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The Analysis of Effect Size of the PBL Model on Science Competence of High School Students

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Abstract

This study aimed to describe a problem-based learning model (PBL) that had succeeded in increasing the competence of high school students. The research method used meta-analysis. The research process included determining research topics, determining data selection criteria, searching for literature, grouping data information, interpreting data, and drawing conclusions. The database was articles published in Scopus-indexed journals and accredited by SINTA. The articles analyzed were articles published in the last 5 years, namely in 2017-2021. 25 articles met the criteria for further analysis. The data analysis technique used an effect size. Effect size values were measured and grouped by subject, grade level, and type of student competency. The results showed that based on the type of science subjects, the PBL model was more widely applied to physics and chemistry subjects compared to biology subjects. The effect size results fell into the medium to very high category. Based on grade level, PBL was effectively used for class XI with high criteria. From this research, it was also known that the critical thinking, problem-solving, and cognitive aspects of students had a high effect size by applying the PBL model. Therefore, the PBL model was effectively applied in science learning in high schools.

1. INTRODUCTION

Education in the 21st century has undergone significant changes, from teacher-centered to student-centered learning, individual to group-based learning, one-way to interactive learning, abstract to dialogue, isolation to network environments, transition to active interaction, informational to analytical, and knowledge transfer to knowledge delivery. Learning activities must alter to emphasize student participation and active engagement as a result of changes in educational patterns. Students must have 21st-century skills to succeed. Critical thinking, problem-solving, collaboration, and communication are examples of such abilities (Miterianifa et al., 2019; Rotherham & Willingham, 2009; Roza, 2018).

Science is knowledge acquired through a series of processes carried out systematically by humans to explain nature. Studying science not only provides students with some concepts that must be hammered but emphasizes the delivery of hands-on experience. Science learning using the right model can improve learning outcomes and develop the competencies required in the 21st century. Indonesian students' science learning outcomes are relatively low compared to other countries' science learning outcomes. PISA data in 2018 stated that the science ability score again decreases to 396, whereas 40 percent of Indonesian students are still below the minimum expected ability. One learning model that can be used to overcome this issue is Problem Based Learning (PBL) (Aditomo & Felicia, 2018; Carin & Sund, 1989; PISA, 2019).

Some studies have also revealed the low competence of students in Indonesia. Research by Putriana et al. (2020); Suzanti et al. (2019) found that the ability to identify, analyze problems, and plan actions for environmental problem-solving practices is still low. A study by (Phito et al., 2019) revealed that West Sumatran high school students still lack strong critical thinking abilities. Research by Khairani et al. (2017) described that the literacy ability of students in Padang City in terms of writing, describing information, describing visuals, creating visuals, and scientific literacy is still low. Another factor that is suspected to be the cause of low physics learning outcomes is that physics learning performed by educators has separated the formal knowledge of student physics from the daily experience of learners. Thus, the learners assume that physics lessons have nothing to do with their lives. The problems presented in conventional teaching materials are only academic in nature and have no relation to the reality of learners. To make physics learning more desirable for learners, physics learning in the classroom cannot be separated from the experience and daily environment of learners (Ananda et al., 2017; Aprianti et al., 2015)

PBL is an active and innovative learning model that starts with confronting learners with real-world problems. In its implementation, students are not passive recipients of information but actively find relevant information. Teachers design problems that require students to gain knowledge, solve problems, learn independently, and participate and collaborate in teams (Guerra, 2017; Musriadi & Rubiah, 2014; Yulianti & Gunawan, 2019). PBL encourages students to achieve metacognition skills, training students to think at a high level so that science process skills can be mastered by students. Therefore, the PBL model can improve the knowledge and process science skills of students (Hasanah, 2017).

Many studies have reported that the PBL model is considered the right solution to improve 21st-century learning and skills outcomes. PBL provides many advantages (positive effects). PBL emphasizes the development of 21st-century competencies and skills, which can help students enhance their science literacy, critical thinking, and problem-solving abilities (Al-Fikry et al., 2018; Hestiana & Rosana, 2020; Sudarmin et al., 2019; Valdez & Bungihan, 2019). PBL also has a positive effect on motivation, self-study, and communication skills. PBL, as an active learning paradigm, is effective at piquing students' attention and improving cognitive learning outcomes. The PBL concept also allows students to work together on a predetermined problem (Balim et al., 2016; Ayyildiz & Tarhan, 2018). PBL enables students to comprehend and interpret information in greater detail, set up knowledge, develop internal motivation, and become logical people. The goal of this meta-analysis is to evaluate the effectiveness of using the Problem Based Learning (PBL) strategy to improve the scientific competency of high school students in Indonesia. Effectiveness is measured by determining the PBL's effect size against several types of competencies, such as critical thinking, problem-solving, science process skills, and cognitive.

2. METHOD

Meta-analysis was used in this study. The flow of meta-analysis research was selected as a study topic, setting data selection criteria, searching for literature, grouping data information, analyzing the data, and drawing a conclusion. Literature searches used the keywords "PBL in high school" and "PBL in science learning" through the Publish or Perish app. Databases were articles published in Scopus-indexed journals, SINTA-accredited journals, and national journals. After being traced, there were 48 articles related to the use of the PBL model in high school science classes. The criteria for the articles used were 1) Application of the PBL model, 2) Application of science learning both physics, chemistry, and biology, 3) Education level in high school, and 4) Articles published from 2017 to 2021. Upon examination, only 25 articles fulfilled the criteria for further analysis. There were 5 articles indexed by Scopus and 20 articles from national journals indexed by Sinta.

The instrument used was an analysis table that contained necessary information from each article. The researcher abstracts the information containing the necessary criteria for the article and then entered all the required information into the critical analysis table. The articles that can be analyzed were the results of quasi-experimental research, which contained the information needed to calculate the effect size according to the formula used. The criteria for the articles used to obtain effect size scores were in the form of average scores of results of the pretest and posttest, average experimental course scores, classes of control, standard deviation, many samples, and statistical test data. The score was processed using equations to obtain effect size values using the following types of formulas (Cohen et al., 2007; Glass, 1981):

a. Average pretest and posttest scores of one sample group

$$ES = \frac{\overline{X}\,post - \overline{X}\,pre}{SDpre} \quad \text{.....(1)}$$

b. Average of two sample groups, post-test data only

$$ES = \frac{\overline{X}E - \overline{X}C}{SDC} \quad \text{.....(2)}$$

c. Average of two sample groups, pretest, and posttest data

$$ES = \frac{\left(\overline{X}\,post - \overline{X}\,pre\right)E - \left(\overline{X}\,post - \overline{X}\,pre\right)C}{\frac{SDpreC + SDpreE + SDpostC}{3}} \quad \text{.....(3)}$$

d. T-test, if the standard deviation is unknown

$$ES = t\sqrt{\frac{1}{nE} + \frac{1}{nC}} \quad \text{.....(4)}$$

Information:
ES = Effect size
Xpost = Average posttest
Xpre = Pretest average
SD = Standard Deviation
XE = Average experimental group
XC = Average control group
XpostE = Average posttest of experimental groups

XpreE = Average pretest of experimental groups
XpostC = Average posttest of control group
Xpre C = Average pretest control group
SDE = Standard Deviation of experimental groups
SDC = Standard Deviation of experimental groups
t = Test result t
nE = Number of experimental groups
nC = Number of control groups

The calculated effect size value was then classified into the appropriate group. The effect size categories are shown in Table 1.

Table 1. Effect Size Values Interpretation

No	Effect Size	Category
1	ES ≤ 0.15	Negligible
2	0.15 < ES < 0.40	Low
3	0.140 < ES < 0.75	Medium
4	0.75 < ES < 1.10	High
5	ES > 1.10	Very high

(Modified from Glass, 1981).

3. RESULTS AND DISCUSSION

The results of the article collection revealed that 48 publications addressed the issue of study on the impact of PBL models on high school students' performance in the sciences of physics, chemistry, and biology. Of these articles, only 25 articles fulfilled the criteria for effect size analysis, as seen in Table 2.

Table 2. List of Articles Related to Research Topics

No	Code	Author/Publisher	Year	Class / Subject
1	J1	Riska Lidia et al., Unnes Physics Education Journal	2018	X, Physics
2	J2	Abdul Karim Budi Sulistiyo et al., Jurnal Pendidikan Sains Indonesia	2017	XI, Chemistry
3	J3	Prahasti Cynthia Hardiyanti et al., Jurnal Inovasi Pendidikan Kimia	2017	XI, Chemistry
4	J5	Yunita Wardianti et al., BIOEDUSAINS: Jurnal Pendidikan Biologi dan Sains	2019	X, Biology
5	J7	Puji Ariyati et al., Jurnal Teknologi Pendidikan	2021	X, Biology

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No	Code	Author/Publisher	Year	Class / Subject
6	J8	Dwi Ayu Lestari et al., EDUSAINS	2020	X, Biology
7	J9	Didik D M Sukmadani and Suryelita Edukimia	2021	XI, Chemistry
8	J10	Azzahrotul Hasanah, Lisa Utami. Jurnal Pendidikan Sains (JPS)	2017	XI, Chemistry
9	J12	Hesti Juliani et al., Jurnal Kumparan Fisika	2021	X, Physics
10	J13	Desi Natalia Purba et al. J. Phys: Conf. Ser. 1811 012020	2021	XI, Fisika
11	J14	Saparuddin, Biogenerasi	2021	XI, Biology
12	J15	Sahyar and Rika YuliaFitri American Journal of Educational Research	2017	X, Physics
13	J16	Siti Rohaniah Hasibuan et al., Journal of Transformative Education and Educational Leadership	2019	X, Chemistry
14	J17	Aweke Shishigu Argaw et al., EURASIA Journal of Mathematics Science and Technology Education	2017	XII, Physics
15	J18	Dissa Feby Octafianellis et al., JSER	2021	XI, Chemistry
16	J19	Parno et al., Jurnal Pendidikan Fisika Indonesia	2019	X, Physics
17	J20	Sulaiman et al., Jurnal Pendidikan Matematika dan IPA	2018	XI, Physics
18	J22	Haris Munandar et al., Jurnal Pendidikan Fisika dan Teknologi	2018	XI, Physics
19	J23	Ike Selviani. IJIS Edu: Indonesian J. Integr. Sci. Education	2019	XI, Biology
20	J24	Sri Siska Rahmayani, Juniar Hutahaean Jurnal Pendidikan Fisika	2017	X, Physics

No	Code	Author/Publisher	Year	Class / Subject
21	J25	Eka Yulianti, Indra Gunawan. Indonesian Journal of Science and Mathematics Education	2019	X, Physics
22	J26	Putri, C. D., Pursitasari, I. D., & Rubini, B JIPI (Jurnal IPA dan Pembelajaran IPA)	2020	X, Physics
23	J27	Fauziyah, S., et al. Journal of Physics: Conference Series	2021	XI, Physics
24	J28	Yogi, Dewa & Wayan. Berkala Ilmiah Pendidikan Fisika	2021	X, Physics
25	J29	Ni Putu Ayu Lisniandila et al. Jurnal Pendidikan dan Pembelajaran	2018	X, Physics

Table 2 shows that 25 articles have been identified based on the required data. There were 11 articles for physics subjects, 9 chemistry articles, and 5 biology articles. Statistical data from the research results of each article was recorded in the form of a table. The data recorded was in the form of averages, standard deviations, many samples, and statistical test scores. These statistical data were processed and analyzed to obtain the effect size of each article. Table 3 shows the statistical data table from the article.

Table 3. Statistical Data of Each Article

Code	Mean				Standard Deviation				Number of students		t_{count}	Formula
	preC	postC	preE	postE	preC	postC	preE	postE	N_C	N_E		
J1	62.25	69.18	64	74.51	-	-	-	-	39	39	1.63	d
J2	58.43	74.42	56.72	85.49	-	-	-	-	72	72	3.475	d
J3	34.76	68.73	39.08	82.05	-	-	-	-	37	37	1.66	d
J5	-	-	-	-	-	-	-	-	40	39	2.869	d
J7	21.66	43.44	20.53	55.31	7.56	13.78	8.56	10.19	-	-	-	c
J8	-	65.16	-	70.08	-	7.84		7.84	36	36	2.243	b
J9	-	70.38	-	83	-	-	-	-	29	29	5.2	d
J10	-	78.75	-	84.38	-	-	-	-	36	36	2.61	d
J12	17.16	57	19.31	76.15	-	-	-	-	32	32	7.77	d
J13	33.20	71.20	19.31	81,.0	11.08	11.39	11.57	8.57	25	25	4.758	c

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Code	Mean				Standard Deviation				Number of students		t_{count}	Formula
	preC	postC	preE	postE	preC	post C	preE	postE	N_C	N_E		
J14	-	-	29.80	77.28	-	-	10.80	7.02	-	50	-	a
J15	-	77.18	-	84.47	-	6.34	-	6.34	34	34	-	b
J16	-	74.79	-	84.47	-	10.58	-	7.649	24	24	2.664	b
J17	22.20	38.54	22.25	50.25	11.51	15.74	11.66	16.09	41	40	-0.021	c
J18	-	-	41.90	71.73	19.68	-	-	-	-	100	-	a
J19	46.6	81.5	48.9	86.9	7.28	7.68	7.88	5.83	28	28	0.97	c
J20	-	-	-	-	-	-	-	-	30	30	2.51	d
J22	27.37	51.29	39.08	65.28	-	-	-	-	38	38	4.29	d
J23	27	78.8	32	85.2	12.4	9.31	6.71	5.45	-	-	-	c
J24	29.94	30.08	66.85	75.34	-	-	-	-	35	35	3.485	d
J25	46.6	63.67	53	9.4	14.4	10	14.5	9.4	-	-	-	c
J26	54.8	74.2	47.4	85.1	6.9	4.8	6.04	4.21	-	-	-	c
J27	33.1	58.62	33.1	83.55	4.49	7.94	9.68	6.63	27	22	-	c
J28	-	55.56	-	72.59	-	15.32	-	5.22	30	31	-	b
J29	-	43.05	-	54.84	-	14.29	-	14.50	-	-	-	b

Based on the data on average values, standard deviations, many samples, and statistical test values, the effect size of the two articles was calculated using the formula, formula b 4 articles, formula c 9 articles, and formula d 13 articles. The selection of formulas was based on information obtained from the article. Table 4 displays the effect size estimation results for each article.

Table 4. Effect Size of Each Article

Code	*Effect Size* (ES)	Category
J1	0.37	Low
J2	0.58	Medium
J3	0.39	Low
J5	0.65	Medium
J7	0.15	Negligible
J8	0.63	Medium
J9	1.37	Very high
J10	0.62	Medium
J12	1.94	Very high
J13	0.23	Low
J14	4.39	Very high

Code	*Effect Size* (ES)	Category
J15	1.15	Very high
J16	0.92	High
J17	0.10	Negligible
J18	1.52	Very high
J19	0.05	Negligible
J20	0.65	Medium
J22	0.98	High
J23	0.02	Negligible
J24	0.83	High
J25	0.09	Negligible
J26	0.34	Low
J27	0.80	High
J28	0.60	Medium
J29	0.83	High
ES : Negligible		5 articles
ES : Low		4 articles
ES : Medium		6 articles
ES : High		5 articles
ES : Very high		5 articles

The findings of the analysis are shown in Table 4. About 5 articles had an effect size value that could be ignored. This is because of the ES ≤ 0.15 in which 4 articles are categorized as low criteria, 6 articles in moderate criteria, 5 articles in high criteria, and 5 articles in very high criteria. Figure 1 shows the average effect size value depending on the subject criteria.

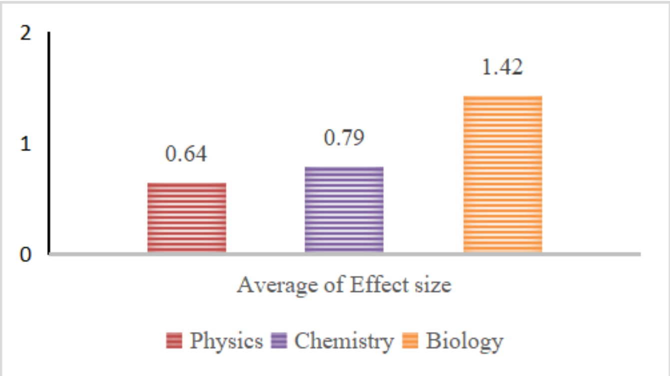

Figure 1. Average Effect Size Based on Subject Criteria

Figure 1 depicts the average effect size value for many science subjects, including biology, chemistry, and physics. The effect size for biology was 1.42 with very high criteria, chemistry 0.79 with high criteria, and physics 0.64 with medium criteria. These findings are in line with Utami et al. (2018) and Astuti et al. (2019) who discovered that using the PBL model on biological learning provides a high-size effect on high school students' biology learning outcomes. These findings indicate that using the PBL paradigm to improve student's learning outcomes has a favorable impact on learning. These results are consistent with a study by

Miterianifa et al. (2019) that the students' chemical and biological learning outcomes are also influenced by PBL, especially for critical thinking skills. These results are inseparable from the PBL model's advantages, which encourage students to conduct their research (independently), conduct observations and be actively involved in communicating, and encourage cooperation in the learning process (Suminarsih, 2021). Effect size values are also analyzed based on class levels as presented in Figure 2.

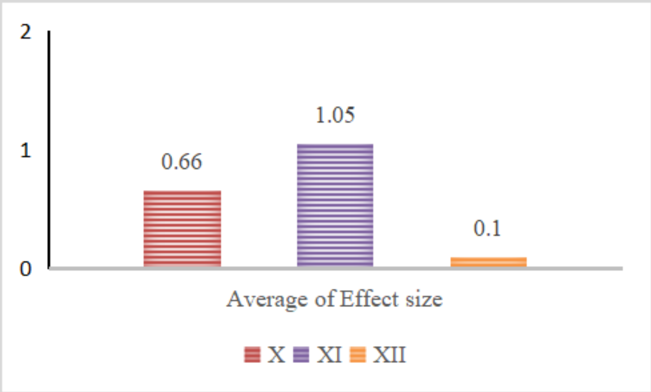

Figure 2. Average Effect Size by Class Level

The maximum effect size value found for class XI was 1.05 with high criteria, class X was 0.66 with medium criteria, and class XII was 0.1 with negligible criteria, according to the analysis findings. Research on the application of PBL in class XII is very rare, only 1 study was found to be conducted for class XII. This can be understood because class XII students are better prepared to encounter the final exam of school, rarely schools that permit researchers to research in the classroom. These findings are consistent with research by Susetyarini & Fauzi (2020) in which there is a tendency that most selective schools to permit researchers to research the third grade of junior high school or high school due to the preparation of strictly scheduled national exams. Based on the type of competence, Table 5 displays the effect size value.

Table 5. Average Effect Size Based on Type of Student Competence

Aspects	Code	Average Effect size	Criteria
Critical Thinking	J7, J8, J13, J14, J18, J19, J22, J23, J25,J26, J27, J28, J29	0.82	High
Problem-solving	J15, J17	0.63	High
Science process skills	J3, J10	0.50	Medium
Cognitive	J1, J2, J5, J9, J12, J16, J20, J24	0.99	High

Table 5 displays the types of students' proficiency in science learning through the use of PBL. The effect size of the category is high for critical thinking, problem-solving, and cognition. For science process skills, the effect size of PBL is relatively moderate. Following study results by Syamina et al. (2021) also found that PBL-based teaching materials are effective to assist students in developing their capacity for critical thought, science process skills, and learning outcomes. Miterianifa et al. (2019) also found that the critical-thinking skills of students are significantly impacted by PBL. Students are not only taught problem-solving principles, but they are also taught to think critically, creatively, and scientifically, as well as gain experience with applying the scientific method to solve problems. It could be stated that using the PBL paradigm in high school science classes can improve critical thinking skills, problem-solving abilities, and learning outcomes in the cognitive domain.

4. CONCLUSION

The association between the impact of the PBL model on high school students' scientific competency was discovered after analyzing 25 articles on the use of the PBL model in high schools. The results of the analysis were viewed from the types of science subjects, grade levels, and science competencies. In terms of the types of science subjects, the PBL model was more widely applied to physics and chemistry subjects compared to biology subjects. The effect size results fell into the medium to very high category. Based on grade level, PBL was effectively used for class XI with high criteria. It was also known that the critical thinking, problem-solving, and cognitive aspects of students showed a high effect size by applying the PBL model. Thus, the PBL paradigm was successfully used in high school science instruction.

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