International Journal of Instruction *October 2021 ● Vol.14, No.4*
e-ISSN: 1308-1470 ● www.e-iji.net *p-ISSN: 1694-609X*
pp. 69-84

Article submission code: 20201019055842
Received: 19/10/2020
Revision: 20/02/2021
Accepted: 17/03/2021
OnlineFirst: 08/07/2021

Effectiveness of Problem-Based Learning on Secondary Students' Achievement in Science: A Meta-Analysis

Aaron A. Funa
Science Education Department, De La Salle University-Manila, Philippines, *aaron_funa@dlsu.edu.ph*

Maricar S. Prudente
Science Education Department, De La Salle University-Manila, Philippines, *maricar.prudente@dlsu.edu.ph*

Preparing students for the real challenges in life is one of the most important goals in education. Constructivism is an approach that uses real-life experiences to construct knowledge. Problem-Based Learning (PBL), for almost five decades now, has been the most innovative constructivist pedagogy used worldwide. However, with the rising popularity, there is a need to revisit empirical studies regarding PBL to serve as a guide and basis for designing new studies, making institutional policies, and evaluating educational curricula. This need has led the researchers to do a meta-analysis to analyse the effectiveness of PBL on secondary students' achievement in different scientific disciplines. Following the set of inclusion and exclusion criteria, 11 studies in Eurasia, Africa, and America conducted from 2016 to 2020 have qualified for this study. Six of which focused on JHS (n = 1047) and five on SHS (n = 375). Studies were obtained from various meta-search engines including Google, ERIC, and JSTOR. Further, the researchers used Harzing's Publish and Perish software to exhaust the search process. Sample size, mean, and standard deviation were analysed using the Comprehensive Meta-Analysis version 3 to determine the effect sizes (Hedge's g) and the results of moderator analysis, forest plot, funnel plot, and Begg-Mazumdar test. Findings have shown that PBL, as an approach to teaching science, had a large and positive effect (ES = .871) on the achievement of secondary students. However, grade levels and various scientific disciplines did not influence students' learning achievement. The conduct of more studies on the different factors affecting PBL implementation and specific effects of PBL on various student domains is recommended to facilitate comparative educational research in the future.

Keywords: constructivism, effect size, meta-analysis method, problem-based learning, students' achievement, secondary students

Citation: Funa, A. A., & Prudente, M. S. (2021). Effectiveness of problem-based learning on secondary students' achievement in science: A meta-analysis. *International Journal of Instruction*, *14*(4), 69-84. https://doi.org/10.29333/iji.2021.1445a

INTRODUCTION

Teaching and learning science has evolved over time. The rampant sole improvement of essential skills, the 3Rs – Reading, 'Riting and 'Rithmetic, is, at present, insufficient to cope with the fast-changing world. The new era of education requires the sharpening of the 21st century skills, the 7C's, to wit: Critical thinking and problem solving; Creativity and innovation; Collaboration, teamwork, and leadership; Cross-cultural understanding; Communications, information, and media literacy; Computing and ICT literacy; and Career and learning self-reliance (Trilling & Fadel, 2009). These sets of skills help prepare students to grow with confidence, to succeed in this rapid transition, and to compete globally in the future. Hence, educators are encouraged to utilize one of the approaches in constructivism; that is, Problem-Based Learning (PBL).

PBL may improve students' achievement and hone their 21st century skills as it reflects modern insights to learning (Dolmans et al., 2005). It has been implemented for almost five decades now and still remain as one of the most innovative constructivist pedagogical approaches used worldwide. It prepares students for the real-life challenges that they may encounter in the future (Moallem et al., 2019). These real-life problems activate students' prior knowledge, elaborate initial discussion, and eventually elicit their interest of the situation. Thus, the use of PBL helps teachers to unveil students' previous knowledge through stimulating problems. Further, when a certain problem exhausts the ideas of students, it triggers their curiosity and initiates their information-seeking behavior (Litman, 2005). As they seek and organize relevant information, they close their own knowledge gaps that lead to understanding and learning new concepts (Rotgans & Schmidt, 2014), making them more self-reliant and responsible of their own learning (Moallem et al., 2019). As defined by Barrows (1996), PBL is a kind of instructional method wherein problem is at the heart of the instructional material that initiates students' learning. In PBL, the enigmatic nature of problem drives students' curiosity and learning. In solving problems, students work in groups to discuss and examine the problem; engender learning goals which will be subjected for further investigations; use learning goals to guide them in self-directed learning and in gathering data; and return to their group and analyze and synthesize the gathered information to come up with the best solution (Moallem et al., 2019). This process leads to the formulation of different teaching and learning approaches, to wit: Project-Based learning (PjBL), Learning by Design (LBD), Inquiry-Based Learning (IBL), and Design Thinking (DT).

The use of PBL in science education mirrors positive effects in improving students' achievements and critical thinking skills (Argaw et al., 2016; Awan et al., 2017; Lisniandila et al., 2018). However, with the growing popularity of PBL, there is a need to summarize studies pertaining to its use in teaching and learning to identify its effectiveness in different grade levels and scientific disciplines. Meta-analysis is utilized to synthesize available evidences for a given question in order to serve as a roadmap of relevant researches, basis for designing new studies, and guide for making institutional policies and educational curricula (Borenstein et al., 2011). In view of that, the researchers utilized meta-analysis to analyze and examine the effectiveness of PBL particularly on secondary students' achievements in science. To the knowledge of the researchers, there has been a need of meta-analysis on PBL that covers the last five years focusing specifically on secondary students' achievements in science. Accordingly, the purpose of this study was to provide analysis of empirical research and valuable information on the secondary students' achievements using PBL along with the investigation of the different PBL approaches used in teaching and learning. Specifically, the researchers aimed to answer the following questions:

1. How effective is the use of PBL approach in secondary students' achievement in science?

2. Is there a significant difference between the effect sizes of junior high school and senior high school in relation to their learning achievement using PBL in science?

3. Is there a significant difference between the effect sizes in students' achievements in relation to the scientific disciplines?

4. What were the PBL teaching strategies that have been investigated?

METHOD

Research Design

The researchers utilized the meta-analysis research design to explore whether PBL is effective on enhancing secondary students' achievements and identify the differences between variables including grade levels and different fields of science. Meta-analysis is a core movement to systematically synthesize the quantitative results from a collection of evidence-based knowledge depending on the purpose of the study and data that are available (Borenstein et al., 2011).

Study Search Procedure

Prior to searching peer-reviewed online journal articles, the researchers set the criteria for inclusion and exclusion in this meta-analysis. Various meta-search engines were used to gather journal articles including Google, Google Scholar, Education Resources Information Center (ERIC), and Journal Storage (JSTOR). In addition, the researchers used the software program Publish or Perish (Harzing, 2007) to find lists of journal articles and analyze academic citations. The search was purposely delimited to 2016 up to the third quarter of 2020. Further, the descriptors entered in meta-search engines were as follows: problem-based learning, effect of problem-based, problem-based learning in science, secondary students, and students' achievement. These words were put randomly and interchangeably in the meta-search engine with the persistent use of the word "problem-based learning" or "problem based learning" until studies were exhausted.

Inclusion and Exclusion Criteria

Research articles relevant to the context of this study utilizing quantitative research design from 2016 up to the third quarter of 2020 were investigated. Specifically, inclusion criteria protocol has set in selecting journal articles, to wit: (a) must be a research article from a peer-reviewed journal published from 2016 up to the third quarter of 2020; (b) must include an explicit reference to problem-based learning in its title or abstract; (c) must use student academic achievement as dependent variable; (d) must be at the middle or upper secondary level; (e) must utilize quasi-experimental design; (f) must focus on scientific disciplines such as Biology, Chemistry, Earth Science, and Physics; (g) must provide sufficient quantitative data to allow effect size computations. Collected journal articles were filtered with the given inclusion criteria. Figure 1 shows the flow of the search process using PRISMA search strategy diagram.

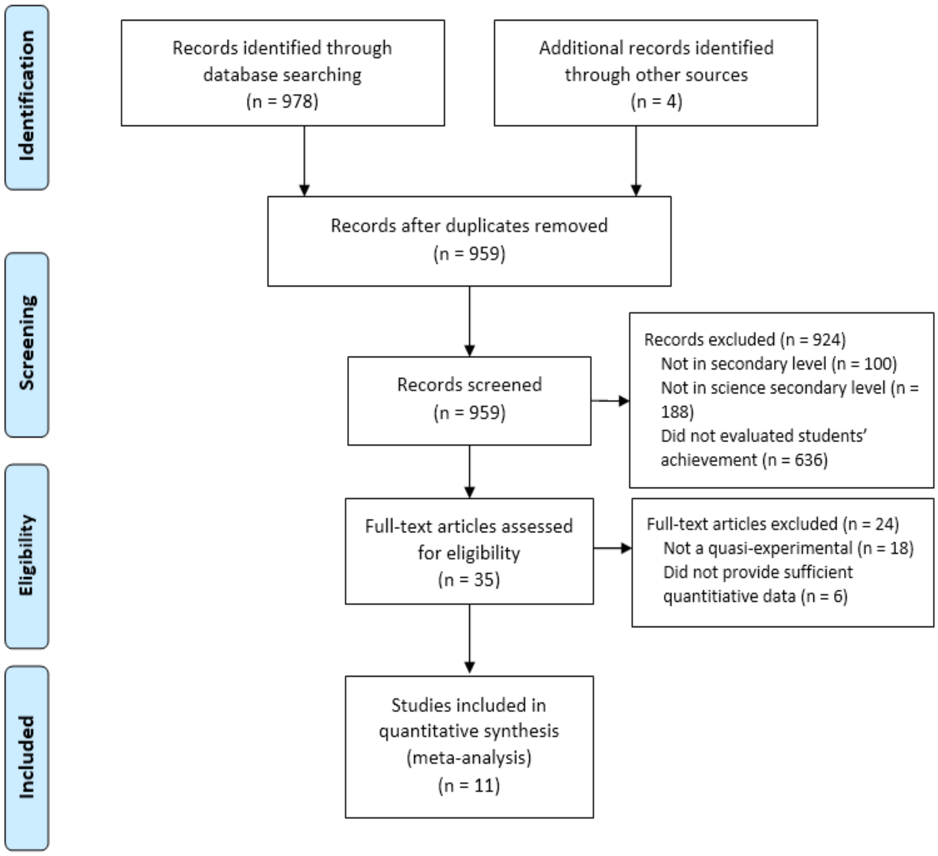

Figure 1
PRISMA search strategy for the effectiveness of PBL in science

There were 982 studies pertaining to PBL screened for this meta-analysis. Subsequently, only 11 articles qualified. These studies were conducted in Africa (n = 2), America (n = 1), and Eurasia (n = 8). The major reason for the miniscule number of qualified articles was that some of the gathered articles did not meet the set inclusion criteria and lacked the necessary statistical information.

Coding Procedures

Collected data from the qualified journal articles were coded using the following: (a) study identification (author's last name and year of publication); (b) students' grade level; (c) scientific discipline explored; (d) databases; (e) control/comparison condition; (f) instrument used; and (g) outcome measure characteristics (sample size, mean, and standard deviation).

Effect Size Calculation

The effect size has been widely utilized to determine standardized mean differences. In this study, the researchers used Hedge's *g* to compute for the effect sizes of the data collected. Hedge's *g* is more accurate than Cohen's *d*, most especially when sample sizes are very small (< 20) (Glen, 2016; Hedges & Olkin, 1985). Data obtained were interpreted using the values .8, .5, and .2 with descriptions of large, medium, and small effects sizes, respectively (Cohen, 1988). In analyzing the data statistically, the researchers utilized the Comprehensive Meta-Analysis (CMA) Version 3 developed by Biostat, Inc. Using this software program, moderator analysis was carried out and utilized in grouping and comparing the data along with the identification of other necessary statistics like effect sizes (fixed and random), heterogeneity, and forest plot. Further, it is recommended that the test for funnel plot asymmetry be used for at least 10 studies (Harbord et al., 2009). This recommendation led the researchers to use the aforementioned software in creating a funnel plot to illustrate the publication bias in the pooled studies. Egger's test is the most widely used approach to test funnel plot asymmetry. However, only 11 studies were obtained in this research and Egger's test may report false positive results in small number of studies (Harbord et al., 2009). As a result, the researchers decided to use the Begg-Mazumdar (Begg & Mazumdar, 1994) test instead. Begg-Mazumdar test was used to calculate for the p-value. If the p-value is less than .05, there will be a publication bias.

FINDINGS

A sample size of 1422 secondary students (junior high school and senior high school) from the 11 qualified empirical research was identified to be included in this meta-analysis. Table 1 presents the frequency of studies along with the students' grade levels and various scientific disciplines.

Table 1
Number of students' grade level and scientific discipline studied

Level	Frequency	Percentage
Junior High School (JHS)	6	55%
Senior High School (SHS)	5	45%
Scientific Discipline		
Biology	3	27.3%
Chemistry	3	27.3%
Environmental Science	2	18.2%
Physics	2	18.2%
Science and Technology	1	9.1%
TOTAL	11	100%

As shown in Table 1, six of the studies obtained from 2016 to 2020 used junior high school (JHS) students (n = 1047) and the other five used senior high school (SHS) students (n = 375) as respondents. PBL is closely associated with self-directed learning (SDL). Studies suggest that SDL can be more effective when utilized for adult learners (Knowles et al., 1998; Linderman, 1926). However, SDL is only an outcome of PBL (Moallem et al., 2019). The result showed that studies on PBL were not only focused on adult learners, signifying that PBL is also widely used in secondary education, both in JHS and in SHS. Table 1 depicts the use of PBL distributed in different fields of science including Biology, Physics, Chemistry, Environmental Science, and Science and Technology, indicating that PBL is extensively used as an approach in teaching various science disciplines. PBL, as an approach to solving problems, first emerged in medical science which was utilized to explain various cases on the field. However, PBL is now being used in science education to hone students' abilities in solving real-life problems (Moallem et al., 2019). Table 2 displays the overall effect size (ES) of the collected studies and other integral values including the number of studies (k), standard error (SE), variance, confidence intervals (CI), Z-value, p-value, and heterogeneity.

Table 2
Overall effect size

					95% CI				Heterogeneity			
	k	ES	SE	Variance	Lower	Upper	Z	p	Q	df (Q)	p	I2
Fixed	11	0.647	0.055	0.003	0.540	0.755	11.810	0.000	63.072	10	0.000	84.145
Random	11	0.871	0.152	0.023	0.572	1.170	5.716	0.000				

As shown in Table 2, the computed Q statistic (Q > df) and p-value ($p < .05$) reflect significant heterogeneity which indicate that studies obtained in this meta-analysis do not share common effect sizes. This result implies that the distribution of the effect sizes is significantly heterogeneous, denoting that the appropriate method to synthesize the studies in this meta-analysis is the random-effect method (Borrenstein et al., 2009). Moreover, the use of PBL in student learning achievement has a significantly large and positive effect as determined by the overall weighted random effect size of .871. Further, I2 obtained a high score of 84.145 suggesting that moderator or subgroup analysis is worthwhile (Borrenstein et al.). In order to show the distribution of effect sizes, Figure 2 presents the forest plot along with detailed analysis of each meta-analyzed studies that provides context for the analysis.

Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Suhirman et al. (2020)	0.957	0.252	0.063	0.464	1.451	3.804	0.000
Ural et al. (2020)	0.690	0.279	0.078	0.143	1.236	2.473	0.013
Malmia et al. (2019)	0.649	0.262	0.068	0.137	1.162	2.482	0.013
Priyadi et al.(2019)	2.194	0.358	0.128	1.493	2.896	6.129	0.000
Lisniandila et al. (2018)	0.809	0.252	0.063	0.316	1.302	3.216	0.001
Arahmat et al. (2017)	0.774	0.259	0.067	0.267	1.282	2.990	0.003
Argaw et al. (2017)	0.729	0.227	0.052	0.283	1.175	3.204	0.001
Awan et al. (2017)	0.447	0.254	0.064	-0.050	0.944	1.764	0.078
Horak et al. (2017)	0.536	0.096	0.009	0.347	0.725	5.571	0.000
Aidoo et al. (2016)	1.945	0.239	0.057	1.476	2.413	8.133	0.000
Balim et al. (2016)	0.304	0.105	0.011	0.098	0.510	2.898	0.004
	0.647	0.055	0.003	0.540	0.755	11.810	0.000

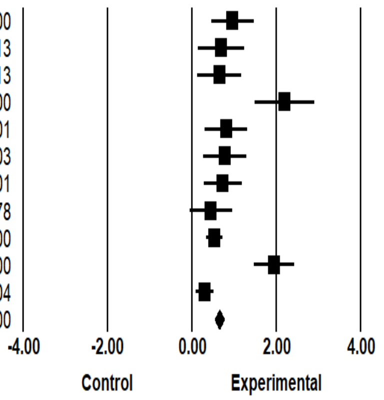

Figure 2
Forest plot of the meta-analysis results of the 11 included empirical studies

As shown in the forest plot, the overall distribution of effect sizes favored the experimental (with PBL) group over the control (non-PBL) group. The studies of Horak and Galluzo (2017) and Balim et al. (2016) played a major role in this research as represented by the shorter confidence interval. In order to verify the obtained effect of PBL of which the studies strongly favor the experimental group, Classic Fail-Safe N analysis was applied. Table 3 shows the result of this analysis.

Table 3
Classic fail-safe N

The Resistance of the Meta-Analysis versus Publication Bias	
Z-value	12.864
p-value	0.000
Alpha value	0.050
Alpha value for the Z-value	1.960
N	11
Number of missing studies that would bring p-value to > alpha	463

From the result of Classic Fail-Safe N analysis in Table 3, the meta-analysis of 11 empirical studies is valid ($p < .05$) and resistant to publication bias. To invalidate the result of meta-analysis, 463 more studies are needed. This outcome was supported by the funnel plot and Begg-Mazumdar test shown in Figure 2 and Table 4.

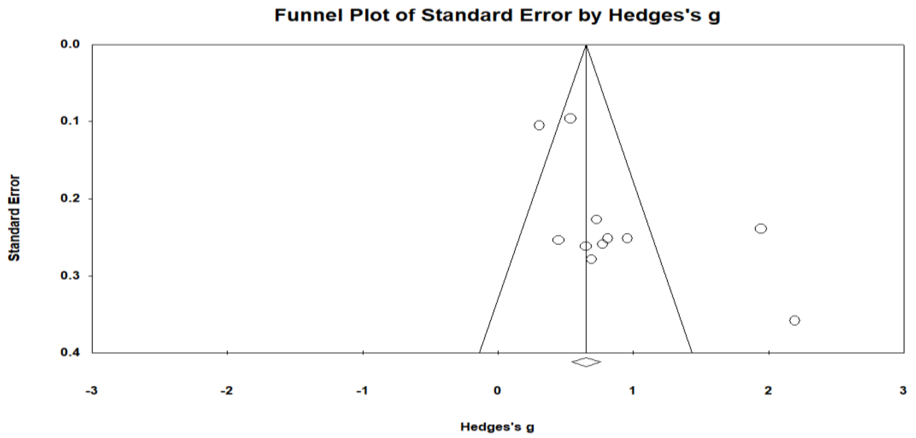

Figure 2
Funnel plot showing publication bias status of obtained studies

Table 4
Publication bias status of sample studies

Publication Bias	
Kendall's S (P-Q)	11
Kendall's tau	0.200
Tau for z-value	0.856
P	0.196

As shown in Figure 2, the funnel plot illustrated three outliers among the studies included in this meta-analysis which account for its asymmetry. However, the Begg-Mazumdar test result yields a p-value of .196 ($p > .05$) which signifies that there is no publication bias among studies. Funnel plot asymmetry is not a guaranteed test for publication bias, most especially for small studies (Harbord et al., 2009). Instead, it should be an approach to evaluating small study effects in general (Lin et al., 2018). To determine the significant difference of effect sizes between groups (grade levels and scientific disciplines), a moderator analysis was performed and is presented in Table 5.

Table 5
Moderator analysis of secondary students' grade level and scientific discipline studied

Moderator Random Effects Model	k	ES	SE	Variance	95% CI Lower	Upper	Z	p	Heterogeneity* Q	df (Q)	p
Level of Education	11	0.865	0.142	0.020	0.587	1.142	6.111	0.000	0.904	1	0.342
JHS	6	0.745	0.190	0.036	0.373	1.116	3.925	0.000			
SHS	5	1.015	0.212	0.045	0.599	1.432	4.780	0.000			
Scientific Discipline	11	0.855	0.219	0.048	0.426	1.285	3.901	0.000	3.021	4	0.554
Biology	3	1.262	0.350	0.123	0.575	1.948	3.600	0.000			
Chemistry	3	1.022	0.340	0.116	0.355	1.689	3.001	0.003			
Environmental Science	2	0.605	0.403	0.162	-0.184	1.394	1.502	0.133			
Physics	2	0.768	0.413	0.171	-0.042	1.579	1.858	0.063			
Science and Technology	1	0.304	0.544	0.295	-0.761	1.370	0.560	0.576			

*Total between was provided under heterogeneity to determine how accurate is the publication status variable in explaining total variance

Table 5 presents the moderator analysis performed to identify the significant difference of effect sizes between the students' achievements according to their grade levels and scientific disciplines wherein PBL was implemented. On one hand, looking at the level of education, both JHS and SHS obtained a large and positive effect sizes of .745 and 1.015, respectively, illustrating that the use of PBL had positive and large effect size on improving secondary students' level of achievement. However, PBL, as applied to SHS, had a larger effect size than applied in JHS. This finding is parallel with the studies claiming that PBL is more effective for adult learners (Knowles et al., 1998; Linderman, 1926). In addition, the heterogeneity results ($Q < df$; and $p > .05$) showed no significant difference which demonstrate that the JHS and the SHS share common effect sizes. This finding indicates that the effect of PBL on students' achievements when compared with conventional method does not vary according to educational level. On the other hand, analyzing the result of scientific disciplines, Biology, Chemistry and Physics obtained large effect sizes of 1.262, 1.022, and .768, respectively. Further, Environmental Science obtained a medium effect size of .605 and Science and Technology obtained a small effect size of .304. The overall effect size for scientific discipline obtained a large effect size of .855. The heterogeneity between scientific fields ($p > .05$) showed no significant effects signifying that PBL as applied to different scientific disciplines may share common effect sizes. This finding demonstrated that the different scientific disciplines where PBL was applied were not included among the factors affecting students' achievements. Although the grade levels and the scientific disciplines shared common effect sizes, the researchers investigated the different teaching strategies where PBL was applied. Table 6 presents the different PBL strategies employed.

Table 6
PBL strategies utilized by obtained studies

PBL Teaching Strategies	Frequency	Percentage
Collaborative	11	100%
Probing Questions during Lecture	11	100%
Choice on how to solve the problem	11	100%
Qualitative problem solving (essay)	10	91%
Quantitative problem solving	2	18%
Reflection	1	9%
Concept Cartoon Integration	1	9%
Mind Mapping Technique	1	9%

As shown in Table 6, the most used PBL teaching strategies are probing questions during lecture; collaboration among students; giving students the freedom to choose their own way of solving the problem; and problem solving in essay form. In contrary, the least used are quantitative problem solving, reflection, concept cartoon integration, and mind mapping technique. Analyzing the methodology of the studies collected, ICT, multimedia and graphic organizers were integrated during the lecture and the organization, development, and presentation of students' investigation results.

DISCUSSION

Problem-Based Learning (PBL) is a widely used constructivist pedagogical approach in science education. Studies have shown that the use of PBL is an effective tool to enhance students' academic performance and 21st century skills. However, in the last five decades of its utilization up to now, there has been a need to update and analyze studies pertaining to its effectiveness. As such, the researchers used meta-analysis to evaluate the effectiveness of PBL as an approach in science teaching in enhancing students' learning achievements.

The result of the study showed that PBL is widely used in secondary students including JHS and SHS and in different disciplines of science. The meta-analysis of the 11 empirical studies obtained from 2016 to 2020 involving 1422 secondary students yielded an overall effect size of .871 which denotes a large and positive effect. This result implies that the use of PBL is generally effective in increasing secondary students' level of achievement in science, thereby supporting the findings that PBL is more effective than the conventional method in developing students' lifelong learning skills (Dolmans & Schmidt, 1996). In contrary, this result disputed the findings that the knowledge acquisition in PBL is as good as knowledge acquisition in conventional teaching setting (Clouston et al., 2010; Colliver, 2000). In this case, it is recommended that PBL be used as a supplemental approach to the existing teaching methods and strategies in science.

Analyzing each study involved, the study of Priyadi and Suyanto (2019), Aidoo et al. (2016), Suhirman et al. (2020)., and Lisniandila et al. (2018) obtained large effect sizes of 2.194, 1.945, .957 and .809, respectively. On the other hand, the study of Arahmat et al. (2017), Argaw et al. (2017), Ural and Dadli (2020), Malmia et al. (2019), Horak et al. (2017), Awan et al. (2017), and Balim et al. (2016) obtained medium effect sizes of .774, .729, .690 .649, .536, .447, and .304, respectively. The overall effect size (ES = .871) is large and positive which indicates that PBL is effective as an approach in teaching. Further, the result of meta-analysis favors the experimental side ($p < .001$) signifying that PBL is more effective than the conventional method of teaching science. The miniscule number of selected studies and the presence of variability on effect sizes in scientific discipline have led the researchers to analyze the publication bias. Asymmetry could be seen on the funnel plot due to the outliers which signaled the researchers to use the Begg-Mazumdar test to check further the presence of publication bias. The Begg-Mazumdar test result generated a p-value of .196 ($p > .05$) which indicates that the meta-analysis had no publication bias. This result may support the argument that, in general, the application of PBL in teaching high school science is effective than the conventional method.

The I2 value is large (I2 = 84.145) signifying the need to perform a subgroup or moderator analysis (Borrenstein et al., 2009). Using moderator analysis, the effectiveness of PBL between grade levels and between scientific disciplines was examined. PBL applied in JHS and SHS obtained large effect sizes of .745 and 1.015, respectively. Combining their effect sizes, the JHS and the SHS obtained .865 indicating a large and positive effect. Looking closely at the results, the effect size obtained in SHS is larger than in JHS. PBL is said to be more effective in adult learners because adult learners have the following characteristics: self-concept, prior experience, readiness to learn, orientation to learning, and motivation to learning (Knowles et al., 1998). In addition, adult learners have the capacity to identify what imperative knowledge of interest they lack to individually fill the gap (Linderman, 1926). These adult characteristics have been found essential in doing PBL. Although PBL is best suited for adults, the result of this meta-analysis showed that PBL is also effective for JHS. Further, heterogeneity showed no significant value implying that JHS and SHS may share common effect sizes. This result indicates that the use of PBL is effective whether the student is in JHS or in SHS. However, precaution of its use is needed. It is recommended that in the application of PBL approach in science teaching, the presence of teacher as guide, tutor, and facilitator is integral. Further, it is suggested that future studies may venture into the teachers' capacity to implement PBL approach in their respective classes.

PBL, as applied in Biology, Chemistry and Physics, obtained large effect sizes of 1.262, 1.022, and .768, respectively. However, PBL as applied in Environmental Science and Science and Technology obtained medium effect sizes of .768 and .304, respectively. Combining the results of the different scientific disciplines, the overall effect size is found to be 0.855 which signifies that the effect of PBL on students' achievement as applied in different scientific disciplines is large. Further, the heterogeneity result is .554 ($p > .05$) indicating that the different fields of science where PBL was applied compared with the conventional method were not included among the factors that affect students' achievement. These results showed that the use of PBL approach in different scientific disciplines is generally effective for secondary students as compared with the conventional method. However, it was found out that the different grade levels and scientific disciplines where PBL was applied were not among the factors affecting students' achievement. Consequently, it is recommended that more studies on the factors affecting students' achievement as an outcome of PBL implementation be pursued.

The researchers investigated the different strategies used by the aggregated studies in the application of PBL approach. Most of the studies used collaboration (100%), probing questions during lecture (100%), giving the students freedom to choose different ways to solve the problem (100%), and qualitative problem solving in an essay format (91%). These strategies were included in the core elements of incorporating PBL in teaching. The best known and widely used process of PBL is the Maastricht Seven Step Model (Clouston et al., 2010), to wit: step 1, clarifying the text and explaining unclear terms and concepts; step 2, defining the key problem; step 3, analyzing the problem and suggesting possible solutions; step 4, elaborating, testing, reviewing, and refining; step 5, formulating learning objectives; step 6, self-study; and step 7, integrating and testing new information (Schmidt, 1983). Most of the studies obtained in this meta-analysis used the processes stated in the Maastricht Seven Step Model along with abovementioned identified strategies. However, the reflexive part of the PBL among students was not given emphasis by the analyzed studies. This omission may be due to the research design used by the studies obtained which is quasi-experimental design that is focused on the quantitative aspect of PBL's effectiveness. Self-assessment and collaborative reflection alongside teachers' evaluation are important parts of PBL to evaluate students' learning (Clouston et al., 2010). Thus, it is recommended that emphasis on self and collaborative reflection may be included in future researches to evaluate students' own learning and progress. PBL, as an approach to teaching, can enhance the motivation of students as well (Awan et al., 2017). On the contrary, Argaw et al. (2016) concluded that PBL may fail to improve students' motivation due to various factors which implies that factors need to be identified in order to address some issues regarding the use of PBL. It is suggested that, in order to enhance the capacity of the PBL approach, different strategies be employed as supplements and evaluation of learning be not limited only to students' academic performance or achievement but also to different factors that holistically affect students. Moreover, future researchers may venture into the study of the effect of PBL on students' affective domains.

CONCLUSION AND RECOMMENDATIONS

The researchers reviewed a total of 11 empirical studies from 2016 to 2020 that qualified to the set inclusion criteria. This research is aimed to investigate the effectiveness of PBL on teaching science in secondary students' achievements. Based on the latest statistical data, it could be concluded that PBL is an effective teaching approach (ES = .871) as applied to different scientific disciplines for secondary students, both JHS and SHS. However, PBL has its own limitations that may hinder meaningful utilization; most especially its application in enhancing academic performance of younger students. As a result, the role of the teachers as facilitator and tutor is imperative. Further, teachers need to understand that students learn in different ways. It is suggested that in order to target particular skills to be developed, teachers may use different teaching strategies combined with PBL. In addition, the findings showed that grade level and scientific discipline in PBL group have no effect on students' achievement. Therefore, it is recommended that more empirical studies on the use of PBL in science education are still needed to facilitate meta-analysis, dwelling on various effects and specific factors affecting students' achievements. Moreover, the development of teachers' skills in the delivery of PBL approaches and strategies is integral, as well as the integration of PBL with the newly emerged and innovative teaching strategies. Teachers and students have different life experiences resulting to different ways of solving problems. Indeed, PBL is one of the constructivist instruments in education to help students hone their skills and prepare them for the real challenges in life.

LIMITATIONS

The discussion of the limitations of this meta-analysis is important prior to the presentation of conclusion and recommendations. The researchers have chosen the studies based on inclusion and exclusion criteria which may be subjected to selection bias. Included in the inclusion criteria is that the study must be from a peer-reviewed journal and all the articles chosen were published online. These published studies may report only statistically significant results (Glass, 1976). Consequently, this assumption led the researchers to employ the Begg-Mazumdar test for publication bias. In addition, although the researchers exhausted all the resources, it reached saturation where the number of studies obtained for this meta-analysis is small that statistical tools for publication bias may report false positive results. However, Harbord et al. (2009) inferred that the use of statistical tools to determine publication bias may be started with at least 10 studies. In this case, the researchers obtained 11 empirical studies indicating its suitability to use statistical analysis for publication bias. The pooled studies came from different countries, to wit: Indonesia (5), Africa (1), America (1), Ethiopia (1), Malaysia (1), Pakistan (1), and Turkey (1). Further, this study is delimited to the results provided by the pooled studies, which aimed to analyze the effectiveness of PBL in secondary student's achievement in science compared with the traditional teaching methods. These studies used quasi-experimental design wherein the PBL was used in the experimental group and the traditional method was used in the control group.

ACKNOWLEDGEMENT

The authors would like to express their sincerest gratitude to the Department of Science and Technology - Science Education Institute (DOST-SEI) through the Capacity Building Program in Science and Mathematics Education (CBPSME) for the support given in this study.

REFERENCES

Aidoo, B., Boateng, S. K., Kissi, P. S., & Ofori, I. (2016). Effect of Problem-Based Learning on Students' Achievement in Chemistry. *Journal of Education and Practice*, *7*(33), 103-108.

Arahmat, Y., Suratno, S., & Wahono, B. (2017). The effect of problem based learning model with mind mapping technique on biology learning achievement. *Pancaran Pendidikan*, *6*(2), 125-132.

Argaw, A. S., Haile, B. B., Ayalew, B. T., & Kuma, S. G. (2016). The effect of problem based learning (PBL) instruction on students' motivation and problem solving skills of physics. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(3), 857-871.

Awan, R. N., Hussain, H., & Anwar, N. (2017). Effects of problem-based learning on students' critical thinking skills, attitudes towards learning and achievement. *Journal of Educational Research*, *20*(2), 28-41.

Balim, A. G., İnel-Ekici, D., & Özcan, E. (2016). Concept Cartoons Supported Problem Based Learning Method in Middle School Science Classrooms. *Journal of Education and Learning*, *5*(2), 272-284.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New directions for teaching and learning*, *1996*(28), 3-12. https://doi.org/10.1002/tl.37219966804

Begg, C. B., and Mazumdar, M. (1994). Operating characteristics of a rank correlation test for publication bias. *Biometrics, 50*(4),1088-1101.

Borenstein, M., Hedges, L., Higgins, J., & Rothstein, H. (2013). Comprehensive Meta-Analysis (Version 3) [computer software]. 2019. Englewood, NJ: Biostat 2013.

Borenstein, M., Hedges, L., Higgins, J. P., & Rothstein, H. R. (2009). *Introduction to meta-analysis.* John Wiley & Sons.

Clouston, T. J., Westcott, L., Whitcombe, S. W., Riley, J., & Matheson, R. (Eds.). (2010). *Problem-based learning in health and social care.* Chichester: Wiley-Blackwell.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ:Erlbaum.

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: research and theory. *Academic medicine, 75*(3), 259-266.

Dolmans, D. H., De Grave, W., Wolfhagen, I. H., & Van Der Vleuten, C. P. (2005). Problem-based learning: Future challenges for educational practice and research. *Medical education*, *39*(7), 732-741.

Dolmans, D. H. J. M., & Schmidt, H. (1996). The advantages of problem-based curricula. *Postgraduate Medical Journal*, *72*(851), 535-538.

Glass, G. V. (1976). Primary, secondary and meta-analysis. *Educational Researcher, 5,* 3-8.

Glen, S. (2016). Hedges' *g*: Definition, Formula. *Statistics_How_To.com: Elementary Statistics for the rest of us*, Retrieved 01 October, 2020 from http://www.statisticshowto.com/hedges-g/

Harbord, R. M., Harris, R. J., & Sterne, J. A. (2009). Updated tests for small-study effects in meta-analyses. *The Stata Journal, 9*(2), 197-210.

Harzing, A. W. (2007). Publish or perish software. Available from https://harzing.com/resources/publish-or-perish.

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. San Diego, CA: Academic Press.

Horak, A. K., & Galluzzo, G. R. (2017). Gifted middle school students' achievement and perceptions of science classroom quality during problem-based learning. *Journal of Advanced Academics*, *28*(1), 28-50.

Hussain, H., & Anwar, N. (2017). Effects of problem based learning on students' critical thinking skills, attitudes towards learning and achievement. *Journal of Educational Research, 20*(2), 28-41.

Knowles, M., Holton, E., & Swanson, R. (1998). *The Adult Learner*; The Definitive in Adult Education and Human Resource Development, 6th edn. Elsevier, London.

Lin, L., Chu, H., Murad, M. H., Hong, C., Qu, Z., Cole, S. R., & Chen, Y. (2018). Empirical comparison of publication bias tests in meta-analysis. *Journal of general internal medicine, 33*(8), 1260-1267.

Linderman, E. C. (1926). *The Meaning of Adult Education.* Republic Inc, New York, NY.

Lisniandila N. P. A., Santyasa, I. W., & Suswandi, I. (2018). The Effect of Problem Based Learning Teaching Method on Students' Critical Thinking Skills in Physics Lesson at SMA Negeri 4 Singaraja. *JPP (Jurnal Pendidikan dan Pembelajaran), 25*(1), 16-24.

Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition & emotion, 19*(6) 793-814.

Malmia, W., Makatita, S. H., Lisaholit, S., Azwan, A., Magfirah, I., Tinggapi, H., & Umanailo, M. C. B. (2019). Problem-based learning as an effort to improve student learning outcomes. *Int. J. Sci. Technol. Res*, *8*(9), 1140-1143.

Moallem, M., Hung, W., & Dabbagh, N. (Eds.). (2019). *The Wiley handbook of problem-based learning.* Wiley Blackwell.

Moher D., Liberati A., Tetzlaff J., Altman D. G., The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

Priyadi, A. A., & Suyanto, S. (2019, December). The Effectiveness of Problem Based Learning in Biology with Fishbone Diagram on Critical Thinking Skill of Senior High School Students. In *Journal of Physics: Conference Series* (Vol. 1397, No. 1, p. 012047). IOP Publishing.

Rotgans, J. I., & Schimdt, H. G. (2014). Situational interest and learning: Thirst for knowledge. *Learning and Instruction, 32,* 37-50.

Schmidt, H. G. (1983). Problem based learning: rationale and descritption. *Medical Education.* 17, 11-16.

Suhirman, S., Yusuf, Y., Muliadi, A., & Prayogi, S. (2020). The Effect of Problem-based Learning with Character Emphasis toward Students' Higher-Order Thinking Skills and Characters. *International Journal of Emerging Technologies in Learning (iJET), 15*(06), 183-191.

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times.* John Wiley & Sons.

Ural, E., & Dadli, G. (2020). The effect of problem-based learning on 7th-grade students' environmental knowledge, attitudes, and reflective thinking skills in environmental education. *Journal of Education in Science, Environment and Health (JESEH), 6*(2), 177-192.DOI:10.21891/jeseh.705145.