1983).

The result aligns with prior findings that analogy-based methods can positively influence learning outcomes across various educational levels (Çalık & Kaya, 2012; Duru, 2002). The funnel plot and classic fail-safe N test indicated that the results were robust and not likely due to publication bias. This meta-analysis provides quantitative evidence supporting the pedagogical value of analogy use in science education.

Effects of moderator variables

Moderator analyses revealed that some variables significantly affected the impact of analogical instruction:

- Subject Area was a significant moderator. Chemistry had the highest mean effect (g = 1.270), followed by physics (g = 1.045), general science (g = 0.911), and biology (g = 0.604). This suggests that analogy-based teaching is particularly beneficial in chemistry, where abstract concepts are common and analogies effectively bridge conceptual gaps.
- Education Level did not significantly moderate the results statistically (Q = 6.163, p > .05), but descriptively, high school students benefited the most (g = 1.213), followed by middle school (g = 1.058), primary school (g = 1.090), and university students (g = 0.551). The comparatively lower effect at the university level may reflect a perception of analogies as too simplistic.
- Implementation Agent (teacher vs. researcher) showed no significant difference (Q = 0.120, p > .05), indicating that analogical instruction is effective regardless of who applies it. Researchers' meticulous preparation and training of teachers for implementation may explain this consistency.
- Intervention Duration did not significantly affect outcomes (Q = 0.892, p > .05), although durations of 3–4 weeks yielded the highest effect size (g = 1.050), suggesting sufficient exposure time is beneficial for concept internalization.
- Type of Analogy Use (analogy alone or combined with another method) was not a statistically significant moderator (Q = 0.265, p > .05). Both uses showed high-level effects (g > 0.998), highlighting the flexibility of analogical methods in diverse instructional designs.
- Test Developer significantly influenced effect sizes (Q = 23.997, p < .05). Tests developed by external sources yielded the highest effect size (g = 1.577), followed by those developed by researchers (g = 1.002), and then jointly developed instruments (g = 0.617), possibly due to greater standardization and reliability in externally developed tests.
- Item Format was a significant moderator (Q = 11.968, p < .05). Multiple-choice (g = 1.156) and three-tier tests (g = 1.124) resulted in the highest effects, while open-ended items yielded the lowest (g = 0.284). The ease of interpretation and scoring of closed formats may partly explain this trend.

These findings suggest that while analogical instruction is generally effective across various contexts, its impact can be optimized by considering variables such as subject area and assessment format.

Limitations and future research directions

This study has several limitations. First, most studies included were conducted in Turkey, limiting the generalizability of findings. More international research is needed. Second, while the analysis included 70 individual effect sizes, some studies contributed multiple outcomes, potentially influencing the dataset's independence. Third, certain potential moderator variables could not be analyzed due to insufficient reporting in the included studies.

Future research should explore the impact of analogy-based instruction across different cultural contexts and student populations. Additionally, deeper examination of teacher variables—such as training in analogy use, content expertise, and instructional style—would be valuable. Studies should also report detailed methodology and data to allow inclusion in future meta-analyses. Finally, longitudinal studies could provide insights into the long-term impact of analogy-based teaching strategies.

Despite these limitations, this meta-analysis contributes to the growing body of literature demonstrating the efficacy of analogies in science education. The findings can inform curriculum designers, teacher educators, and policy-makers aiming to enhance science instruction and student learning outcomes.

Declarations

Ethics statements

This study is a meta-analysis that synthesizes data from previously published research. Since no new data was collected from human participants or animals, obtaining ethical approval was not required. All studies included in this meta-analysis were assumed to have been conducted in accordance with ethical guidelines and regulations.

Informed consent

This study did not involve human participants, human data, or human tissue. Therefore, obtaining informed consent was not applicable.

Availability of data and materials

The data supporting the findings of this study were obtained from previously published research articles included in the meta-analysis. All data is publicly available from the cited sources in the reference list. No new datasets were generated during the current study.

Competing interests

The authors declare that they have no financial or non-financial competing interests related to this study.

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Authors' contributions

Jülide YAZICI, Conceptualization, data collection, data analysis and interpretation, manuscript drafting, and revision. Erol TAŞ, Supervision, methodological development, guidance in data analysis, critical review of the manuscript, and final approval. Note: This study constitutes a part of the first author's doctoral dissertation. The second author served as the dissertation advisor, providing academic guidance throughout the research process.

Artificial intelligence

The authors declare that no artificial intelligence tools were used in the preparation, writing, or editing of this manuscript.

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