JURNAL PENDIDIKAN MATEMATIKA DAN IPA

Vol. 14, No. 1 (2023) h. 16-32

http://jurnal.untan.ac.id/index.php/PMP

META-ANALYSIS THE EFFECT OF STEM INTEGRATED PROBLEM BASED LEARNING MODEL ON SCIENCE LEARNING OUTCOMES

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DOI: http://dx.doi.org/10.26418/jpmipa.v14i1.51678

Abstract

The goal of the research is to analyze the impact of Science, Technology, Engineering, and Mathematics (STEM) integrated Problem Based Learning methods on science learning. Research methods use meta-analysis. The research method using meta-analysis with the research flow is determining the research topic, developing data selection criteria, conducting library searches, classifying data information, analyzing data, and drawing conclusions. Databases are articles published in Scopus-indexed journals, Sinta accredited, and on Google Scholar. The articles analyzed are those published in the last 5 years, namely from 2017-2021. 22 articles meet the criteria for further analysis. Data analysis techniques use effect size. Effect size values are measured as a whole and grouped based on educational levels, subjects, and types of learning outcomes. The results of the study demonstrated that the use of STEM integrated PBL has a large impact, with an average effect size of 1.036. STEM integrated PBL has a high influence on the college level. Based on the type of subject, the highest effect size average is for biology. Depending on the sort of learning outcome, the highest average size for scientific literacy. It may be stated that the STEM integrated PBL approach is more effective for biology and chemistry, as well as scientific components, in high schools and colleges.

Keywords: *Problem Based Learning, Science Technology Engineering and Mathematics, Science Learning.*

INTRODUCTION

The 21st century is the era of science and technology. Qualified human resources are characterized by the mastery of science and technology needed in the 21st century. Qualified and competitive human beings can be realized through education. One of the

Received : 03/01/2022
Revised : 05/12/2022
Accepted : 15/12/2022

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variables that influence students' abilities and skills to reach 21st-century educational goals is the use of learning models.

According to certain studies, student science learning outcomes in Indonesia are still poor. PISA data in 2018 said that the science ability score was 396, where as many as 40 percent of Indonesian students were still below the minimum expected ability (PISA, 2019). Nofiana & Julianto (2018) research revealed that the science literacy of junior high school students in aspects of content, process, and context is relatively low. A low understanding of students' science concepts will have an impact on the low ability of science applications (Santoso & Mosik, 2019). According to research by Pamungkas et al. (2018), high school pupils still have poor levels of metacognition, which has an impact on their low ability to think critically and problems solving. Other results revealed that prospective biology teacher students' critical thinking skills on parts of analytical and explanatory skills were competent, but self-regulation skills were woefully insufficient. To equip the 21st century generation to compete and tackle diverse difficulties in the future, critical thinking abilities are very crucial for prospective pupils (Hudha et al., 2017; Nuraini, 2017).

These issues can be solved by using the appropriate learning paradigm to teach 21st-century skills. One of the models that can be used in STEM integrated PBL (Problem Based Learning). PBL is a teaching model that uses real-life scenarios to assist pupils to learn scientific concepts. The PBL model requires students to instill the fundamentals of scientific thinking, train students to gain knowledge, solve problems, have their way of learning as well as participate and collaborate within teams (Diani et al., 2019; Guerra, 2017; Yuliati et al., 2018; Sulaiman et al., 2018). In the learning scenario, PBL involves the principles of 4Cs namely critical thinking, communication, collaboration, and creativity. Problem-based learning over a long period can improve learning outcomes and high-level thinking skills (Putri et al., 2020).

Science learning is closely related to technology. Technology can help and support the development of people's lives. These conditions are very possible for the integration of STEM (Science, Technology, Engineering, and Mathematics) in Science learning of physics, chemistry, and biology (Ariyatun & Octavianelis, 2020; Sumarni et al., 2022). STEM literacy, according to Bybee (2013), assists students in comprehending concepts, principles, and procedures from science, technology, engineering, and mathematics that are employed in everyday life.

STEM approaches to science learning contribute to comprehensively enhancing students' knowledge and skills to compete in the 21st century (Becker & Park, 2011; Sumarni et al., 2020; Zakiyah & Sudarmin, 2022). STEM education may help students effectively plan, build, and use technology, which will enhance their affective, psychomotor, and cognitive abilities (Kapila & Iskander, 2014). Some research results show that STEM can improve conceptual knowledge and high-level thinking skills (Fan & Yu, 2015; Qori et al., 2020). STEM can also enhance complex problem-solving, collaboratively (Bybee, 2013;

Lin et al., 2015; Reffiane et al., 2021), and is capable of bridging the gap between education and crucial competencies required in the workplace (Jang, 2016).

Critical thinking abilities, problem-solving abilities, literacy, creativity, and science learning outcomes can all be enhanced by effective science learning. The application of STEM integrated PBL models today can be an alternative in science learning ranging from elementary education to college because it can develop students' potential in the face of global competition (Adiwiguna et al., 2019).

There are many advantages of STEM integrated PBL in science learning, so researchers are interested in studying how the advantages of STEM integrated PBL are most effective in improving the ability and quality of students' science learning. PBL and STEM models have been the subject of meta-analytical investigations by several researchers. However, there has yet to be a meta-analysis of the STEM integrated PBL model's impact. This paper analyzes how the STEM integrated PBL approach impacts the outcomes of scientific learning.

Based on the above description, it is vital to investigate the STEM integrated PBL model's impact on science learning. The magnitude of influence is measured by calculating the effect size of the STEM integrated PBL model against several aspects, namely education levels, subjects, and types of learning outcomes. Students are encouraged to use critical thinking, creativity, and innovation to collaborate in teams to solve problems in the real world through STEM integrated PBL learning (Firman, 2016). The findings of this meta-analysis are predicted to have a positive impact on scientific teaching, particularly for teachers who are employing STEM integrated PBL models.

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METHODS

The methodology is a meta-analysis study using a quantitative approach. Meta-analysis is created by summarizing data from several articles in national and international journals. Search literature using the keyword “STEM Problem Based Learning" through the Publish or Perish application. Databases are articles published in Scopus-indexed journals, Sinta accredited journals and national journals.

There were 42 publications connected to the application of STEM integrated PBL in science education. The criteria for the articles used are 1) The application of STEM integrated PBL in integrated science, physics, chemistry, and biology learning, 2) The types of research were pre-experimental and quasi-experimental, and 3) Articles published from 2017-2021. After being analyzed, only 22 articles met the criteria for further analysis because they contained the required variables and information. 2 articles have data for several aspects of learning outcomes.

The instrument used is an analysis table that contains the necessary information from each article. The researcher abstracts the information that contains the necessary criteria for the article and then enters all the required information into the analysis table. Data analysis techniques use effect size. The criteria

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of the articles used to obtain effect size scores are in the form of average scores of pretest and posttest findings, average scores of experimental classes and control classes, standard deviations, many samples, and statistical test data. The score is processed using equations to obtain effect size values by using the following types of formulas (Cohen, J., 2013).

a. Average pretest and posttest scores of one sample group (Cohen, J., 2013).

$$ES = \frac{\overline{X}post - \overline{X}pre}{SDpre}$$

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

$$ES = \frac{\overline{X}E - \overline{X}C}{SDC}$$

c. Average of two sample groups, pretest, and post-test data

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

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

$$ES = t\sqrt{\frac{1}{nE} + \frac{1}{nC}}$$

Information:

ES = Effect size
$\overline{X}$post = Average posttest
$\overline{X}$pre = Pretest average
SD = Standard Deviation
$\overline{X}$E = Average experimental group
$\overline{X}$C = Average control group
$\overline{X}$postE = Average posttest of experimental groups
$\overline{X}$preE = Average pretest of experimental groups
$\overline{X}$ postC = Average posttest of control group
$\overline{X}$pre 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

Effect size values that have been obtained are interpreted according to the categories that have been set. The category of effect size values is shown in Table 1.

Table 1. Effect size value interpretation

No	Effect Size	Category
1	$0 < ES \leq 0.2$	Low
2	$0.2 < ES \leq 0.8$	Medium
3	$0.8 < ES$	High

(J. Cohen, 2013)

RESULTS AND DISCUSSION

Based on the search results, some articles raised research topics about the STEM integrated PBL model in science learning. 22 articles met the criteria that had been set for effect size analysis. Table 2 below shows a collection of articles related to the research subject.

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Table 2. List of articles analyzed

Code	Journal, Year	Author	Education Level	Subjects
A1	JEC: Journal of Educational Chemistry, 2020.	Ariyatun, A., & Octavianelis, D. F.	High schools	Chemistry
A2	E-Journal Pendidikan IPA, 2018	Cahyaningtyas, et al.	Junior high school	Integrated science
A3	Bioed: Jurnal Pendidikan Biologi, 2019	Melati, L. T., et al	High schools	Biology
A4	Jurnal IPA Dan Pembelajaran IPA, 2020	Putri, C. D., et al.	High schools	Physics
A6	Jurnal Pendidikan Sains Indonesia, 2021	Hasanah	High schools	Biologi
A8	Berkala Ilmiah Pendidikan Fisika, 2021	I Putu Yogi Setia Permana, et al	High schools	Physics
A10	Jurnal Pendidikan Dasar Indonesia, 2019	Adiwiguna, et al	Elementary school	Science
A11	BIOEDUKASI, 2020	Anita, et al	College	Biology
A12	Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan, 2018	Rivai, et al	High schools	Physics
A13	International Conference Recent Innovation, 2020.	Faa'izah Abiyyah Rihhadatul'aysi, T	High schools	Chemistry
A14	Universitas Jember, 2020	Dama	Elementary school	Science
A15	Jurnal Pencerahan, 2020	Syukri, et al	High schools	Physics
A16	Can. J. Sci. Math. Techn. Educ., 2019	Lee, et al	Junior high school	Integrated science
A17	Journal of University of Shanghai for Science and Technology, 2020	Rahim, et al	College	Biology
A18	JRPF (Jurnal Riset Pendidikan Fisika), 2020	Indriyawanti, et al	Junior high school	Integrated science
A19	Jurnal Pendidikan IPA Indonesia, 2020	Parno, et al	High schools	Physics

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Code	Journal, Year	Author	Education Level	Subjects
A20	Journal of Physics: Conference Series, 2019	Parno, et al	High schools	Physics
A21	Thinking Skills and Creativity, 2018	Kuo, et al	College	Physics/ Technical
A22	Journal of Educational Science and Technology, 2019	Madyani, et al	Junior high school	Integrated science
A23	Jurnal Penelitian Pendidikan Kimia, 2019	Winda, et al	College	Chemistry
A24	Jurnal Riset Pendidikan Kimia, 2018	Pusparini, et al	High schools	Chemistry
A25	Journal of Physics: Conference Series, 2021	Fauziyah, et al	High schools	Physics

The statistical data of each article is recorded in the form of a table. The data recorded is in the form of averages, standard deviations, many samples, and statistical test scores. To determine the effect size of each item, statistical data is processed and examined. Table 3 displays the article's statistical data.

Table 3. Statistical data of each article

Code	Mean				Standard Deviation				Number of students		t count
	preC	postC	preE	postE	preC	postC	preE	post E	N_C	N_E	
A1	58.43	74.42	56.72	85.49	-	-	-	-	72	72	8.23
A2	-	-	56.49	80.46	-	-	10.89	8,63	35	35	-
A3	-	-	31.20	80.12	-	-	3.50	4.45	46	46	2.5
A4	54.8	74.2	47.4	85.1	6.9	4.8	6.04	4.21	-	-	-
A6	29.92	63.72	29.15	75.28	-	-	4.23	5.51	-	71	-
A8	-	55.56	-	72.59	-	15.32	-	5.22	-	-	-
A10	-	60.33	-	70.53	-	12.49	-	13,13	-	-	-
A11	68,4	69,2	68,6	79,8	-	-	-	-	34	34	7.708
A12	-	-	65,93	85,74	-	-	12,56	14,80		27	-
A13	-	-	-	-	-	-	-	-	32	32	0,524

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Code	Mean				Standard Deviation				Number of students		t count
	preC	postC	preE	postE	preC	postC	preE	post E	N_C	N_E	
A14	-	-	-	-	-	-	-	-	26	26	6.027
A15	-	-	-	-	-	-	-	-	26	26	2.478
A16	-	-	-	-	-	-	-	-	96	51	5.587
A17	-	-	41.7	49.3	6.1	-	-	-		50	-
A18	20.9	45.9	22.2	60.4	-	-	5.343	12.887	33	33	-
A19	42.15	54.33	46.09	79.03	7.66	9.18	9.71	15.25	33	33	-
A20	31.66	44.89	29.76	60.2	8.01	7.02	10.14	10.46	38	38	-
A21a	-	-	4.4	4.64	0.39	-	-	-	-	-	-
A21b	-	-	63.36	68.44	1.79	-	-	-	-	-	-
A21c	-	-	4.03	4.43	0.64	-	-	-	-	-	-
A21d	-	-	4.68	4.75	0.44	-	-	-	-	-	-
A22a	35.94	57.94	27.25	68.13	-	-	-	-	32	32	0.055
A22b	36.09	45.31	40.16	69.69	-	-	-	-	32	32	0.354
A23	-	66.93	-	87	-	-	-	-	32	32	7.389
A24	-	-	-	-	-	-	-	-	30	30	0.284
A25	39.07	58.62	33.05	83.49	4.49	7.94	9.68	6.63	29	22	-

Based on data on average values, standard deviations, many samples, and statistical test values, the effect size of the article is calculated using formula an as many as 6 articles, formula b as many as 2 articles, formula c as many as 5 articles, and formula d as many as 7 articles. The selection of formulas is based on information obtained from the article. The effect size estimation results for each article are shown in Table 4.

Table 4. Effect size value

No	Code	***Effect Size* (ES)**	Category
1	A1	1.37	High
2	A2	0.75	Medium
3	A3	1.49	High
4	A4	0.34	Medium
5	A6	2.73	High
6	A8	1.49	High
7	A10	0.82	High
8	A11	1.87	High
9	A12	1.44	High
10	A13	0.13	Low

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No	Code	*Effect Size* (ES)	Category
11	A14	1.67	High
12	A15	0.69	Medium
13	A16	0.97	High
14	A17	1.25	High
15	A18	2.71	High
16	A19	0.26	Medium
17	A20	0.23	Medium
18	A21a	0.62	Medium
19	A21b	2.84	High
20	A21c	0.62	Medium
21	A21d	0.16	Low
22	A22a	0.01	Low
23	A22b	0.09	Low
24	A23	1.85	High
25	A24	0.07	Low
26	A25	0.47	Medium
ES Average = 1.036			High
Low :			5 data
Medium :			8 data
High :			13 data

Using the data in Table 4 as a guide. The average effect size value of all published publications is found to be high, with a value of 1.036. These findings are relevant to the results of (Ananda & Salamah, 2021) who found that the STEM integrated PBL model provides a higher effect size compared to the STEM integrated PjBL model, as well as the STEM, integrated guided inquiry model. Several studies have also found that the STEM-integrated PBL model has many advantages over traditional teaching in terms of student learning outcomes, critical thinking, communication, literacy, and conceptual understanding (Hasanah et al., 2021; Anita et al., 2020; Madyani et al., 2019).

Five articles have a low effect size, 8 articles with medium criteria, and 13 articles with high criteria. Table 5 shows the average value of the effect size based on the degree of education criteria.

Table 5. Average effect size score based on education level

Education Level	Code	Average Effect size	Criteria
Elementary school	A10, A14	0.69	Medium
Junior high school	A2, A16, A18, A22a, A22b	0.91	High

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Education Level	Code	Average Effect size	Criteria
High schools	A1, A3, A4, A6, A8, A12, A13, A15, A19, A20, A24, A25	0.89	High
College	A11. A17, A21a, A21b, A21c, A21d, A23	1.32	High

The biggest effect size value was reached in the use of STEM integrated PBL in College, which is 1,32 with high criteria, according to the results of the analysis. Application in junior high and high school also with high criteria, and elementary with moderate criteria. STEM integration into lectures, according to White (2014) may drive students to create, develop, and implement technology, as well as polish cognitive, manipulative, and emotional skills and apply knowledge. PBL provides opportunities for students to master knowledge, and obtain information or data that is then used as a consideration to choose the right way to solve the problem. Making decisions certainly requires logical, critical, and systematic thinking. These skills are acquired through the application of STEM integrated PBL in College.

PBL is a learning model based on constructivism theory. Constructivism is one of the philosophies of knowledge that emphasizes that one's knowledge is the construction of the person himself. At the college level, students are likely to have more knowledge and experience, so that the process of equilibrium, scheme formation, assimilation, and accommodation continues to occur. This process can be better than students at other levels. In addition, psychological maturity factors influence the utilization of STEM integrated PBL in science learning at all levels of education. Students and teachers have a more stable psychological maturity effect compared to high school, junior high, and elementary school (Astutik & Jauhariyah, 2021; Suparno, 1997).

The results of the examination of the STEM integrated PBL model's use are categorized by the type of subject or course. Table 6 displays the effect size value.

Table 6. Average effect size grades by subjects

Education Level	Subjects	Code	Average Effect Size	Criteria
Elementary school	Science	A10, A14	0.69	Medium
Junior high school	Integrated Science	A2, A16, A18, A22a, A22b	0.91	High

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Education Level	Subjects	Code	Average Effect Size	Criteria
High schools	Physics	A4, A8, A12, A15, A19, A20, A25	0.76	High
	Chemistry	A1, A13, A24	0.52	Medium
	Biology	A3, A6	2.11	High
College	Physics	A21a, A21b, A21c, A21d	1.06	High
	Chemistry	A23	1.85	High
	Biology	A11, A17	1.56	High

Data in Table 6 shows the average effect size value based on the type of subject/ course. Biology subjects in high school and chemistry courses at the college level with high standards had the largest effect sizes. These results are relevant to the research conducted by (Khoiri, 2019) that STEM integration learning is very well applied at the university level because it requires critical thinking skills to solve global and complex problems. Applying it to students will be more precise and easier. The lowest effect size is found in chemistry subjects in high school with moderate criteria. For physics subjects, the effect size value is at a high criterion. These findings are consistent with the findings of (Astutik & Jauhariyah, 2021) who found that using PBL in physics instruction had a significant impact on critical thinking abilities when used at the college level.

Effect size values are also analyzed based on the type of learning outcome. Table 7 summarizes the findings.

Table 7. Average effect size value based on learning outcomes

Learning Outcomes	Code	Average Effect size	Criteria
Critical thinking	A1, A2, A3, A4, A6, A8, A10, A24, A25	1.06	High
Problem-solving	A18, A20	1.47	High
Creativity	A21b, A22b	1.46	High
Scientific and environmental literacy	A11, A19	2,36	High
Results of learning	A12, A13, A14, A22a, A23	1.02	High
Affective	A16	0.97	High
Interest	A15, A21d,	0.43	Medium
Motivation	A21a	0.62	Medium
Self-efficacy	A21c	0.62	Medium

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Table 7 lists the various types of learning outcomes by applying the STEM integrated PBL model. In science learning, effect sizes have high categories for scientific and environmental literacy, problem-solving, creativity, critical thinking, and results of learning. This is relevant to the results of research by (Luster-Teasley et al., 2017) and (Moaveni & Chou, 2017) that STEM integrated learning produces problem-solving skills. Effect sizes with high criteria were found to be critical thinking, learning outcomes, and affective.

The effect size of the aspects of interest, motivation, and self-efficacy is moderate. Scientific procedures, inquisitive skills, and creative thinking all benefit from STEM integration. STEM can improve learning outcomes, according to (Khoiri, 2019) not only understanding but also 21st-century competencies of students. STEM features as a tool to overcome difficulties in life in various circumstances around the world. It is also relevant to the findings of (Fidan & Tuncel, 2019; Guerra, 2017) and (Syamina et al., 2021).

CONCLUSION

According to the conclusions of a review of 22 studies on the impact of STEM integrated PBL models on science learning in the twenty-first century, STEM integrated PBL is impactful at the college level. Based on the type of subject/course, the highest effect size average is for biology. Based on the type of learning outcome the highest average effect size for scientific literacy. It may be inferred that the STEM integrated PBL model is more effective in high schools and colleges for components of scientific literacy in the fields of biology and chemistry.

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