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The Impact of the Project-Based Learning Model on Students' Critical and Creative Thinking Skills in Science and Physics Learning: A Meta-Analysis

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Abstract: This research is a meta-analysis to see the influence of the Project-Based Learning (PjBL) model in learning science and physics on students' critical and creative thinking skills. The method used is meta-analysis with a population and research sample, namely scientific articles that have been published through Google Scholar on a national to international scale in 2016–2023, that discuss the application and influence of the PjBL model in learning science and physics on students' critical and creative thinking skills. Overall, the results of the research show that the application of the PjBL model in learning science and physics has an influence in the high category, both on students' critical and creative thinking skills. In the school-level category, the implementation of the PjBL model had the highest effect on students' critical thinking skills at university levels. Whereas in terms of creative thinking skills, the implementation of PjBL has the highest influence at the elementary school levels. In the subject category, the application of the PjBL model has a high effect on both critical thinking skills and creative thinking when applied to science and physics subjects.

Keywords: Creative thinking skill; Critical thingking skill; Meta-analysis; Physics; Project-based learning; Science

Introduction

The rapid development of science and technology in the 21st century requires teachers to be able to keep up with these developments (Devanda et al., 2023). The educational process in schools must be able to help and prepare students to face developments in the current era (Firda & Sunarti, 2022). Students must be able to study independently, seek information, and have good competence (Azmi & Festiyed, 2023b), so that not only knowledge is needed but also skills, because skills are an important component needed in various fields of life (Saputri et al., 2022).

The main skills needed for the development of science and technology in the 21st century include critical and creative thinking skills (Lestari, 2021). Critical and creative thinking skills are needed to enable students to solve the problems they face (Asman et al., 2022). Critical thinking skills can help the success of learning because critical thinking does not only involve processes but also involves the ability to predict, analyze, synthesize, evaluate, reason, and so on (Sumardiana et al., 2019). Creative thinking skills refer to a person's ability to create something new and useful. The average person can build and discover fresh answers to issues by thinking creatively. Besides that, creative thinking is also able to facilitate the disclosure of knowledge and imagination (Leasa et al., 2023).

Critical and creative thinking skills are needed in learning science. Science is a study of natural occurrences, including includes inanimate as well as animate things (Gunawan et al., 2018). Science education holds a special part in developing students who are capable of thinking critically, creatively, rationally, and

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take effort in dealing with scientific and technological improvements. Physics, as a discipline of science that examines phenomena of nature, educates human beings skills to live in harmony with natural laws. Physics, according to Giancoli (2001), is fundamental knowledge because it discusses the behavior and structure of an object (Halmaida et al., 2020). Physics learning requires students to conduct research, experiments, and practicums so that they can find and build a conceptual understanding of the phenomena they face (Azmi & Festiyed, 2023a).

The rapid progress of science and technology needs to be balanced by an increase in learning quality, especially in physics (Ashel & Lestari, 2023). The problem that frequently appears in the current implementation of physics learning is a lack of opportunities for students to take part actively in the learning process (Ansori et al., 2019). The majority of students continue to possess misconceptions about physics (Martawijaya et al., 2023).

Project-based learning (PjBL) is a learning model in which students act as subjects who have a fundamental role in their educational experience (Ansori et al., 2019). PjBL can help students develop problem-solving abilities and give meaningful learning, according to Ibragimov (2021), by leading them to construct knowledge and procedures and complete their own work (Chistyakov et al., 2023). PjBL is also possible outside of the classroom environment, using a variety of equipment and technologies (Mihardi et al., 2013). With the implementation of PjBL, students are able to be guided in solving learning challenges and given the opportunity to study various real-life issues and gain knowledge from multiple sources (Fiteriani et al., 2021). The application of the PjBL model in physics education will help students improve their critical and creative thinking skills (Asman et al., 2022).

There has been a lot of study done on the impact of using the project-based learning approach in physics learning on students' critical and creative thinking skills. According to the findings of Rauziani et al. (2016) study, "Implementation of the Project Based Learning (PjBL) Model in Improving Student Learning Outcomes and Critical Thinking on Static Fluid Material at Inshafuddin High School," the use of the PjBL model in learning physics on fluid material had a positive impact on a high category of students' critical thinking skills (Rauziani et al., 2016). The results of a study conducted by Andrini et al. (2019) on "The Effect of Flipped Classroom and Project-Based Learning Model on Students' Critical Thinking Ability" revealed that the use of the PjBL model in the learning process had an influence on the medium category (Andrini et al., 2019). According to the findings of a study conducted by I Made Astra et al. (2019) named "Effect of Project-Based Learning Model Assisted by Student Worksheet on Critical Thinking Abilities of High School Students," the application of the PjBL model in learning physics can enhance students' critical thinking skills in the medium category (Astra et al., 2019). The results of Nur Diana Rosyidah's et al.'s (2020) research on "Students' Critical Thinking Skills through the PjBL STEM Model accompanied by Authentic Assessment of Static Fluid Material" indicated that the application of STEM-integrated PjBL accompanied by authentic assessment had a low effect on students' critical thinking skills (Rosyidah et al., 2020).

On students' creative thinking skills, based on the research of Marivane de Oliveira Biazus and Sayidah Mahtari (2022), entitled "The Impact of Project-Based Learning (PjBL) Model on Secondary Students' Creative Thinking Skills" it was found that the implementation of PjBL had a significant impact on improving students' creative thinking skills in physics material (Biazus & Mahtari, 2022). The findings of Chairatul Umamah and Herman Jufri Andi's study on "The Effect of the Project Based Learning Model on Creative Thinking Skills in Applied Physics Learning" show that there is a significant influence from the application of the PjBL model in physics learning on students' creative thinking skills when compared to students who study without PjBL models (Umamah et al., 2019). Whereas in Chasanah's et al. (2016) research with the title "Effectiveness of the Project Based Learning Model on Science Process Skills and Students' Creative Thinking Ability in the Subject of Heat Class X SMAN 1 Wonosegoro Academic Year 2014/2015", the results showed that there is an increase in the creative thinking skills of students who use the PjbL model in physics learning compared to those who do not, but the effect is still in the moderate category in both classes (Chasanah et al., 2016).

Previous research has limitations, including the results described in the study do not explain the effect of similar studies on different science and physics topics and it does not explain the effect of applying the PjBL model at different grade levels and educational levels on students' critical and creative thinking skills. Based on these constraints, this study used meta-analysis to assess the extent of the influence of multiple similar studies on the implementation of the PjBL model in science and physics learning on students' critical and creative thinking skills.

Glass (1976) describes meta-analysis as "a statistical analysis of a set of analysis results from individual studies for the purpose of integrating the findings" (Kulik et al., 1989). Meta-analysis is research that is conducted to assess empirical studies carried out by previous researchers. This study is accomplished by summarizing, integrating, synthesizing, and analyzing

the findings of selected studies in various domains of science (Retnawati et al., 2018). There have been many studies discussing the effect of the PjBL model in learning science and physics on students' critical and creative thinking skills, but there has been no research on the effect of several similar studies regarding the use of the PjBL model in learning physics on students' abilities to think critically and creatively.

Method

This study is a meta-analysis that takes a quantitative approach. The purpose of this research is to examine several national and international articles as well as articles in national and international proceedings on the same topic. The article criteria used were research studies published in the last eight years from 2016 to 2023, had a DOI, samples were gathered from elementary schools to universities, and included information that might support meta-analysis as well as descriptive statistical information to estimate effect size values.

The articles that were used in this study can be found on Google Scholar. Independent variables, dependent variables, and moderator variables are used. In this study, the independent variable is the project-based learning model, the dependent variable is students' critical and creative thinking skills, and the moderator variables are scientific and physics lessons as well as education level.

The research procedure started with determining the research topic, determining the period and criteria for articles to be analyzed, collecting relevant articles into one folder, writing research data, and then determining the effect size of each article (Asrizal et al., 2022). The collected articles are then analyzed using meta-analysis research analytical techniques, including calculating or determining the value of the effect size using Cohen's d equation and calculating the conclusions from the effect size using the random effect model and the fixed effect model. The categorization of the effect size data is shown in Table 1.

Table 1. Catagorizes of Effect Size (Becker, 2000)

Effect size	Category
$0 \leq ES \leq 0.2$	Low
$0.2 \leq ES \leq 0.8$	Medium
$ES \geq 0.8$	High

Result and Discussion

Based on the results of the heterogeneity test that has been carried out, it can be seen that the random effect model is suitable to be used to determine the magnitude of the influence of several similar studies regarding the project-based learning model in science and physics learning on students' critical and creative thinking skills.

Based on the data collected currently, only 27 articles match the criteria, and the effect size can be determined based on the 85 articles obtained. The 27 articles were summarized in the form of coding for analysis to determine the size of the influence between variables in each of the research reviewed and used to draw conclusions.

The weakness of this meta-analysis article's explanation is that it uses phases to test the hypothesis. The p-value is obtained by determining the effect size. The meta-analysis results indicate that if the p value < than the significant value (0.05), then there is an influence from the implementation of the PjBL model in scientific and physics learning on students' critical and creative thinking skills. The study of the 27 articles revealed the following results.

Analysis of the Effect of Similar Articles on Students' Critical Thinking and Creativity Skills

Data collected by researchers Google Scholar. The 27 articles used in this study met the following criteria: PjBL learning model research, used in science and physics learning, and their influence on students' critical and creative thinking skills.

The 27 articles with codes A1 to A27 analyzed and the calculated effect sizes were grouped according to three criteria: students' critical and creative thinking skills, education level, learning Table 2 presents findings from an analysis of the entire article in the effect of the PjBL learning model onthe PjBL model of students' critical and creative thinking skills in science and physics learning.

Based on the results of the effect size analysis of the 27 similar articles listed in Table 2, the Z value of the 27 articles is 6.4. The results of the hypothesis test show that the value of the p value < α indicates that the hypothesis H_o is rejected. H_o's rejection indicates that overall, there is an influence from the use of the Project Based Learning (PjBL) model in learning science and physics on students' critical and creative thinking skills.

The results of the analysis of the collected data show that the application of the PjBL model in learning science and physics has a positive and significant impact on students' critical and creative thinking skills. The application of the PjBL model is one of the innovations in learning that can encourage students to come up with creative and critical ideas and solutions to solve a problem in learning (Fitriyah et al., 2021). The application of PjBL allows students to understand concepts that are meaningful to them and can improve their thinking abilities, such as cause-effect thinking, predicting reasonable results, analyzing data through

various points of view, evaluating, and creating (Sumarni et al., 2020).

In Table 3, an analysis of similar articles is presented regarding the application of the PjBL model in science and physics learning to students' critical and creative thinking skills separately. The PjBL model has a major influence on students' critical and creative thinking skills. For critical thinking skills, an effect size of 1.270 is obtained, and for creative thinking skills, it is 1.308. The results of the p-value analysis show that these two skills have a p-value < 0.05, which indicates that the application of the PjBL model in science and physics learning has a significant influence on students' critical and creative thinking skills.

Table 2. The Result of Calculating the Effect Size of a Number of Similar Articles on Students' Critical Thinking and Creativity Skills

Resource	Code	Y_i	V_{Yi}	T^2	$V_{Yi} + T^2$	W_i*	W_i*Y_i
(Chasanah et al., 2016)	A1	1.124	0.0765	0.5056	0.5821	0.9193	1.0338
(Umamah & Andi, 2019)	A2	0.564	0.0930	0.5056	0.5986	0.9056	0.5110
(Yunus et al., 2016)	A3	1.308	0.0741	0.5056	0.5798	0.9213	1.2052
(Andi et al., 2019)	A4	1.140	0.0768	0.5056	0.5824	0.9191	1.0474
(Ridlo et al., 2020)	A5	0.903	0.0521	0.5056	0.5577	0.9404	0.8492
(Mawarni & Sani, 2020)	A6	0.641	0.0588	0.5056	0.5645	0.9345	0.5994
(Permata et al., 2018)	A7	0.967	0.0765	0.5056	0.5821	0.9193	0.8888
(Biazus & Mahtari, 2022)	A8	1.278	0.0938	0.5056	0.5995	0.9049	1.1565
(S. U. Putri et al., 2019)	A9	2.553	0.1586	0.5056	0.6642	0.8548	2.1820
(Parno et al., 2022)	A10	1.130	0.0887	0.5056	0.5943	0.9091	1.0277
(Khoiri et al., 2016)	A11	0.430	0.0572	0.5056	0.5628	0.9359	0.4022
(Nurfa & Nana, 2020)	A12	0.680	0.0548	0.5056	0.5604	0.9381	0.6378
(Saefullah et al., 2021)	A13	0.878	0.0711	0.5056	0.5768	0.9239	0.8113
(Viana et al., 2019)	A14	1.438	0.0818	0.5056	0.5874	0.9149	1.3154
(Rahardhian, 2022)	A15	1.798	0.0136	0.5056	0.5193	0.9757	1.7543
(Andrini et al., 2019)	A16	2.393	0.0191	0.5056	0.5247	0.9706	2.3223
(Pratama & Prastyaningrum, 2016)	A17	2.859	0.3406	0.5056	0.8462	0.7397	2.1149
(Widyasmah et al., 2020)	A18	2.866	0.1988	0.5056	0.7044	0.8264	2.3688
(Muhibbuddin et al., 2020)	A19	1.564	0.0404	0.5056	0.5461	0.9508	1.4871
(Astra et al., 2019)	A20	1.080	0.0642	0.5056	0.5698	0.9298	1.0043
(Atmojo et al., 2023)	A21	3.046	0.1523	0.5056	0.6579	0.8594	2.6182
(Fauziah et al., 2023)	A22	1.645	0.1046	0.5056	0.6102	0.8962	1.4745
(Rahim et al., 2019)	A23	0.147	0.0750	0.5056	0.5807	0.9206	0.1356
(Alawi & Soh, 2019)	A24	0.790	0.0732	0.5056	0.5788	0.9221	0.7289
(Suastra & Ristiati, 2019)	A25	0.815	0.0705	0.5056	0.5761	0.9244	0.7532
(Lou et al., 2017)	A26	1.194	0.0739	0.5056	0.5795	0.9215	1.1004
(Dywan & Airlanda, 2020)	A27	0.254	0.0193	0.5056	0.5249	0.9703	0.2461
Total						24.649	31.776
M*							1.2892
VM*							0.0406
SEM*							0.2014
LLM*							0.894
ULM*							1.684
Z							6.400
p-Value							0.0000

In students' critical thinking skills, the application of the PjBL model can make students face real-world problems where they are required to find solutions to overcome these problems by making projects. The making of the project is able to cause students to be active in the learning process (Efendi et al., 2020). This is also supported because the syntax of the PjBL model contains various activities that can encourage students to think and play an active role during the learning process (Nawangsari et al., 2022).

The application of the PjBL model to creative thinking skills can train students to find multiple solutions to problems they face, find multiple ideas, and be able to explore these ideas in detail (Putri et al., 2021). In addition, with the implementation of PjBL, students are asked to be able to make a project where creativity is needed in making the project so that they can solve the problems they face (Sudianto et al., 2019). Therefore, it can be stated that the PjBL model is one of the most appropriate and innovative learning models to be used in developing students' 21st century skills (Putri et al., 2019).

Table 3. Effect of Similar Articles Based on Dependent Variables

Skill	Code	ES	SEM	LLM	ULM	p	Decision
Critical Thinking Skill	A3 A7 A10 A15 A16 A17 A19 A20 A22 A23 A24 A25 A27	1.270	0.314	0.654	1.886	0.000	Rejected H_o
Creative Thinking Skill	A1 A2 A4 A5 A6 A8 A9 A11 A12 A13 A14 A18 A21	1.308	0.259	0.800	1.815	0.000	Rejected H_o

Analysis of the Effect of Similar Research Based on School Level

Table 4 shows the research findings regarding influence PjBL learning model for students' critical and creative thinking skills in science and physics learning based on education level, with elementary level, junior high school level, senior high school level, and university level**.**

In Table 4, data is presented on the results of an analysis of the effect of implementing PjBL in learning science and physics at educational levels consisting of elementary schools, junior high schools, high schools, and universities. In terms of critical thinking skills, the application of PjBL has a high impact when applied in elementary schools and has the highest impact at the university level. Whereas for creative thinking skills, the application of the PjBL model has a high influence on creative thinking skills in its application at the university and has the highest influence when it is applied in elementary schools.

Table 4. Effect of Similar Articles Based on School Level

School Level	Skills	ES	SEM	LLM	ULM	p	Decision
Elementary School	Critical Thinking	0.934	0.967	-0.963	2.830	0.167	Accepted H_o
	Creative Thinking	2.808	0.209	2.398	3.218	0	Rejected H_o
Junior High School	Critical Thinking	1.322	0.679	-0.010	2.653	0.026	Rejected H_o
	Creative Thinking	1.241	0.194	0.861	1.622	0.000	Rejected H_o
Senior High School	Critical Thinking	1.006	0.230	0.555	1.457	0.000	Rejected H_o
	Creative Thinking	1.102	0.266	0.582	1.623	0.000	Rejected H_o
University	Critical Thinking	1.622	0.572	0.500	2.744	0.002	Rejected H_o
	Creative Thinking	0.815	0.127	0.565	1.065	0.000	Rejected H_o

In calculating the p-value, it can be seen that the aspect of critical thinking skills at every level of education has a p-value < 0.05 except at the elementary school level, where it has a p-value of 0.167 > 0.05. So that it can be concluded that at the junior high school to university education levels, Ho is rejected, which indicates that there is a significant influence from the application of the PjBL model on students' critical thinking skills, whereas at the elementary school level, Ho is accepted, which indicates that although there is an influence from the application of PjBL on students' critical thinking skills, this effect is not significant. For

the calculation of the p-value for aspects of creative thinking, it can be seen that from the elementary school level to the university, the p-value < 0.05 indicates that there is a significant effect of the application of the PjBL model in learning on students' creative thinking skills.

Based on the theory of constructivism by Piaget, it is emphasized that skills can be built in a child's mind. In the implementation of PjBL, knowledge is built by the students themselves through understanding an existing problem through group discussions (Atmojo et al., 2023). The teacher only acts as a facilitator, so students are given complete freedom in the learning process (Nadiyah & Tirtoni, 2023). With this freedom in learning, it causes students to be more enthusiastic about accepting the material provided by the teacher, thus giving rise to new ideas to solve problems in learning (Mabruroh, 2019). The application of the PjBL model in elementary schools is able to create a pleasant atmosphere during the learning process, so as to reduce students' fear and tension during the learning process (Gunawan et al., 2018).

The PjBL model can be used as an alternative learning strategy in high schools (Hanif et al., 2019). This model's implementation emphasizes challenging problems and complex activities in order to encourage students to be able to create, manage work, and generate genuine products (Paramita et al., 2023) to resolve the problems that have occurred (Yamin et al., 2020). With the use of PjBL, students can develop critical thinking skills and self-efficacy, allowing them to evaluate their own work and generate realistic criticism of the power of their own reasoning (Mutakinati et al., 2018).

In the learning process, students learn by connecting previous knowledge with new knowledge so that meaningful understanding can be obtained. In addition, students are allowed to build their knowledge independently through a process of inquiry and exploration, so that they can be encouraged to think more critically (Issa & Khataibeh, 2021). By applying the PjBL model, students can also understand basic concepts and ideas better and are able to interact well with fellow students, encouraging them to think inclusively when formulating their own hypotheses. Such a learning atmosphere is also able to stimulate increased student achievement and motivation (Widyantini et al., 2023).

In addition to implementing it in schools, the PjBL model also needs to be implemented at the university level. Critical thinking skills are also needed for students to be able to explore and evaluate various kinds of information. By adopting one of the best learning techniques, such as PjBL, lecturers can offer students the tools to solve problems, make good decisions, and identify solutions for future learning experiences and professional careers (Dimmitt, 2017). In addition to critical thinking skills, creative thinking skills are also needed. The application of the PjBL model at the university level can effectively improve students' creative thinking skills (Setyarini et al., 2020).

Analysis of the Effect of Similar Research Based on the Subject Learning

The PjBL learning model influences students' critical and creative thinking skills based on science and physics subjects. This can be seen in table 5 which shows that the heterogeneity test results on for 2 subjects, it was found that science and physics showed a value of Q> df, so the estimated variance between articles was quite large and the data was heterogeneous.

Table 5 presents the results of data analysis of similar articles regarding the application of the PjBL model to students' critical and creative thinking skills based on integrated subjects, namely science and physics. It can be seen from the results of the analysis that the application of the PjBL model has a high effect when applied to science and physics learning on students' critical and creative thinking skills. In the aspect of critical thinking, the application of the PjBL model has the highest influence when applied to physics subjects, while in creative thinking skills, the application of PjBL has the highest influence when applied to science subjects.

Table 5. Effect of Similar Articles Based on Subject Learning

Subject Learning	Skills	ES	SEM	LLM	ULM	P	Decision
Science	Critical Thinking	1.244	0.578	0.111	2.377	0.016	Rejected H_o
	Creative Thinking	1.999	0.614	0.796	3.257	0.0006	Rejected H_o
Physics	Critical Thinking	1.279	0.350	0.592	1.965	0.0001	Rejected H_o
	Creative Thinking	1.020	0.209	0.610	1.431	0.000	Rejected H_o

In calculating the p-value of the data, it was found that both in the application of PjBL in science or physics learning, a p-value < 0.05 was obtained, with the conclusion that Ho was rejected both in critical and creative thinking skills. This indicates that there is a significant influence from the application of the PjBL model in learning science and physics on students' critical and creative thinking skills.

Science learning is synonymous with natural and artificial resources. The application of the PjBL model in science learning is able to utilize existing items in students' daily lives for project creation (Dywan &

Airlanda, 2020). The PjBL model is able to increase student activity in the learning process (Paramita et al., 2023). The application of PjBL is able to improve students' critical thinking skills in learning science (Sumarni & Kadarwati, 2020). With the application of PjBL in science learning, it is able to train students to analyze the relationship between the concepts they learn at school and situations in the real world, so that students get meaningful learning (Rahmawati et al., 2021). With PjBL in science learning, it can also improve students' creative thinking skills (Putri et al., 2019). With the PjBL model, students are asked to take part in the PjBL process, which consists of preparation, implementation, presentations, evaluations, and correction. The process has an impact on improving students' design and production abilities, including student creativity (Lou et al., 2017).

Learning physics is a process based on hypotheses, research, experiments, and the development of thinking processes (Rohman et al., 2021), where in the learning process it is not enough to study the product but also to make the product, both in a scientific process and in the development of students' scientific attitudes (Handayani, 2019). Therefore, critical and creative thinking skills are needed in the thinking process. There is a significant influence from the application of PjBL in learning physics on students' critical thinking skills (Rahardhian, 2022). The application of PjBL in physics learning provides opportunities for students to be more active in learning and to think more critically (Rahim et al., 2019), so students have the ability to think better (Issa & Khataibeh, 2021). In addition to critical thinking skills, the application of PjBL in physics learning is also able to improve students' creative thinking skills in physics learning (Nurfa & Nana, 2020). These creative thinking skills can also help students solve problems in learning physics that they face (Viana et al., 2019).

Conclusion

The main conclusions from the research results is the use of the project-based learning (PjBL) model in learning science and physics has a significant influence on students' critical and creative thinking skills. The application of the PjBL model based on educational level, showing the aspect of students' thinking skills, has a high influence on its application at the elementary school level and has a higher influence on its application at the junior high school to university levels. Whereas in the aspect of creative thinking skills, the PjBL model has a high influence on its application at the university level and a higher influence at the elementary to high school levels. Based on the integrated subjects, both in their application to science and physics subjects, the application of the PjBL model has a high influence on critical and creative thinking skills. So the application of the PjBL model in learning science and physics influences students' critical and creative thinking skills based on educational level as well as the integrated material. This research can be used as a reference for innovation and strategies in learning, namely using the PjBL model in learning science and physics based on educational level.

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Author Contributions
Nur Hikmah: writing-original draft preparation, analyzingthe research data, writing the result and editing; Dhea Febriya: writing the methodology, discussion, and conclusion; Asrizal and Fatni Mufit proofreading and reviewing.

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Conflict of Interest
The authors declare that there is no conflict of interestregarding the publication of this paper.

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