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Improvement of Students' Problem-Solving Skill on Physics Learning: A Meta-Analysis

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Abstract

Problem-solving skills can be realised by not necessarily depending only on how much students' maturity level is, but also on the problems they experience directly. This study looked into how students' problem-solving skills may be improved in physics learning by paying attention to the level of education, models, media, and learning topics used. This study employs a meta-analysis of 14 scientific publications on student problem-solving skills in physics education, with a focus on articles that were published between 2017 and 2022, accepted by Scopus and SINTA, employing quasi-experimental research designs, satisfying the statistical data requirements for calculating effect sizes, and providing details on the subjects, media, learning models, and educational level in physics education. The data analysis approach was executed using the VOSviewer tool for bibliometric analysis and effect size estimates for metadata analysis. According to the meta-analysis results, students' physics learning outcomes would greatly benefit from exercising their problem-solving abilities, with an average effect size of 1.29 and an influence of 88%. Using the Project-Based Learning (PjBL) learning model in high schools, together with student worksheet learning materials on heat energy, would significantly enhance students' problem-solving abilities in physics classes. This meta-analysis study intends to provide teachers with a standard to measure their choices of models, media, and lesson subjects to improve their students' ability to solve problems when studying physics.

Keywords: meta-analysis; physics learning; problem-solving skill

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INTRODUCTION

Today, science and technology are developing rapidly, impacting every individual so that they can participate in growing and developing amid global competition. This development has also penetrated the world of education in the 21st century. A visible change lies in the learning process, where previous

learning was often teacher-centred, but now learning is more student-centred (Miterianifa et al., 2019). Students have a considerably greater opportunity to participate actively in the learning process when they are positioned as learning centres; this will have an impact on learning that will be more effective in building an understanding of the material



skills in physics learning. A meta-analysis of earlier work by Lindberg et al., (2010) focuses on how gender and students' arithmetic proficiency affect students' ability to solve physics problems. The study considered the pupils' age, country, ethnicity, and ability. It did not, however, address the educational level, model, medium, or learning topics that are employed in instruction.

This study builds on earlier research by Hikmah & Jauhariyah (2021), a meta-analysis about enhancing students' critical thinking abilities in physics. The entire study examined how models, media, and learning subjects, together with educational level, might enhance critical thinking abilities in studying

physics. By reflecting on that research, the findings of this meta-analysis research are anticipated to serve as a standard for educators in selecting the proper learning methods, media, and subjects to enhance students' problem-solving skills in physics classes.

METHOD

The research employed in this study, which intends to evaluate the growth in students' problem-solving skills when learning physics, is literature research (King, 1990), especially utilising the meta-analysis approach. Meta-analysis is a statistical method that combines data from related previous studies to obtain general conclusions. The steps taken with the meta-analysis method are as follows:

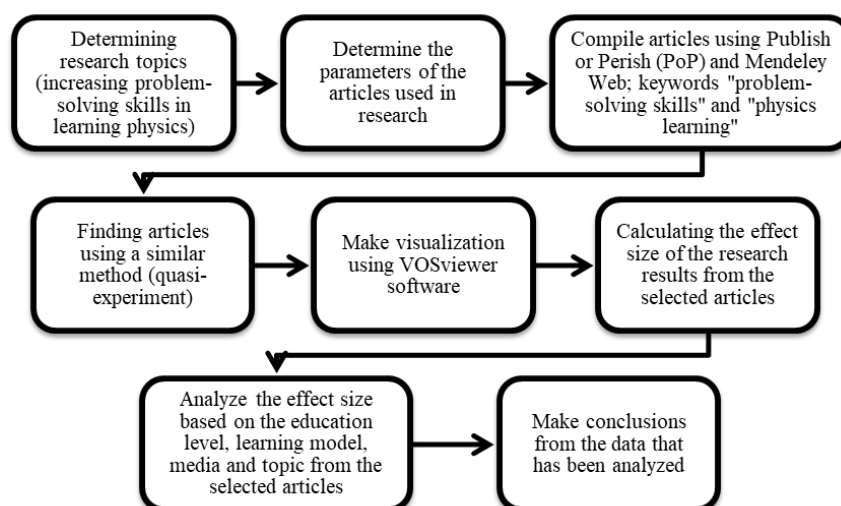


Figure 3 Data collection and analysis techniques
(Obtained from studies carried out by Hikmah & Jauhariyah, 2021)

Research data collection methods make use of secondary data from earlier studies in the form of publications in scientific journals that meet the following standards: (1) The article focus is on enhancing students' problem-solving skills when studying physics; (2) Articles are from SINTA accredited journals and indexed by Scopus with a minimum rating of three on SINTA and third quartile on Scopus; (3) Articles published in the period 2017–2022; (4) The

research design used in the article is quasi-experimental; (5) The article fulfils the statistical data requirements in calculating the Effect Size (ES); and (6) Articles include details on education levels, media, models, and physics learning subjects.

This study's analytical strategy is a quantitative descriptive method that entails figuring out the ES, a measure of a variable's influence on other variables that are influenced by sample size. This

study looks at how much students' problem-solving skills in physics have improved by considering their educational background, models, media, and learning topics. The increase in students' problem-solving abilities, thus, was measured using the effect size equation (Cohen et al., 2007) based on data from 14 published studies utilising the kind of quasi-experiment study known as mean value, standard deviation, t-test for between subjects, and degrees of freedom.

If the mean and standard deviation values from the quasi-experiment study are available, then the effect size equation that is employed is (Cohen et al., 2007):

$$ES = \frac{M_{posttest} - M_{pretest}}{\sqrt{\frac{SD_{posttest}^2 + SD_{pretest}^2}{2}}} \quad \dots (1)$$

Additionally, suppose the t-test value for the relationship between subjects and degrees of freedom in the quasi-experiment study used as reference data is known. In that case, the ES equation employed is (Cohen et al., 2007):

$$ES = \frac{2t}{\sqrt{df}} \quad \dots (2)$$

In addition to using the equation above, effect size calculations can be performed using a website-based ES calculator (Breker, 2022) to minimise errors in manual calculations. The outcomes of the ES computation are then shown in Table 1, based on several criteria.

Table 1 ES criteria

ES	Criteria
$ES \leq 0.15$	Negligible Effect
$0.15 < ES \leq 0.40$	Low Effect
$0.40 < ES \leq 0.75$	Medium Effect
$0.75 < ES \leq 1.10$	High Effect
$ES > 1.10$	Very High Effect

After determining the ES value, Table 2 presents the result as a percentage indicating the degree to which the dependent variable influences the independent variable. In this study,

learning physics by paying attention to the degree of education, model, medium, and learning themes employed is the independent variable, while developing students' problem-solving skills (measured by ES) is the dependent variable.

Table 2 ES interpretation

ES	Influence (%)
0.0	50
0.1	54
0.2	58
0.3	62
0.4	66
0.5	69
0.6	73
0.7	76
0.8	79
0.9	82
1.0	84
1.2	88
1.4	92
1.6	95
1.8	96
2.0	98
2.5	99
3.0	99.9

RESULT AND DISCUSSION

In order to complete the meta-analysis for this study, 14 published articles that satisfied the requirements for data collection and analysis were used. These articles are concerned with increasing students' problem-solving skills when learning physics. The study presented in those articles aims to enhance students' problem-solving skills in physics by applying certain learning models.

The number of articles by year of publication can be seen in Figure 4, where 14 articles selected in this meta-analysis experience publication instability each year. This suggests that given that problem-solving skills are one of the competencies that 21st-century learners must possess, research on students' problem-solving abilities in physics learning only focuses on sustainable advancements in the field of education every year (Jayadi et al., 2020).

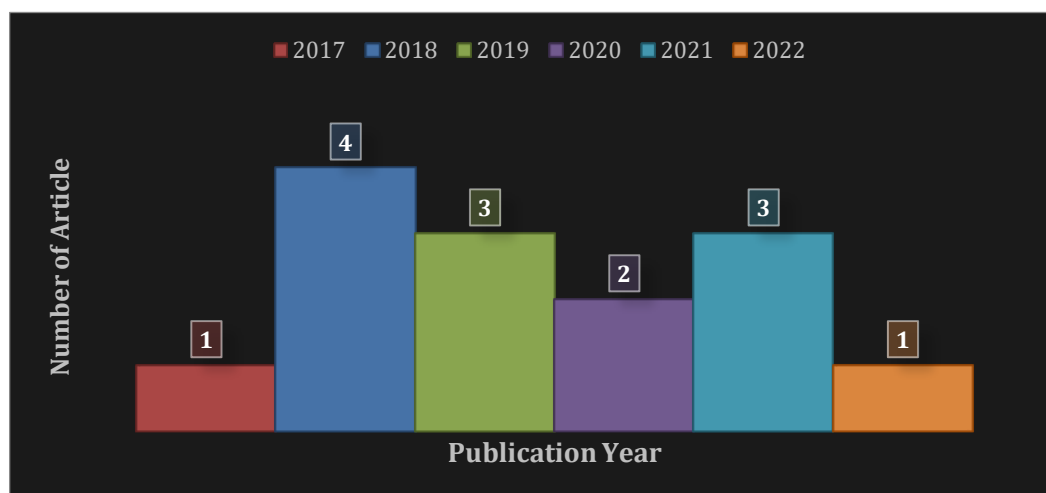


Figure 4 Articles about physics learning students' problem-solving skills published between 2017 and 2022

The results of observations on all 14 articles used are listed in Table 3. The learning models used are PBL, IMM-PS,

STEM learning, metacognitive strategy, PjBL, discovery learning, and PIL.

Table 3 Categorisation of 14 articles based on educational level, learning model, media, and topics

Code	Source	School Level	Model	Media	Topic
PS 1	(Simanjuntak et al., 2021)	Senior High School	PBL	Computer Simulation Module	Impulse and Momentum
PS 2	(Syukri et al., 2018)	Junior High School		Non-Media	Electricity and Magnetism
PS 3	(Argaw et al., 2017)	Senior High School			Unidentified
PS 4	(Yuberti et al., 2019)	Senior High School	IMM-PS	Interactive multimedia	Impulse and Momentum
PS 5	(Manurung & Panggabean, 2020)	University		Non-Media	Wave Electric Magnetic
PS 6	(Yanto & Enjoni, 2022)	Senior High School	PBL	Non-Media	Heat Energy
PS 7	(Alatas & Yakin, 2021)		STEM Learning	Student Worksheet	Work and Energy
PS 8	(Syahbrudin & Anggraini, 2019)		Metacognitive Strategy		Unidentified
PS 9	(Makrufi et al., 2018)	Senior High School	PjBL	Non-Media	Dynamic Fluid
PS 10	(Himawan & Winarti, 2018)		Metacognitive Strategy		Kinetic Theory of Gases
PS 11	(Wartono et al., 2018)		Discovery Learning	PhET Colorado	Unidentified
PS 12	(Wardani et al., 2021)		PIL	Non-Media	

Code	Source	School Level	Model	Media	Topic
PS 13	(Nst et al., 2020)		PjBL		Optical Instrument
PS 14	(Fitriyani et al., 2019)		PBL	Student Worksheet	Vertical Motion

Furthermore, the coding data in Table 4, which categorises the magnitudes of each variable, presents information that may

be acquired about themes, learning methods, media, and educational levels.

Table 4 Article information classification with coding data

Information	School Level	Model	Media	Topic
Junior High School	1			
Senior High School	12			
University	1			
PBL		6		
IMM-PS		1		
STEM Learning		1		
Metacognitive Strategy		2		
PjBL		2		
Discovery Learning		1		
PIL		1		
Computer Simulation			1	
Module			1	
Interactive Multimedia			1	
Student Worksheet			4	
PhET Colorado			1	
Non-Media			6	
Impuls and Momentum				2
Electricity and Magnetism				1
Wave Electric Mgnetic				1
Heat Energy				1
Work and Energy				1
Dynamic Fluid				1
Kinetic Theory of Gases				2
Optical Instrument				1
Vertical Motion				1
Not Identify				3
Total Articles	14	14	14	14

Bibliometric analysis

To find out the reflection of the correlation between studies in the 14 articles used, a bibliometric analysis was carried out on the distribution of studies according to the similarity of keywords in each article shown in Figure 5. Notably, ten related terms are categorised into 4 clusters with varying colour

representations in studies on enhancing students' problem-solving skills when learning physics.

Furthermore, it is evident that, compared to the other labels, the problem-solving skill label is the greatest, indicating that problem-solving skill is a keyword that often appears and correlates with other keywords.

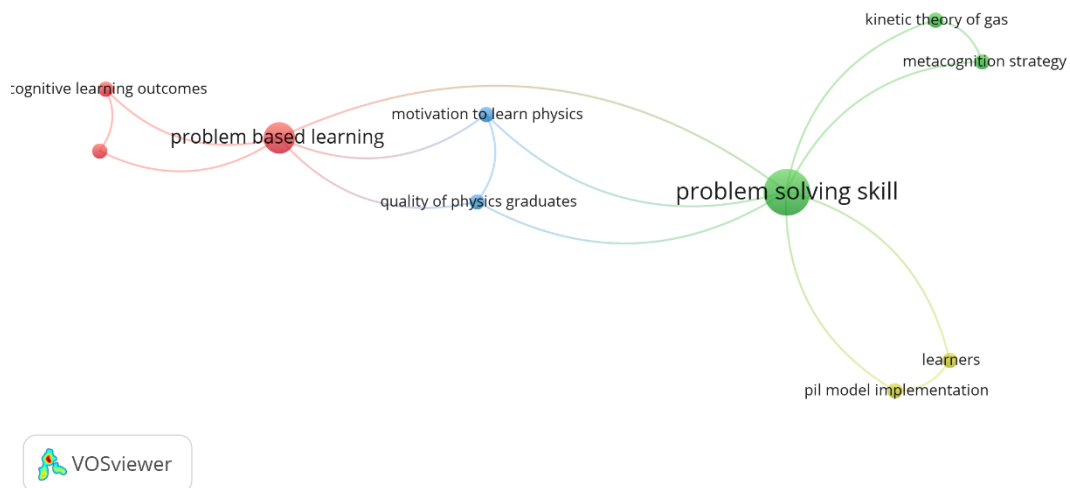


Figure 5 Imaging correlation between articles with network visualisation on keywords

Based on this imagery, there is a correlation between the keyword problem-solving skill occurring in several learning models and how it influences research. In the green cluster, problem-solving skills are closely related to the metacognition strategy, which is very influential on the topic of gas kinetic theory; research that discusses this matter is contained in an article compiled by (Himawan & Winarti, 2018). Then, in the yellow cluster, it is evident that the use of the PIL model, which significantly impacts learners, is tightly linked to problem-solving skills; research that discusses this matter is contained in articles compiled by (Wardani et al., 2021). Slightly different from other correlations, in the blue and red clusters, the keyword problem-based learning becomes a bridge between cognitive learning outcomes and differentiated learning, its effect on motivation to learn physics and the quality of physics

graduates, which are closely related to problem-solving skills. This shows that the research conducted in the entire article is dominated by research that fits these keywords.

Meta-analysis

Due to the limitation of bibliometric analysis results that only reflect the correlation of the same keywords, the impact of developing students' problem-solving skills in physics learning is investigated through meta-analysis, which considers education level, topic, method, and learning media in more detail. Table 3 displays the articles that satisfied the study's criteria. The ES values of these articles were determined using two distinct methods : one involved utilising the pretest, posttest, and standard deviation values; the other used t values and degrees of freedom. The findings of the ES calculation performed on these articles are shown in Table 5.

Table 5 ES calculation results on articles

Code	Effect Size Using Standard Deviation	Effect Size Using T-test	Criteria	Influence (%)
PS 1	1.16		Very High	88
PS 2		0.62	Medium	73
PS 3	0.74		Medium	76
PS 4		1.07	High	84
PS 5	0.74		Medium	76
PS 6	2.58		Very High	99

Code	Effect Size Using Standard Deviation	Effect Size Using T-test	Criteria	Influence (%)
PS 7	1.68	0.37	Very High	95
PS 8			Low	66
PS 9	2.44		Very High	98
PS 10	1.20		Very High	88
PS 11		1.35	Very High	92
PS 12		0.63	Medium	73
PS 13	1.29		Very High	88
PS 14	2.28		Very High	98
Average	1.29		Very High	88

Of the 14 articles, nine had research data in the form of pretest, posttest, and standard deviation values, while in the other five, research data was in the form of t-values and degrees of freedom. From the overall effect size calculation results in the articles, it was found that eight articles had very high effect criteria, 1 had high effect criteria, 4 had medium effect criteria, and 1 had low effect criteria. With an influence of 88% and an average ES of 1.29 across all data, it is clear that students' problem-solving skills

greatly impact their understanding of physics. Subsequently, each indication influencing the enhancement of students' problem-solving skills in physics learning has its ES calculated.

Each article was categorised according to the educational level of the research subject—junior high school, senior high school, and university—to determine the impact of education level on enhancing students' problem-solving skills in physics learning, shown in Table 6.

Table 6 ES determined by education level

Education Level	ES	Criteria	Influence (%)
Junior High School	0.62	Medium	73
Senior High School	1.39	Very High	92
University	0.74	Medium	76

Based on the article's overall effect size calculation results, it was determined that articles with a senior high school education level had an influence of 92% and a very high effect criterion. Therefore, compared to other educational levels, it was concluded that the Senior High School education level greatly

improved students' problem-solving skills when learning physics.

Other than that, each article is grouped according to the learning model used in the study, as shown in Table 7: PBL, STEM Learning, Metacognitive Strategy, PjBL, Discovery Learning, PIL, and IMM-PS.

Table 7 ES determined by learning model

Learning Model	ES	Criteria	Influence (%)
PBL	1.41	Very High	92
IMM-PS	0.74	Medium	76
STEM Learning	1.68	Very High	95
Metacognitive Strategy	0.78	High	79
PjBL	1.87	Very High	96
Discovery Learning	1.35	Very High	92
PIL	0.63	Medium	73

This allows researchers to determine the impact of the learning model on students' problem-solving skills during physics learning. In comparison to other

learning models, the PjBL model was found to have a very high effect on improving students' problem-solving skills when it came to learning physics,

as evidenced by the article's overall effect size calculation results, which showed that the PjBL learning model had an effect of 96% and a very high effect criterion. This is reinforced by the statement (Makrubi et al., 2018) that teaching with the project-based learning approach can assist students in connecting different aspects of problem-solving, like carrying out in-depth analyses of the issues they are encountering.

Each article was also categorised according to the learning resources utilised in the study and shown in Tabel 8, which included computer simulation, module, interactive multimedia, student worksheet, PhET Colorado, and Non-Media, in order to determine the impact of learning media on enhancing students' problem-solving skills in physics learning.

Table 8 ES determined by media

Media	ES	Criteria	Influence (%)
Computer Simulation	1.16	Very High	88
Module	0.62	Medium	73
Interactive Multimedia	0.74	Medium	76
Student Worksheet	1.41	Very High	92
PhET Colorado	1.35	Very High	92
Non-Media	1.40	Very High	92

Based on these findings, it can be concluded that, compared to other learning media, the Student Worksheet learning media had a very high effect on improving students' problem-solving skills in physics learning. The overall results of the calculation of the effect size in the article showed that the article with the student worksheet learning media had a very high effect criterion and had an effect of 92%. This is reinforced by the statement (Alatas & Yakin, 2021) that learning via the use of learning resources, such as student worksheets, may assist students in creating their knowledge

about the ideas being covered by employing technology in order to make it easier for them to solve difficulties.

And last, each article is grouped according to the learning topic used in the research (Tabel 9), which includes impulse and momentum; electricity and magnetism; wave electric magnetic; heat energy; work and energy; dynamic fluids; kinetic theory of gases; optical instruments; vertical motions; and not identify, in order to ascertain the extent to which learning topics influence students' problem-solving skills when learning physics.

Table 9 ES determined by topics

Topic	ES	Criteria	Influence (%)
Impuls and Momentum	1.12	Very High	84
Electricity and Magnetism	0.62	Medium	73
Wave Electric Magnetic	0.74	Medium	76
Heat Energy	2.58	Very High	99
Work and Energy	1.68	Very High	95
Dynamic Fluid	2.44	Very High	98
Kinetic Theory of Gases	1.28	Very High	88
Optical Instrument	1.29	Very High	88
Vertical Motion	2.28	Very High	98
Unidentified	0.58	Medium	73

In comparison to other learning topics, the topic of Heat Energy learning

had a very high effect on improving students' problem-solving skills in

physics learning, as determined by the overall results of the calculation of the ES in the article, which showed that the article with the topic of Heat Energy learning had an effect of 99% and a very high effect criterion.

CONCLUSION

With an average ES of 1.29 and an effect of 88%, the research's findings using the meta-analysis suggest that students' problem-solving skills have a very high influence on learning physics. If the PjBL learning model is used at the senior high school education level, it will significantly impact students' ability to solve problems when learning physics. Furthermore, it is strongly advised that study materials like student worksheets be used while covering subjects like heat energy.

It is anticipated that the outcomes of this meta-analysis study will guide educators in selecting the most appropriate model, learning materials, and subject matter to enhance students' problem-solving skills in physics learning. Additionally, the findings of this meta-analysis study may serve as a useful source of information for future investigations aimed at enhancing students' problem-solving skills in physics learning.

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