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ORIGINAL ARTICLE

The Effect of Problem-Based Learning in Science Education on Academic Achievement: A Meta-Analytical Study

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ABSTRACT

This meta-analysis study aimed to scrutinize the effect of the problem-based learning (PBL) approach on students' academic achievement in science lessons compared to the traditional instructional approach. As research data, the researcher accessed 55 experimental studies as a result of steps of a systematic review with the keywords "problem-based learning," "science," and "academic achievement or success" from the Education Resources Information Center, Scopus, Web of Science, Proquest, Taylor and Francis, Center of Higher Education National Thesis Center, and Wiley Online databases. The results showed that the PBL method used in science education had a high effect size on academic achievement compared to the traditional instructional method. The results also explained significant differences between the effect sizes of publication types (conference papers, articles, master's thesis, and doctoral thesis). On the other hand, they demonstrated that academic achievement was similar in the nationality of the studies, educational levels, instructional variations with PBL, and relevant science areas. It is expected that integrating innovative instructional approaches into PBL could guide researchers who establish a research problem about how it can affect science academic achievement.

KEY WORDS: Meta-analysis; problem-based learning; science education; systematic review

INTRODUCTION

In the past three decades, the world has seen significant changes in how we communicate, access information, learn, and use technology. Changes in the way of teaching are needed to prepare students to cope with these changes. For such an instructional process, students need more knowledge and skills to ask and answer questions, seek and find appropriate resources, and effectively teach others the solutions they find (Duch et al., 2001). Henceforth, scholars have advocated transitioning from teacher-centered instruction to a new paradigm called student-centered instruction in their learning–teaching understandings (Blumberg, 2019). Problem-based learning (PBL) is considered an educational method that provides a paradigmatic shift in students' understanding of knowledge, learning, and teaching. On the axis of this transformation, research evidence shows that PBL leads to a change in the thinking structures of students, and this change also carries it beyond a superficial level of learning (Ge and Chua, 2019). For this reason, it is seen as an educational strategy that facilitates the building of thinking and communication skills necessary for today's success (Duch et al., 2001). As a result of this function, compared to the traditional teaching method, PBL encourages students to think, motivate, and work more (Graaff and Kolmos, 2003).

Unlike traditional instructional methods (i.e., chalk and talk and rote memorization), PBL uses problem-based instruction, self-regulated learning, and small-group learning to help students construct their topics. PBL transforms learning from memorizing abstract factual knowledge to developing knowledge that can be transferred to real-life situations, from passively acquiring knowledge to actively seeking knowledge, from a mere individual understanding of learning to building shared knowledge in collaboration with others. As a result of this transformation, PBL enables students to acquire integrated knowledge, skills, and attitudes to become independent problem solvers, better knowledge seekers, influential team players, and lifelong learners (Hung et al., 2019). The meta-analysis of Vernon and Blake's (1993) study revealed that PBL is superior to traditional methods in student characteristics such as student mental health, classroom participation, academic knowledge and skills, and attitudes. Although Vernon and Blake's study showed that PBL had superior aspects more generally, there is a need for a meta-analysis study that includes more recent research on the effects of PBL on academic achievement, specifically in science education.

Science education is an appropriate area where the PBL approach can be applied to real-life subject areas such as socio-scientific issues and STEM (Lubis et al., 2022; Ngoc-Giang, 2020; Rehmat and Hartley, 2020). As a result, compared to traditional instruction, PBL in science education is an instructional method with potential effects on learning outcomes. This research examined the effect of PBL on science academic success as a learning outcome through the meta-analysis method. After this section, the conceptual framework regarding the development, definition, and steps of PBL will be given.

PBL

PBL first emerged in 1969 as a result of an effort to reform medical education at McMaster University in Canada (Schmidt, 2012). Since its emergence, the interest in PBL can be seen in the number of educational programs (Savin-Baden, 2003). Many educational institutions at all educational levels have incorporated PBL into their curricula (Hernández-Ramos et al., 2021). PBL, an instructional method compatible with constructivist learning principles (Hendry and Murphy, 1995), is a student-centered, active learning approach that provides students with the opportunity to construct their knowledge through peer interaction and collaborative research or inquiry (Gerhardt and Gerhardt, 2008; Liu et al., 2008).

The main feature of PBL is that it encourages students to do research by deepening their understanding of teaching and learning through practice and inquiry in collaborative work in line with constructivist learning principles (Naslund and Prodan, 2016). Therefore, PBL provides a framework for structuring and facilitating collaborative thinking processes based on creative problem-solving (Poikela et al., 2008).

The primary purpose of PBL as a learning model is to enable students to solve complex, ill-structured real-world problems collaboratively as participants in their learning responsibility, and to acquire the ability to cope with the challenges they will face in the future (Duch et al., 2001; Rotgans and Schmidt, 2019; Russell, 2008). Bae (2008) explained that PBL guides students to identify and fill existing knowledge gaps. He also pointed out that PBL enhances students' metacognitive skills by improving their ability to build new knowledge on existing knowledge. Moreover, Hmelo-Silver (2004) expressed that PBL contributes to the development of four skill areas in students:

a. Practical problem-solving skills with flexible information presentation
b. Self-regulated learning skills
c. Effective teamwork skills
d. Intrinsic motivation skills.

Processes of PBL

The essential component of learning in PBL is an ill-structured authentic real-life problem scenario (Yew and O'Grady, 2012). PBL uses authentic real-life problems that contextualize subject matter knowledge to make it easier for them to connect subject matter knowledge and the situations in which it can be applied (Hung, 2019). Carefully designed authentic problems offer a solid foundation for learning (Poikela et al., 2008). Students work individually and collaboratively on these authentic problems. They learn to deepen content knowledge, synthesize and make sense of information, solve problems, and think critically (Dabbagh, 2019; Hmelo-Silver, 2004).

After the design of these problem scenarios, a PBL consists of seven stages (Servant-Miklos et al., 2019):

- Step 1. Clarifying terms and concepts that are not easily comprehensible,
- Step 2. Defining the problem,
- Step 3. Analyzing the problem,
- Step 4. Creating a list of comments extracted from Step 3,
- Step 5. Constructing the learning objectives,
- Step 6. Collecting additional information from outside the group
- Step 7. Integrating and controlling newly acquired knowledge.

In a more detailed manner, students primarily focus on a complex problem for which there is no single correct answer. Collaboratively, they try to identify the knowledge and skills they need to learn to find a solution to a problem. Students define and analyze the problem by describing the relevant facts in the scenario. As students acquire a better understanding of the problem, they hypothesize about possible solutions. A critical action of this cycle is diagnosing knowledge gaps related to the problem through self-regulated learning. In this process, students become responsible for their own learning. Following self-regulated learning, they apply their newly learned knowledge to the problem. They reflect on the efficacy of the strategies they learned and used. Based on the hypotheses established at the end of the problem, they make an evaluation on possible solutions.

They inform and report on the solutions found at the end of this process. Instead of presenting information in all these steps, the teacher helps them learn the cognitive skills necessary for problem-solving and collaboration and facilitates the learning process (Hmelo-Silver, 2004; Wijnia et al., 2019; Yew and Schmidt, 2012).

PBL in Science Education

PBL is an approach intertwined with technology and socio-scientific issues that facilitate learning subject area knowledge, thinking, and studying skills necessary to produce new knowledge (Hernández-Ramos et al., 2021). As a model related to socio-scientific issues, PBL makes it easier to relate science to everyday life and society in science teaching (Ke et al., 2021). PBL has become quite common, especially in science lessons (Yıldızay and Tarhan, 2018). In experimental and action research, PBL applications in science teaching improved students' learning outcomes. For example, PBL applications in science education have an impact on attitudes toward science (Baran and Sözbilir, 2018; Musalamani et al., 2021; Ural and Dadlı, 2020), interest in science (Baran and Sözbilir, 2018), and motivation (Hugerat et al., 2021). Cognitively, PBL also affects problem-solving (Valdez and Bungihan, 2019), reflective thinking (Ural and Dadlı, 2020), and socio-scientific decision-making skills in science teaching (Nurtamara et al., 2020). Another cognitive construct is academic achievement in science, and academic achievement as the dependent variable lies at the focus of this meta-analysis. The systematic review also shows that PBL increases academic achievement in science (Baran and Sözbilir, 2018; Günter, 2020; Günter et al., 2017; Yıldızay and Tarhan, 2018).

The Problem Statement

Studies have shown that PBL affects academic achievement as well as other learning outcomes in science teaching. In order to answer the question, “Does PBL-based instruction positively affect students’ academic success in science?,” a systematic review of the effect of PBL on academic achievement is needed. The way to construct such a study is to combine the results of experimental research to compare the effects of the two groups on academic achievement in a control group with traditional instruction and an experimental group with PBL-based instruction. Meta-analysis is a quantitative method that gives a general result about the effectiveness of the method applied in the experimental group based on the statistical data revealed in experimental studies (Borenstein et al., 2009). Therefore, the study conducted with meta-analysis processes aims to obtain a holistic understanding of the effect of PBL on academic success in science courses. Dağyar and Demirel (2015) comprehensively studied the effects of PBL on academic achievement in science, social sciences, mathematics, health sciences, and computer science courses. Dağyar and Demirel (2015) included experimental studies conducted between 1997 and 2014 in their meta-analysis. The current meta-analysis study consists of the research findings between 1998 and 2022. Funa and Prudente’s (2021) meta-analysis consisted of experimental studies conducted on high school students between 2016 and 2020. Their meta-analysis considered grade levels and science branches as moderator variables.

The unique aspects of this meta-analysis study that differ from the studies of Dağyar and Demirel (2015) and Funa and Prudente (2020) are (1) to incorporate current research in the meta-analysis; (2) to separate academic achievement in science into physics, chemistry, and biology courses at all educational levels; (3) grouping only PBL studies, technology-supported PBL, thinking-oriented PBL, paper-based PBL, and PBL integrated with constructivist approaches; and (4) clustering the nationality of research into domestic and international research. These matters will give an idea to researchers who want to conduct a meta-analysis on PBL. Based on the mentioned matters, this meta-analysis study was needed because it has new and unique features.

The Research Goal

The primary purpose of this research was to study the effect of the PBL approach on students’ academic achievement in science lessons compared to the traditional instructional approach. Sub-research questions were designed following the aforementioned primary purpose and the rationale of the research.

The Research Sub-Questions

RQ1. What are the frequency and percentage distributions of the studies included in the meta-analysis?
RQ2. What is the effect of the PBL approach on students’ academic achievement in science lessons compared to the traditional instructional approach?
RQ3. What is difference between the effect sizes of publication types related to PBL on academic achievement in science?
RQ4. What is difference between the effect sizes of PBL on academic achievement among science subjects?
RQ5. How do the effect sizes on academic achievement in science differ significantly in instructional variations with PBL?
RQ6. What is difference between the effect sizes of PBL on science academic achievement in terms of educational levels?
RQ7. What do the effect sizes of PBL on science academic achievement differ significantly in studies conducted in Turkey and abroad?

RESEARCH DESIGN

This research has employed the meta-analysis method to reveal the effects of the PBL approach on science academic achievement compared to the traditional instructional approach. A meta-analysis is a form of statistical method that combines the quantitative results obtained from more than one study to produce holistic applied knowledge about a particular subject (Littell et al., 2008). Based on the results obtained in this meta-analysis study, the effect sizes of the effects of PBL on academic achievement in science are calculated. The meta-analysis steps followed in obtaining this effect size are explained, clearly and systematically.

Steps of Meta-Analysis

The steps to be followed in conducting a meta-analysis study are as follows: (1) identifying the topic and structuring the research questions, (2) determining the type of meta-analysis, (3) defining the inclusion criteria, (4) accessing and obtaining resources, (5) creating the coding form and recording the data, (6) calculating the effect sizes, (7) performing the coding reliability, and (8) reporting the results (Cooper, 2017).

(1) Identifying the subject of meta-analysis

In this meta-analysis study, the PBL model, one commonly used model among the constructivist learning approaches, was adopted. The PBL model was defined as the independent variable, and academic achievement in science lessons was defined as the dependent variable.

(2) Determining the type of meta-analysis

In this meta-analysis study, the experiment effectiveness meta-analysis method was preferred since the primary aim was to examine the effect of teaching with the PBL model on science academic achievement compared to traditional teaching. In this meta-analysis method, only post-test mean scores, standard deviation, and study size values of the experiment and control group were considered.

(3) Defining the study eligibility criteria

The third step is establishing specific eligibility criteria to determine which studies can be included or excluded from the meta-analysis (Littell et al., 2008). The criteria established in this meta-analysis study were as follows:

- The primary purpose of the meta-analysis was to study the effect of PBL on academic achievement in science lessons compared to the traditional instructional approach.
- This meta-analysis comprised experimental studies including pre-test and post-test with a control group in science lessons.
- This meta-analysis focused on studies that include PBL as the independent variable and academic achievement on science subjects as the dependent variable.
- This meta-analysis considered experimental studies with parametric tests, including post-test mean scores, standard deviation, and the number of participants in the control and experimental groups.

(4) Accessing and obtaining resources to be included in the meta-analysis

After determining the independent and dependent variables, the resources were accessed and obtained through databases with related concepts or terms in this meta-analysis. "PBL" was defined as the independent variable, and "academic achievement or success" as the dependent variable. In the scope of the research, the term "science" was also included in the search words since it was restricted to PBL in science education. These three concepts were simultaneously available in "ERIC - Education Resources Information Center," "SCOPUS," "Taylor and Francis," "Wiley Online," "Web of Science," "ProQuest Dissertations and Theses," and "CoHE National Thesis Center." They were searched in the "research titles" and "abstracts." A total of 566 studies were accessed in the specified databases. The inclusion process of studies in line with the eligibility criteria of the resources is depicted in Figure 1.

Four hundred and ninety-one of 566 studies reviewed in the titles and abstracts were excluded because they were not suitable for the purpose and scope of this meta-analysis study. The studies excluded consisted of review studies (95), qualitative research (81), correlational research (44), survey studies (48), design studies (5), causal-comparative research (1), not related to science education (103), not related to academic success (53), not related to PBL (61), and single-group experimental studies (17).

After this review, 75 potential studies remained for this meta-analysis. As a result of the evaluation of the remaining studies, 18 of 75 potential studies with full text were excluded due to 8 studies with no full text and 10 recurring studies.

Ten of the 57 studies were excluded from the meta-analysis because they had unrelated sampling (1), the absence of standard deviation values (7), and post-test scores (2). Forty-seven individual studies remained.

Due to more than one experimental group in 47 studies, 8 more data sets were added to the meta-analysis as a separate study resource. For example, Williams et al. (1988) have two research data sets and for this study they are referred to as Williams et al. (1988a) and Williams et al. (1988b) for the meta-analysis (Appendix A). This is similar for: Fidan and Tuncel (2019), Arıcı and Yılmaz (2022), Güzel (2018), Sağlam (2022), Kızılkaya (2017), and Eyceyurt-Türk (2017). As a result of this process, a total of 55 study data represent the data source of this meta-analysis.

(5) Creating coding form and recording data

Parameter values defined in the experimental effectiveness meta-analysis method were entered and recorded in an Excel sheet. In addition to the values mentioned in the coding form, the following variables were determined for moderator analysis:

- *The control and experimental groups' parameters:* Post-test mean scores, standard deviation values, and sample sizes.
- *The publication type:* Conference papers, articles, master's thesis, and doctoral dissertation.
- *The nationality of studies:* Domestic (Turkey) and abroad (outside Turkey) studies.
- *The relevant science areas:* Physics, chemistry, and biology subjects.
- *Instructional variations with PBL model:* Only PBL studies, technology-supported PBL, thinking-oriented PBL, constructivist PBL, and paper-based PBL.
- *Educational levels:* Primary school, middle school, high school, and university.
- In line with the inclusion criteria, the parameter data of 55 individual studies in the meta-analysis were recorded in the coding form.

(6) Calculating effect sizes

After creating the coding form, the next step is to perform statistical analysis on the parameters of the studies (post-test of the groups, standard deviation, and sample size). In order to combine studies statistically in the meta-analysis, it is necessary to obtain comparable measures among studies. The study results in the meta-analysis were converted into the basic unit of measure called the effect size (Littell et al., 2008). According to Littell et al. (2008), most effect size measures fall into three categories: proportional, mean, and correlation coefficients. The choice of effect size is influenced by the purpose and design of a study and the data format. The meta-analyses with experimental effects often report differences in ratio or mean scores (e.g., between pre-test and post-test or between experimental and control groups). This analysis revealed the effect size or power of PBL on science academic achievement when the instruction carried out with the PBL approach in the experimental group was compared with the traditional instruction in the control group (Borenstein et al., 2009).

The research data recorded in the Excel sheet have been analyzed with the help of CMA V3 (Comprehensive Meta-Analysis V3). Meta-analysis uses fixed effects and random effects models to calculate the effect size. These models utilize different procedures for weighting the study's effect size, calculating the mean effects, and establishing confidence intervals for the mean effects. Fixed effects models depend on

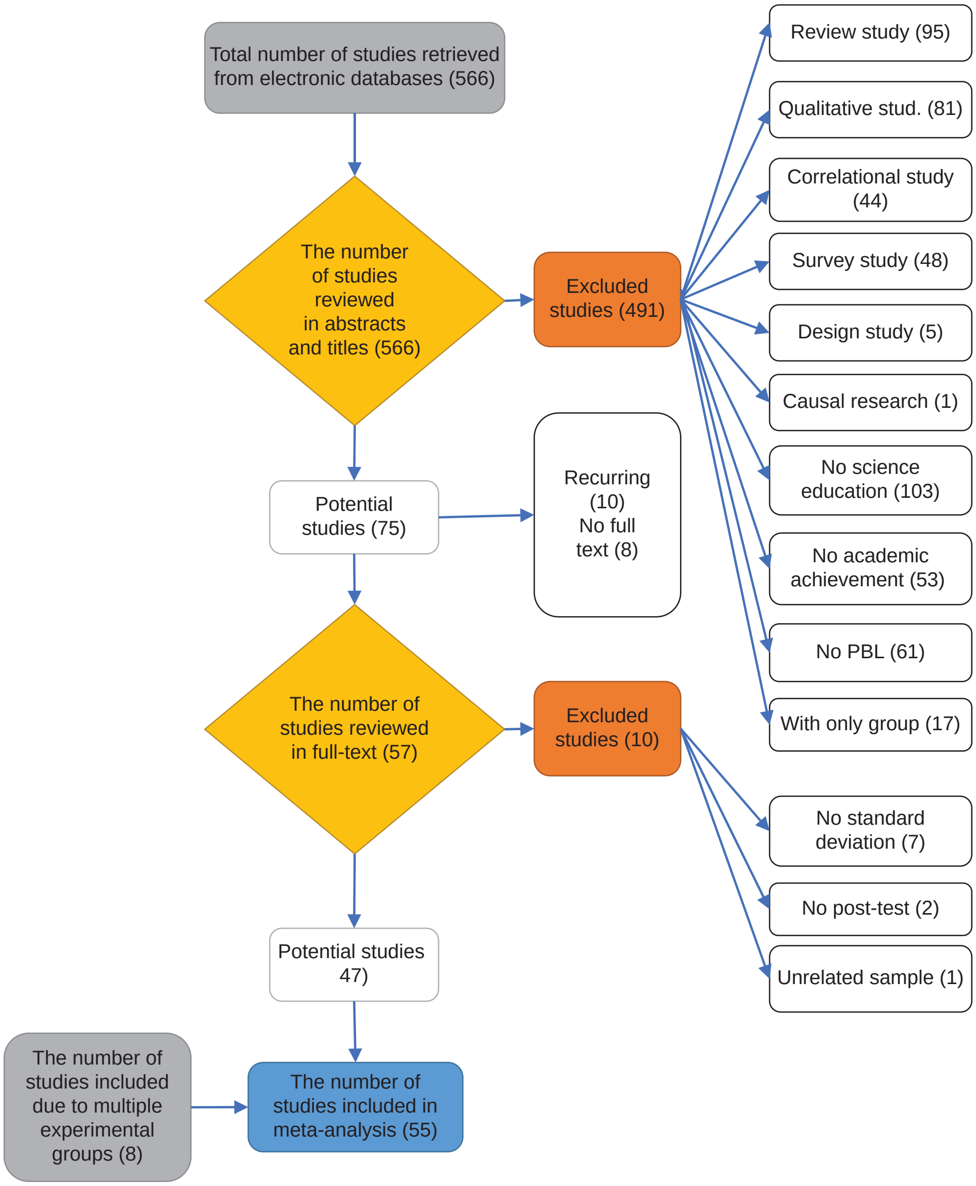

Figure 1: The process of incorporating studies into the meta-analysis

the assumption that all studies come from the same population and produce a single effect size. While this assumption suggests that all factors affecting effect size are the same in all studies, random effect models rely on the assumption that the actual effect may vary between samples and studies (Borenstein et al., 2009). The meta-analysis results point out the random effects model since the effect size distribution of the studies is not homogeneous (Q = 508.460; $P < 0.05$). In addition to the Q value, the I^2 value is a parameter explaining how heterogeneous the studies in the meta-analysis are. The parameter also indicates that the value is heterogeneous at 89.38% (Higgins et al., 2003). According to Cohen's (1988) classification of effect sizes, the Hedge's g coefficient has a small effect size between 0.2 and 0.5, a moderate between 0.5 and 0.8, and a high effect size of 0.8 and above. In line with this classification, interpretations were made about the average effect size of PBL on science academic achievement and the effect sizes of the subgroups in the moderator analyses.

(7) Coding reliability of studies in meta-analysis

After the research data were entered as a result of the eligibility criteria, it was necessary to understand whether the parameters of the studies had been entered accurately into the data template. Two researchers coded the characteristics of the studies in the meta-analysis according to the parameters in the coding form. Based on the formula proposed by Miles and Huberman (1994), the coding results uncovered that the coding reliability was at an accepted value.

RESULTS

The results of the research questions are given in this section.

The Results of Research Question 1 (RQ1)

The descriptive statistics were performed to answer "RQ1." Table 1 presents the frequency and percentage distributions of the characteristic features of the studies in the meta-analysis.

As shown in Table 1, 2 of the 55 studies in the meta-analysis were conference papers (3.64%), 21 research articles (38.18%), 20 masters' (36.36%), and 12 doctoral theses (21.82%) by *publication type*. 87.27% of the studies in the meta-analysis were carried out in Turkey (Turkey), and the remaining 12.73% were performed abroad. In terms of the *Instructional variations* with *the PBL model*, there were also 42 (76.36%) purely PBL, 2 (3.64%) paper-based PBL, 4 (7.27%) technology-assisted PBL, 3 (5.45%) thinking-oriented PBL, and 4 (7.27%) constructivist PBL studies integrated with contemporary teaching approaches. Moreover, physics subjects constituted 34.55%, chemistry subjects 40%, biology subjects 21.82%, and science area unspecified (3.64%) of all the studies. Finally, the research data consisted of one primary school, 33 secondary schools, 6 high schools, and 15 universities within *the educational level*.

Results of Research Question 2 (RQ2)

To search for an answer to "RQ2," the meta-analysis results performed are presented in Table 2. It shows the heterogeneity value, mean effect size, and confidence interval values of the studies included in the meta-analysis.

Table 1: Frequency and percentage distributions of studies included in the meta-analysis

Moderator variables	Frequency (%)
Publication type	
Conference presentation	2 (3.64)
Article	21 (38.18)
Master thesis	20 (36.36)
Doctoral dissertation	12 (21.82)
The nationality of studies	
National	48 (87.27)
International	7 (12.73)
Instructional variations with PBL model	
Pure PBL	42 (76.36)
Paper-based PBL	2 (3.64)
Technology-supported PBL	4 (7.27)
Thinking-oriented PBL	3 (5.45)
Constructivist-assisted PBL	4 (7.27)
Science subjects	
Physics subjects	19 (34.55)
Chemistry subjects	22 (40)
Biology subjects	12 (21.82)
Not specified	2 (3.64)
Educational level	
Elementary school	1 (1.82)
Middle school	33 (60)
High school	6 (10.91)
University	15 (27.27)
Total	56 (100)

PBL: Problem-based learning

Table 2 shows that the lower (0.728) and upper (0.858) confidence intervals vary according to the fixed effects model. The average effect size (Hedges's g) is 0.793. On the other hand, the heterogeneity test's result demonstrates that the effect size distribution between studies is not homogeneous (Q=508.460; $P < 0.05$). Based on this result, the random effects model was chosen as the effect size approach in the meta-analysis. According to the random effects model, the effect size's lower and upper limit values vary between 0.805 and 1.213 in the 95% confidence interval. The average effect size is 1.009. Compared with the traditional instructional method in the control group, the PBL model in the experimental group positively affects academic achievement in science education (Cohen, 1988).

The forest graph showing the effect sizes, confidence intervals, and total effect size of the studies according to the random effects model is depicted in Figure 2.

Figure 2 displays the forest plot describing the effect sizes of the studies included in the meta-analysis. The forest graph illustrates that Aktı-Aslan (2019) and Kaçar (2012) had the largest effect size in their studies, while the smallest effect size was in the study of Eyceyurt-Türk (2017). On the other hand, the studies of Williams et al. (1998a, 1998b), Güzel (2018), and Eyceyurt-Türk (2017b, 2017d: see Appendix) had negative effect sizes. In other words, academic achievement scores in the control group with traditional instructional methods were higher than in the experimental group with PBL. In the remaining 52 studies, the PBL was more influential on academic achievement in the experimental group. In general, according to the random effects model, the effect size of PBL on science academic achievement is 1.009, at a high grade.

Classical fail-safe N test values were checked to ensure the validity of the effect size (1.009) calculated according to the random effects model.

The fact that the P-value is smaller than the alpha P-value in Table 3 explains that the effect size revealed in the meta-analysis is a valid and reliable result ($P < 0.05$) (Cohen, 1988).

One method of understanding that studies produce reliable results in meta-analysis is to test whether there is publication bias among studies (Borenstein et al., 2009). The funnel plot of standard error by Hedges's g is indicated in Figure 3.

In the funnel plot, the distribution is skewed to the left since the effect size of 2 studies among 55 studies is higher than usual. Nevertheless, it was added to the results of the research. In general, there was no publication bias.

The Results of Research Question 3 (RQ3)

To explore for an answer to "RQ3," the meta-analysis results conducted are presented in Table 4.

Table 4 shows that the homogeneity structure of the effect sizes of the studies differed significantly by publication types (Q=28,161; $P < 0.05$). Based on these results, it is possible to say that the ranking of the effect sizes of PBL

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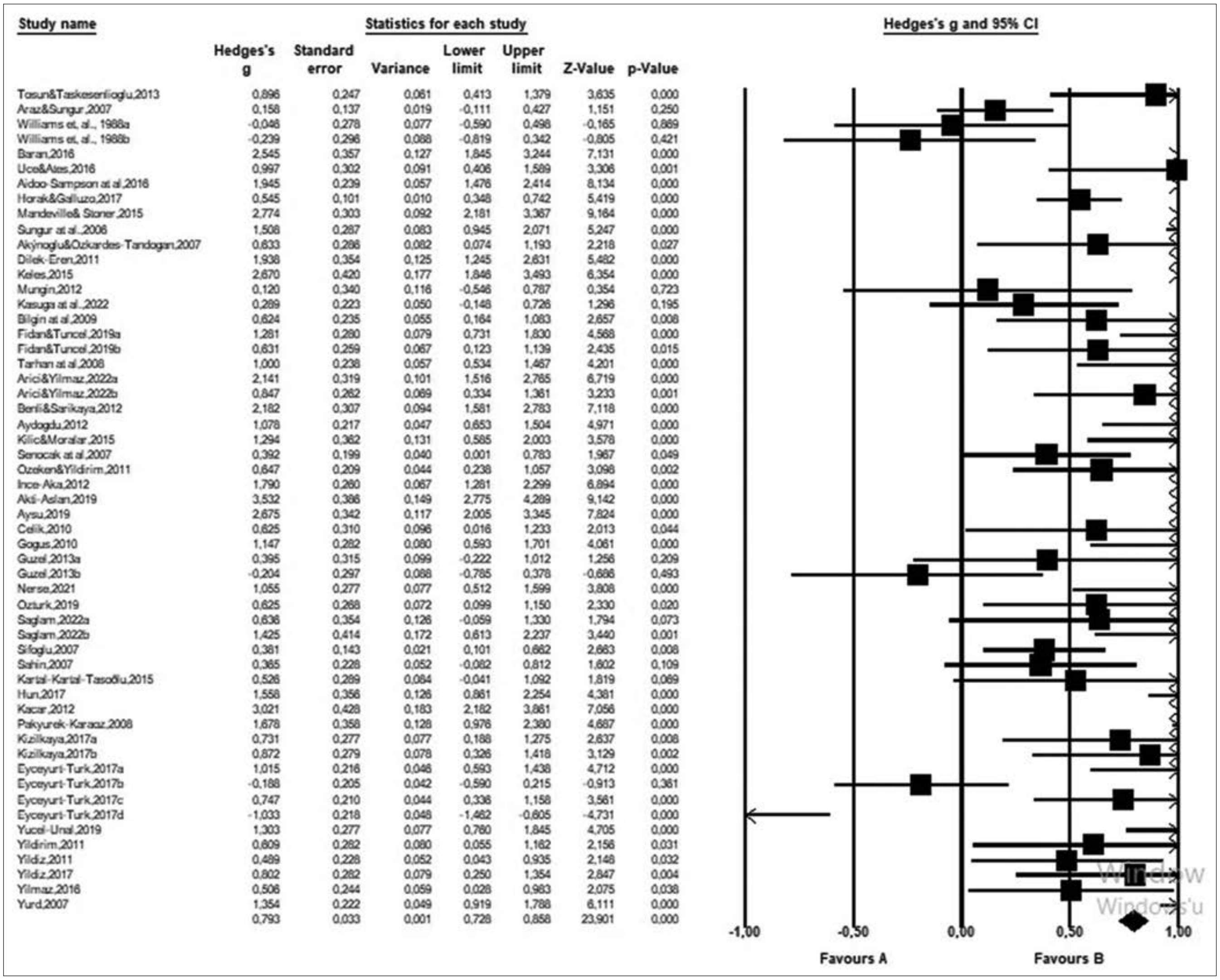
Table 2: Heterogeneity value, average effect size, and confidence interval values of studies included in meta-analysis

Model	n	Hedges's g	95% confidence lower	95% confidence upper	Q-between class effects	I^2	*P*-value
Fixed effects model	55	0.793	0.728	0.858	508.460	89.380	0.000
Random effects model	55	1.009	0.805	1.213			

**P*-value is significant at 0.05 level



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Tosun&Taskesenlioglu,2013	0,896	0,247	0,061	0,413	1,379	3,635	0,000
Araz&Sungur,2007	0,158	0,137	0,019	-0,111	0,427	1,151	0,250
Williams et, al., 1988a	-0,046	0,278	0,077	-0,590	0,498	-0,165	0,869
Williams et, al., 1988b	-0,239	0,296	0,088	-0,819	0,342	-0,805	0,421
Baran,2016	2,545	0,357	0,127	1,845	3,244	7,131	0,000
Uce&Ates,2016	0,997	0,302	0,091	0,406	1,589	3,306	0,001
Aidoo-Sampson at al,2016	1,945	0,239	0,057	1,476	2,414	8,134	0,000
Horak&Galluzo,2017	0,545	0,101	0,010	0,348	0,742	5,419	0,000
Mandeville& Stoner,2015	2,774	0,303	0,092	2,181	3,367	9,164	0,000
Sungur at al.,2006	1,508	0,287	0,083	0,945	2,071	5,247	0,000
Akýnoglu&Ozkardes-Tandogan,2007	0,633	0,286	0,082	0,074	1,193	2,218	0,027
Dilek-Eren,2011	1,938	0,354	0,125	1,245	2,631	5,482	0,000
Keles,2015	2,670	0,420	0,177	1,846	3,493	6,354	0,000
Mungin,2012	0,120	0,340	0,116	-0,546	0,787	0,354	0,723
Kasuga at al.,2022	0,289	0,223	0,050	-0,148	0,726	1,296	0,195
Bilgin at al,2009	0,624	0,235	0,055	0,164	1,083	2,657	0,008
Fidan&Tuncel,2019a	1,281	0,280	0,079	0,731	1,830	4,568	0,000
Fidan&Tuncel,2019b	0,631	0,259	0,067	0,123	1,139	2,435	0,015
Tarhan at al,2008	1,000	0,238	0,057	0,534	1,467	4,201	0,000
Arici&Yilmaz,2022a	2,141	0,319	0,101	1,516	2,765	6,719	0,000
Arici&Yilmaz,2022b	0,847	0,262	0,069	0,334	1,361	3,233	0,001
Benli&Sarikaya,2012	2,182	0,307	0,094	1,581	2,783	7,118	0,000
Aydogdu,2012	1,078	0,217	0,047	0,653	1,504	4,971	0,000
Kilic&Moralar,2015	1,294	0,362	0,131	0,585	2,003	3,578	0,000
Senocak at al,2007	0,392	0,199	0,040	0,001	0,783	1,967	0,049
Ozeken&Yildirim,2011	0,647	0,209	0,044	0,238	1,057	3,098	0,002
Ince-Aka,2012	1,790	0,260	0,067	1,281	2,299	6,894	0,000
Akti-Aslan,2019	3,532	0,386	0,149	2,775	4,289	9,142	0,000
Aysu,2019	2,675	0,342	0,117	2,005	3,345	7,824	0,000
Celik,2010	0,625	0,310	0,096	0,016	1,233	2,013	0,044
Gogus,2010	1,147	0,282	0,080	0,593	1,701	4,061	0,000
Guzel,2013a	0,395	0,315	0,099	-0,222	1,012	1,256	0,209
Guzel,2013b	-0,204	0,297	0,088	-0,785	0,378	-0,686	0,493
Nerse,2021	1,055	0,277	0,077	0,512	1,599	3,808	0,000
Ozturk,2019	0,625	0,268	0,072	0,099	1,150	2,330	0,020
Saglam,2022a	0,636	0,354	0,126	-0,059	1,330	1,794	0,073
Saglam,2022b	1,425	0,414	0,172	0,613	2,237	3,440	0,001
Sifoglu,2007	0,381	0,143	0,021	0,101	0,662	2,663	0,008
Sahin,2007	0,365	0,228	0,052	-0,082	0,812	1,602	0,109
Kartal-Kartal-Tasođlu,2015	0,526	0,289	0,084	-0,041	1,092	1,819	0,069
Hun,2017	1,558	0,356	0,126	0,861	2,254	4,381	0,000
Kacar,2012	3,021	0,428	0,183	2,182	3,861	7,056	0,000
Pakyurek-Karaaz,2008	1,678	0,358	0,128	0,976	2,380	4,687	0,000
Kizilkaya,2017a	0,731	0,277	0,077	0,188	1,275	2,637	0,008
Kizilkaya,2017b	0,872	0,279	0,078	0,326	1,418	3,129	0,002
Eyceyurt-Turk,2017a	1,015	0,216	0,046	0,593	1,438	4,712	0,000
Eyceyurt-Turk,2017b	-0,188	0,205	0,042	-0,590	0,215	-0,913	0,361
Eyceyurt-Turk,2017c	0,747	0,210	0,044	0,336	1,158	3,561	0,000
Eyceyurt-Turk,2017d	-1,033	0,218	0,048	-1,462	-0,605	-4,731	0,000
Yucel-Unal,2019	1,303	0,277	0,077	0,760	1,845	4,705	0,000
Yildirim,2011	0,609	0,282	0,080	0,055	1,162	2,156	0,031
Yildiz,2011	0,489	0,228	0,052	0,043	0,935	2,148	0,032
Yildiz,2017	0,802	0,282	0,079	0,250	1,354	2,847	0,004
Yilmaz,2016	0,506	0,244	0,059	0,028	0,983	2,075	0,038
Yurd,2007	1,354	0,222	0,049	0,919	1,788	6,111	0,000
	0,793	0,033	0,001	0,728	0,858	23,901	0,000

Figure 2: Forest plot of the effect sizes of the studies in the meta-analysis

on science academic achievement was in articles (1.130), doctoral theses (1.031), and master's theses (0.982). On the other hand, it has been found that the effect of PBL practices on science academic achievement was significant and in the negative direction in conference proceedings (Hedges's g = −0.136).

The Results of Research Question 4 (RQ4)

To search for an answer to "RQ4," the meta-analysis results conducted are depicted in Table 5. It gives the effect sizes, 95% confidence interval lower and upper limit scores, Q value, df, and *P* values about the effects of PBL on academic achievement in science subjects.

In Table 5, the results explain that PBL had high effect sizes on academic achievements in physics (1.069), biology (0.981), and chemistry (0.961). However, the heterogeneity test displays that the effect sizes of these three science areas exhibited a homogeneous distribution ($Q=0.263$; $P > 0.5$). In line with these results, it is possible to say that PBL instruction in the three science fields may have a similar or equal effect on academic achievement, regardless of the biology, physics, and chemistry subjects.

The Results of Research Question 5 (RQ5)

In Table 6, the meta-analysis results conducted are presented to search for an answer to "RQ5." It demonstrates the effect

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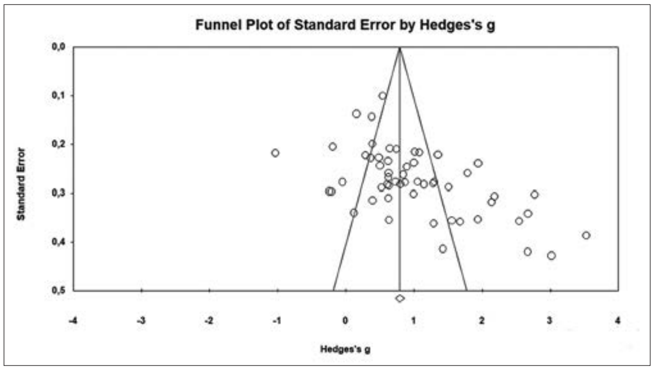

Figure 3: The funnel plot of standard error by Hedges's g

Table 3: Classic fail-safe *n*

Power of the meta-analysis	Coefficients
Z	26.29185
P	0.00*
Alpha value	0.05
Alpha value for the *Z*-value	1.96
n	55
P>the number of missing studies for the alpha result	9843

**P*-value is significant at 0.05 level

sizes of PBL applications on academic achievement in science subjects, 95% confidence interval lower and upper limit scores, Q value, df, and p values in terms of educational levels.

Table 6 shows that PBL applications at middle school (1.360), high school (1.074), and university (0.898) levels had a high effect size on science academic achievement. In contrast, the effect size of a study conducted at primary school (0.609) was medium. However, it is noteworthy that there was no significant difference in the effects of PBL on academic achievement in science between educational levels (Q=3.313; *P* > 0.5). Based on this result, it can be said that PBL applications in primary school, secondary school, high school, and university contribute equally or similarly to increasing academic achievement in science lessons.

The results of Research Question 6 (RQ6)

To search for an answer to "RQ6," meta-analysis results show that the effect sizes of PBL on academic achievement in science lessons in terms of the instructional variations with the PBL model are presented in Table 7.

Thinking-oriented PBL (0.951), paper-based PBL (1.665), pure PBL (0.950), technology-supported PBL (1.100), and constructive-supported PBL applications (1.267) had

Table 4: Effect sizes of studies included in meta-analysis by publication type

Model Random effects model	*n*	Hedges's g	95% confidence lower	95% confidence upper	Heterogeneity test (Q)	df	*P*-value
Conference proceedings	2	−0.136	−0.533	0.261	28.161	3	0.000
Article	21	1.130	0.837	1.423			
Master thesis	20	0.982	0.689	1.275			
Doctoral Dissertation	12	1.031	0.393	1.669			
Total between							

**P*-value is significant at 0.05 level (Field, 2018)

Table 5: Effect sizes of studies included in meta-analysis by science areas

Model Random effects model	*n*	Hedges's g	95% confidence lower	95% confidence upper	Heterogeneity test (Q)	SD	*P*-value
Biology	12	0.981	0.548	1.641	0.233	3	0.972
Physics	19	1.069	0.722	1.416			
Chemistry	22	0.961	0.635	1.288			
Unspecified	2	1.157	−0.864	3.214			
Total between							

**P*-value is significant at 0.05 level. SD: Standard deviation (Field, 2018)

Table 6: Effect sizes of studies included in meta-analysis by educational levels

Model Random effects model	*n*	Hedges's g	95% confidence lower	95% confidence upper	Heterogeneity test (Q)	SD	*P*-value
Elementary school	1	0.609	0.055	1.186	3.313	3	0.346
Middle school	33	1.007	0.760	1.255			
High school	6	1.360	0.734	1.986			
University	15	0.898	0.451	1.345			
Total between							

**P*-value is significant at 0.05 level. SD: Standard deviation (Field, 2018)

Table 7: Effect sizes of studies included in the meta-analysis by problem-based learning application method

Model Random effects model	*n*	Hedges's g	95% confidence lower	95% confidence upper	Heterogeneity test (Q)	SD	*P*-value
Thinking-oriented PBL	3	0.951	0.645	1.258	0.657	4	0.957
Paper-based PBL	2	1.665	−2.056	5.333			
Pure PBL	42	0.950	0.726	1.174			
Technology-supported PBL	4	1.100	0.239	1.961			
Constructivist-assisted PBL	4	1.267	0.346	2.188			
Total between							

**P*-value is significant at 0.05 level. PBL: Problem-based learning, SD: Standard deviation (Field, 2018)

Table 8: Effect sizes of studies included in meta-analysis by nationality of publication

Model Random effects model	*n*	Hedges's g	95% confidence lower	95% confidence upper	Heterogeneity test (Q)	df	*P*-value
National	48	1.044	0.827	1.261			
International	7	0.770	0.085	1.454			
Total between					0.562	1	0.454

**P*-value is significant at 0.05 level (Field, 2018)

high average effect sizes associated with science academic achievement. The results also show no significant difference between the studies included in the meta-analysis by instructional variations with PBL (Q=0.657; $P > 0.05$). Based on these results, the effects of PBL applications on science academic achievement would be close or similar to each other, regardless of pure PBL or thinking-oriented PBL, technology-supported PBL, paper-based PBL, and constructivist PBL applications.

The results of Research Question 7 (RQ7)

To search for an answer to "RQ7," the effect sizes of PBL applications on academic achievement in science subjects by the nationality of publication are presented in Table 8.

As shown in Table 8, the effect sizes of studies published in Turkey and abroad on the effects of PBL on academic achievement in science were 1.044 and 0.770, respectively. The results showed that the effect sizes of academic achievement scores in both study groups were high. However, the heterogeneity test results revealed no significant difference between the effect sizes of these two groups (Q=0.562; P > 0.05). Based on this result, it is possible to say that studies on PBL applications could increase academic achievement at a similar or similar level, whether they were conducted in Turkey or abroad.

DISCUSSION AND CONCLUSION

This meta-analysis study aimed to scrutinize the effects of PBL on academic achievement in science education compared to traditional instructional methods. The research results showed that the PBL method in science education had a high effect on academic achievement. In addition, meta-analysis results revealed that academic achievement scores in science courses did not change significantly in terms of nationality of the studies, the way the PBL was applied, the science areas, or educational levels. On the other hand, it was found that PBL in science education differed significantly by type of publication.

The most important result of this meta-analysis was that the PBL approach highly affects students' academic achievement in science lessons according to Cohen's (1988) effect size classification. In PBL, collaboratively participating in authentic scenarios triggers significantly students cognitively and activates their thinking processes. Students become more engaged with the problem since an unsolved problem related to an ill-structured scenario is exciting and attractive. In this context, during the problem process, students have the opportunity to exchange ideas with each other as a result of interaction, to question and research more about the subject area, to reflect on the ideas they find, to produce and refute hypotheses, and to put the significant hypotheses into practice (Magaji, 2021; Pitchayakorn et al., 2022; Toker and Akbay, 2022). In PBL, students' thinking processes are activated by incorporating scientific problem-solving steps to solve an unsolved problem in a scenario within a research community. This process allows students to have conceptual knowledge about the problem and the necessary scientific problem-solving skills to acquire conceptual knowledge (Akpur, 2021; Güner and Semirhan, 2021; Miterianifa et al., 2019). Therefore, it is possible to say that PBL increases greatly academic success in science as a constructivist, authentic, and student-centered approach. In three meta-analysis studies, which formed different studies in terms of time/year interval, discipline, and sample level, the total results of PBL applications on academic achievement at high level support the result of this study (Batdı, 2014; Dağyar and Demirel, 2015; Funa and Prudente, 2021).

One of the most remarkable results was that science academic achievements of thinking-oriented PBL, paper-based PBL, technology-supported PBL, constructivist PBL, and pure PBL practices were similar. Although there were no significant differences between subgroups, the effect sizes of paper-based PBL, constructivist-supported PBL, thinking-oriented PBL, and technology-supported PBL applications were higher than the effect sizes of studies in which only PBL was applied. Based on these results, PBL can be a more effective instructional strategy

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that has an impact on academic success in science lessons when PBL is integrated with technological tools, thinking-oriented methods, and contemporary constructivist approaches (Arıcı and Yılmaz, 2022; Eyceyurt-Türk, 2017; Fidan and Tuncel, 2019; Güzel, 2018; Kaçar, 2012; Nerse, 2021; Sağlam, 2022). Apart from these results, it can be said that PBL alone is an approach that increases academic success in science lessons at a high level (Kartal-Taşoğlu, 2015; Kızılkaya, 2017; Öztürk, 2019).

Another result showed no significant change in students' academic achievement in the science areas. From this result, it could be concluded that PBL is an inclusive and practical approach that shows similar effects on academic achievement within physics, chemistry, and biology in science education. Similarly, Dağyar and Demirel (2015) examined the effects of the PBL approach on academic achievement more holistically in terms of science education, social sciences, mathematics, health sciences, and computer sciences. They found that PBL practices in these disciplines have similar effects on increasing academic achievement. Batdı (2014) also uncovered that the studies in his meta-analysis did not differ significantly between the academic achievement scores of PBL studies in science (15), mathematics (6), and social (5). Likewise, Funa and Prudente's (2021) study revealed that PBL applications in high school physics, chemistry, and biology courses do not have a distinctive effect on academic achievement. Their result supports the conclusion that PBL has the same effects on academic achievement in the sub-branches mentioned in disciplines.

This meta-analysis results showed a significant difference between the effects of PBL on academic achievement in science by publication types. Based on this result, the rankings of effect sizes in publication types are research articles, doctoral theses, and master's theses, respectively. On the other hand, PBL applications in conference proceedings negatively affected academic achievement in science. Smith (1980) compared the effect sizes of publication type from eight meta-analyses and revealed that the effect sizes of published studies (e.g., research articles) were larger than those of unpublished studies (e.g., master and doctoral theses). Lipsey and Wilson (1993) claimed that this is because researchers are likely to publish large and statistically significant results, while journal editors and reviewers are likely to view this research more positively. Accordingly, this evidence and reasons support the conclusion that the effect sizes of research articles are larger than those found in theses.

One of the variables considered a moderator in this meta-analysis study was educational level. The moderator analysis results indicated that these differences were insignificant, although there were apparent differences among the effect sizes of subgroups. Yıldırım's (2011) study was included in the meta-analysis, especially at the primary school level. At least two studies must be found to calculate a meaningful effect size in a meta-analysis study (Borenstein et al., 2009). It may have prevented a significant difference between other educational levels. On the other hand, Dağyar and Demirel's (2015) meta-analysis revealed that educational level did not have a modifying effect of PBL in affecting science academic achievement. However, the meta-analysis study by Funa and Prudente (2021), which studied on high school students, displayed no significant differences in academic achievement in science, even between high school grade levels. The results of these two meta-analyses supported the result of the current meta-analysis study.

Limitations

This meta-analysis study is limited to the studies retrieved from the specified databases. Since the scope of the research is the studies included in science education, the studies in social sciences, medicine, and engineering sciences are excluded.

Suggestions

- In an experimental study, integrating innovative instructional approaches into PBL could guide researchers who establish a research problem about how it can affect academic achievement.
- Current instructional approaches and methods such as gamification, virtual and augmented reality, robotic coding, and STEM can be further integrated into PBL.
- Experimental studies on the effect of PBL on academic achievement at the primary school level can be published.
- Although PBL is a scenario-oriented model, out-of-school learning environments such as museums and science centers can be integrated into PBL in order to enable students to learn problems more authentically.

Ethical Statement

Only previously published data were used in this study. Therefore, ethical approval was not required.

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APPENDIX

Appendix A: The characteristics of studies included in the meta-analysis

Study name (Year)	Target group	Study size	Publication type	Science areas	PBL type
Tosun and Taskesenlioğlu, 2013	University	71	Article	Chemistry	Only PBL
Araz and Sungur, 2007	Middle school	217	Article	Biology	Only PBL
Williams et al., 1988a	Middle school	67	Conference paper	Biology	Technology-supported PBL
Williams et al., 1988b	Middle school	49	Conference paper	Biology	Paper-based
Baran, 2016	High school	56	Article	Chemistry	Only PBL
Üce and Ateş, 2016	High school	48	Article	Chemistry	Only PBL
Aidoo-Sampson et al., 2016	High school	102	Article	Chemistry	Only PBL
Horak and Galluzzo, 2017	Middle school	409	Article	Biology	Only PBL
Mandeville and Stoner, 2015	University	85	Article	Biology	Only PBL
Sungur et al., 2006	High school	61	Article	Biology	Only PBL
Akınoğlu and Özkardeş-Tandoğan, 2007	Middle school	50	Article	Physics	Only PBL
Dilek-Eren, 2011	University	46	PhD thesis	Physics	Only PBL
Keleş, 2015	Middle school	42	PhD thesis	Biology	Only PBL
Mungin, 2012	Middle school	33	PhD thesis	-	Only PBL
Kasuga et al., 2022	High school	80	Article	Biology	Only PBL
Bilgin et al., 2009	University	75	Article	Chemistry	Only PBL
Fidan and Tuncel, 2019a	Middle school	60	Article	Physics	Technology-supported PBL
Fidan and Tuncel, 2019b	Middle school	61	Article	Physics	Only PBL
Tarhan et al., 2008	High school	78	Article	Chemistry	Only PBL
Arıcı and Yılmaz, 2022a	Middle school	61	Article	Biology	Technology-supported PBL
Arıcı and Yılmaz, 2022b	Middle school	62	Article	Biology	Only PBL
Benli and Sarıkaya, 2012	University	67	Article	-	Only PBL
Aydoğdu, 2012	University	96	Article	Chemistry	Only PBL
Kılıç and Moralar, 2015	Middle school	36	Article	Chemistry	Only PBL
Şenocak et al., 2007	University	101	Article	Chemistry	Only PBL
Özeken and Yıldırım, 2011	University	95	Article	Chemistry	Only PBL
İnce-Aka, 2012	University	82	PhD thesis	Chemistry	Only PBL
Aktı-Aslan, 2019	Middle school	70	PhD thesis	Physics	Paper-based
Aysu, 2019	Middle school	64	Master thesis	Physics	Only PBL
Çelik, 2010	Middle school	42	Master thesis	Chemistry	Only PBL
Göğüş, 2010	Middle school	58	Master thesis	Physics	Only PBL
Güzel, 2018a	Middle school	40	Master thesis	Physics	Constructivist-assisted PBL
Güzel, 2018b	Middle school	44	Master thesis	Physics	Only PBL
Nerse, 2021	Middle school	58	Master thesis	Physics	Technology-supported PBL
Öztürk, 2019	Middle school	57	Master thesis	Physics	Only PBL
Sağlam, 2022a	Middle school	32	Master thesis	Physics	Only PBL
Sağlam,2022b	Middle school	28	Master thesis	Physics	Thinking-oriented PBL
Sifoğlu, 2007	Middle school	197	Master thesis	Biology	Only PBL
Şahin, 2011	University	77	Master thesis	Physics	Only PBL
Kartal-Taşoğlu, 2015	University	48	PhD thesis	Physics	Only PBL
Hun, 2017	Middle school	40	Master thesis	Chemistry	Only PBL
Kaçar, 2012	Middle school	46	Master thesis	Chemistry	Constructivist-assisted PBL
Pakyürek-Karaöz, 2008	Middle school	41	Master thesis	Physics	Only PBL
Kızılkaya, 2017a	Middle school	54	PhD thesis	Chemistry	Only PBL
Kızılkaya, 2017b	Middle school	55	PhD thesis	Chemistry	Only PBL
Eyceyurt-Türk, 2017a	University	96	PhD thesis	Chemistry	Thinking-oriented PBL
Eyceyurt-Türk, 2017b	University	94	PhD thesis	Chemistry	Only PBL
Eyceyurt-Türk, 2017c	University	96	PhD thesis	Chemistry	Thinking-oriented PBL
Eyceyurt-Türk, 2017d	University	94	PhD thesis	Chemistry	Only PBL
Yücel-Ünal, 2019	Middle school	62	Master thesis	Biology	Only PBL
Yıldırım, 2011	Primary school	51	Master thesis	Physics	Only PBL
Yıldız, 2010	Middle school	78	Master thesis	Chemistry	Constructivist-assisted PBL
Yıldız, 2017	Middle school	53	Master thesis	Chemistry	Only PBL
Yılmaz, 2016	Middle school	68	Master thesis	Physics	Only PBL
Yurd, 2007	Middle school	99	Master thesis	Physics	Constructivist-assisted PBL