Jurnal Inovasi Pembelajaran

JINoP. November, 2023, 9 (2): page 191-209
p-ISSN 2443-159, e-ISSN 2460-0873
https://doi.org/10.22219/jinop.v9i2.22142

Effectiveness of project-based learning for enhancing students critical thinking skills: A meta-analysis

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uploaded: 11/Aug/2022
revised: 05/May/2023
accepted: 04/Sep/2023
published: 22/Nov/2023

Tafakur, T., Retnawati, H., & Shukri, A. A. M. (2023). Effectiveness of project-based learning for enhancing students critical thinking skills: A meta-analysis. *JINoP (Jurnal Inovasi Pembelajaran)*, 9(2), 191–209. https://doi.org/10.22219/jinop.v9i2.22142

Abstract

Innovative learning models like Project-based learning are believed to encourage not only the achievement of student learning outcomes but also 21st-century skills. Many studies on Project-based learning are related to developing 21st-century skills, one of which is critical thinking, with different results. Therefore, it is necessary to conduct a study that can elaborate on various studies on the effectiveness of Project-based learning on students' thinking skills. This study aims to determine the difference in critical thinking skills between students participating in project-based learning and other models. This study uses a quantitative approach with meta-analysis. The data is secondary data from studies published in journal articles indexed by Scopus and Google Scholar in the last ten years with a total of 29 studies that are suitable for analysis. The estimated aggregate is the difference between groups. Data analysis used Comprehensive Meta-Analysis Vers.3 to calculate and estimate aggregates, draw forest plots, test hypotheses, and analyze biases. The analysis results show that Project-based learning promotes students' critical thinking skills, although moderated by education level and comparative learning strategies. Project-based learning is superior to traditional learning at various levels of education. Project-based learning and other scientific learning are known to support students' critical thinking skills. Teachers can also make PjBL more innovative by utilizing information technology, and the contextual environment, as well as integrating various media, content, and other learning strategies to encourage student critical thinking skills.

Keywords: Critical thinking skill; Instructional strategy; Meta-analysis; Project-based learning.

INTRODUCTION

The innovative learning model emphasizes student activity-oriented learning to encourage 21st-century skills. Various learning models have emerged since the discovery of various learning theories as one of the developments in education.

One innovative instructional model is Project-Based Learning (PjBL). PjBL is a type of indirect instruction strategy (Rüütmann & Kipper, 2011), that is in line with the characteristics of constructivist learning, which suggests how learners can construct knowledge based on experiences encountered in real life (Jumaat et al., 2017). PjBL tends to emphasize the construction of knowledge (Guo et al., 2020). With constructivist learning, teachers enable students to make classroom rules and class decisions, discuss social and moral issues, conflict resolution and consult what students want to learn (DeVries, 2000). So far, many studies have been conducted regarding implementing project-based learning. PjBL models are believed to encourage students' cognitive, affective, and behavioral aspects (Guo et al., 2020). Additionally, it has been demonstrated that project-based learning treatments raise higher-order cognitive abilities, self-efficacy, teamwork, and communication abilities (Fini et al., 2018). Involving students in brainstorming activities is believed to be an effective learning strategy.

PjBL is believed to be very useful for encouraging the 4Cs identified by the 21st-century framework to support students participate in more profound levels of participation, including critical thinking, communication, collaboration, and creativity (Dede, 2010; Estrada et al., 2020). On the other hand, in implementing PjBL, it is necessary to rely on the 4Cs to encourage students to solve real and meaningful problems through designed projects (Treadwell, 2018). This shows that innovative learning, such as project-based learning, is believed to shape students' critical thinking skills and vice versa and also requires students' critical thinking skills to implement. Critical thinking abilities are anticipated to support the 2030 Sustainable Development Goals (SDGs) as a crucial 21st-century ability. Based on the survey results, various skills needed in education until 2030 with critical thinking skills are the most needed (Unesco-Unevoc, 2020). However, research on factors related to critical thinking in a digital context is still scant (van-Laar et al., 2020). Various studies have revealed that PjBL significantly affects students' critical thinking skills (Issa & Khataibeh, 2021; Sasson et al., 2018). However, several studies show insignificant effects of the consequences of using PjBL against other learning models on students' critical thinking skills (Muluk et al., 2015; Sari et al., 2019; Triningsih & Mawardi, 2020). Therefore, by looking at various research results that have implemented PjBL, it is necessary to examine how effective it is as an innovative learning model in promoting students' critical thinking skills. Meta-analysis was conducted to see the findings of several studies' quantitative research that have been conducted on students' critical thinking skills. By knowing more about how effective it is, it is hoped that it will be useful for practitioners in the field of education to consider the application of project-based learning models in their learning. With meta-analysis, this study seeks to answer research questions: 1) How is the effectiveness of project-based learning in supporting students' critical thinking skills? and 2) How does project-based learning affect students' thinking skills compared to various other learning strategies at various levels of education?

LITERATURE REVIEW

PjBL is one type of indirect instruction (Rüütmann & Kipper, 2011). In project-based learning, students complete a sequence of tasks and issues that lead to the creation of something physical (such as artifacts, media, or performances)(Petrina, 2006). PjBL is, to put it more precisely, an active, student-centered style of instruction that emphasizes student autonomy, goal-setting, productive inquiry, communication, cooperation, and reflection on actual practice (Kokotsaki et al., 2016). Even PjBL is said to be a form of individualization in which Students choose assignments and tasks that encourage and promote the development of their knowledge and skills. PjBL provides assignments stemming from problems. Students are required to solve problems independently with authentic problems to enable the development of student's skills and knowledge. PjBL is organized around the creation, execution, and completion of the production of something (Fogarty, 1997). Therefore, this learning can encourage students to be creative and develop skills on an ongoing basis.

PjBL will help students communicate better, learn new information, solve problems in context, and practice the design process, leading to professionally prepared students (Gary, 2015). Furthermore, collaborative projects with ICT can encourage effective and meaningful learning experiences linked to realistic, practical practices and as the catalyst for helping improve learners' interaction with the information (Al-Taai, 2022). This explanation is also relevant that the constructivist approach is applied to PjBL, for instructors or teachers are advised to meet the guidelines: 1) Teachers must understand students' prior knowledge so that when exploring new knowledge, students need to bring the knowledge they already have; 2) the teacher facilitates the learning process to help students gain new knowledge and complete assignments; 3) the teacher must plan the subject matter and the method of assessment used during the teaching and learning process; 4) learning activities must allow students to work in groups collaboratively with their peers; 5) learning activities must be realistic and authentic (Jumaat et al., 2017).

Epistemologically, the project-based learning approach, which is founded on the educational philosophy of progressive educators and constructivist learning theory can be implemented through several learning steps/syntax. The PjBL procedure is divided into six phases. The teacher starts by outlining the essential information, comprehension, and abilities needed by the class to finish the project. Second, the teacher offers driving questions that specify developmental difficulties that must be solved or particular questions that must be resolved by the end of the project. Third, instructors engage students in ongoing research projects and educational activities both within and beyond the classroom. Fourth, there is a time for teachers and students to discuss the learning process, standards for good work, and how to get over potential obstacles. Fifth, students are given time to evaluate and edit their work using a self- and peer-review process based on the teacher-provided criteria. When it is practicable, the product is shown to the public at its final stage; nevertheless, the instructor may select the presentation format they feel is most appropriate (Treadwell, 2018).

Many studies have proven the significant advantages of implementing PjBL, such as encouraging motivation and learning outcomes (Maros et al., 2021; Tafakur & Suyanto, 2015), affecting creativity and critical thinking (Anazifa & Djukri, 2017; Sumarni & Kadarwati, 2020; Yustina et al., 2020), build students' confidence and teamwork (Sakulvirikitkul et al., 2020), enhance student more active (Anggraini & Wulandari, 2021), produced student engagement (Almulla, 2020), is very interesting learning for students (Maros et al., 2021), and encourage elaboration, critical thinking, self-regulation, metacognition, and higher autonomic support (Stefanou et al., 2013). Thus, from elementary school through higher education, the PjBL paradigm has been investigated in a variety of settings. However, in most studies, a causal relationship between PjBL instruction and positive student outcomes cannot be scientifically established (Kokotsaki et al., 2016). Based on a study that has been conducted Chen & Yang (2019) on 30 journals from 9 countries, when compared to traditional instruction, PjBL is recognized to have a medium to significant favorable impact on student's academic progress. Another study was also conducted by Balemen and Özer Keskin (2018) on 48 studies and found that PjBL was found to have a great effect size in the field of science at different levels (primary, secondary, and tertiary) on student`s academic achievement so that PjBL can therefore be considered more successful than conventional learning strategies. In applying PjBL to critical thinking skills, a meta-analysis study conducted by Anggreni et al. (2019) states that the effect size results are low to high. However, according to this study, PjBL has an impact on students' capacity for critical thought in the context of high school physics classes.

METHODS

This study uses a quantitative approach with a meta-analysis type. We followed the meta-analytic procedures suggested by Field and Gillett (2010) by doing the following steps: 1) Do a literature search, 2) Decide on inclusion criteria, 3) Calculate the effect sizes, 4) Do the basic meta-analysis, 5) Do some more advanced analysis for analyzing Moderator and Estimating publication bias, and 6) Write it up. Data analysis used Comprehensive Meta-Analysis software to calculate and estimate aggregates, determine the distribution of effect size on forest plots, moderator analysis, and analysis of publication bias estimates. The estimated aggregates are the mean and differences between groups. Therefore, the information used in this study is secondary and was found in journal papers from 2012 to 2022 that were indexed by Scopus and Google Scholar.

Literature search and selection

This study aims to answer questions about how Using project-based learning strategies can help students develop their critical thinking skills. To obtain research studies that have been carried out previously, we searched for research articles published in national and international scientific journals from various databases. The search was carried out using a search engine on the Scopus and Google Scholar databases through search keywords for the title, abstract, and keywords of the research article. The search keywords were: "project-based learning critical thinking, project-based learning, critical thinking, critical thinking skills." The search is

limited to the publication of scientific articles in the last ten years or 2012-2022, to ensure that the research results of the studies mapped are up to date.

Search, identification, and selection

An electronic search was conducted through the Google Scholar and Scopus databases with relevant keywords, and 4.449 articles were obtained from various studies. The results of this study were then selected for relevant studies involving project-based learning and critical thinking, and 203 relevant studies were obtained. The study's objectives, these various studies selected studies using an experimental/quasi-experimental design and obtained 96 studies. The experimental design was chosen utilizing a group comparison design with a non-equivalent control group design and a posttest-only control group design out of the 96 experimental studies conducted by various researchers. Forty-nine studies using this design were obtained from the results of this selection. Furthermore, the availability of complete research data was examined and obtained in as many as 29 studies with complete data. In full, it can be seen in Figure 1.

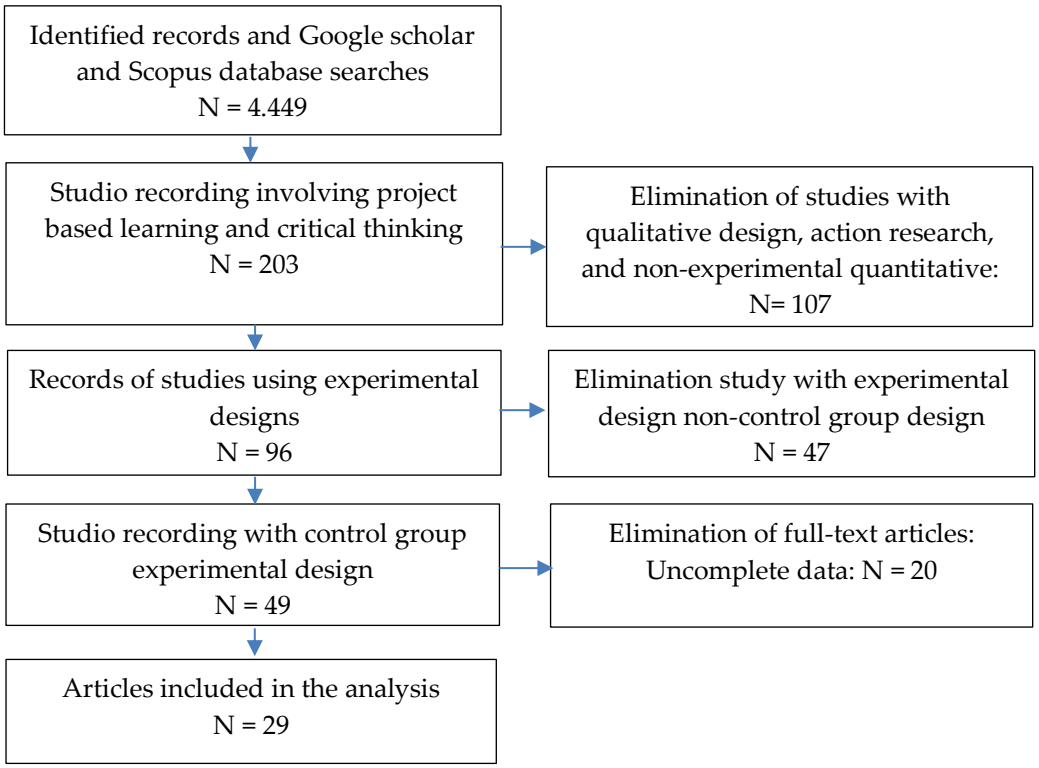

Figure 1. The process of identification and selection of analyzed studies

Selection Criteria

We selected the analyzed studies to ensure that the analyzed studies were relevant and supported the acquisition of strong information. Several selection criteria for the studies included: type of publication, year of publication, language used, and research design. The selection criteria we used to determine the analyzed studies can be seen in Table 1.

Table 1. Study selection criteria analyzed

No	Criteria	Study taken	Eliminated studies
1	Publication Type	peer-to-peer review journal article	In addition to peer-to-peer review journal articles
2	Publication Year	Last ten years (2012-2022)	Before 2012
3	Language used	English Indonesian	Languages other than English and Indonesian
4	Research design	Experiments/Quasi-experiments with control groups involving project-based learning models/strategies for critical thinking	- qualitative study -action research -non-experimental research -non-control group experimental research

Final selection and data extraction

The study records that have been selected are then extracted with data to answer the questions that have been asked. The data extracted were: author and year of publication, mean critical thinking ability score, the standard deviation of critical thinking ability, sample size, t-count value, and effect direction. Based on data extraction results from 29 studies, data were obtained from 19 studies that included complete mean, standard deviation, and sample size data, as well as 10 studies that did not include standard deviation information but t-count values. Thus, it is still possible to calculate the effect size for the 29 specified studies.

Data analysis

Analysis of this research data is using the software Comprehensive Meta-Analysis V3. The tests carried out included heterogeneity tests and meta-analysis tests. The heterogeneity test was conducted to determine the effect model used, namely the fixed effect model or the random effect model. Meta-analysis was carried out by calculating the effect size by standardizing the mean difference with bias correction (Hedges' g), calculating the standard error effect size, calculating the std diff in mean, calculating the summary effect, calculating the standard error summary effect, calculating the lower and upper limits, calculating Z value and hypothesis testing, as well as interpreting the Summary Effect, describing the forest plot, and correcting publication bias through funnel plot diagrams (Retnawati et al., 2018).

RESULT

The purpose of this study is to evaluate the impact of project-based learning models or strategies on students' critical thinking skills. For this reason, 29 studies have been obtained that examine the effectiveness of PjBL through a quasi-experimental research design with a control group design from 2012 to 2022 at all levels of education. The total sample of all analyzed studies amounted to 3,503 students, divided into 1777 participants who took part in PjBL and 1726 who took other courses. Completely, the analyzed study data can be seen in Appendix 1.

Meta-Analysis Results

Table 2 displays the findings of the analysis performed using the Comprehensive Meta-Analysis program.

Table 2. Meta-Analysis Results

Model		Effect size and 95% confidence interval					Test of null (2-tail)	
	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	p-value
Fixed	29	0.597	0.040	0.002	0.518	0.675	14.922	0.000
Random	29	0.743	0.122	0.015	0.504	0.982	6.094	0.000

The summary effect size from the fixed model, the overall standard difference in means is 0,597(95% CI, 0,518 to 0,675) with p-value = 0.00 (<0.05). In the summary effect size from the random model, the overall standard difference in means is 0.743 (95% CI 0.504 to 0.982) with a p-value = 0.00 (<0.05). In both results, the positive sign describes the summary effect size directed at the learning model. Thus, the PjBL learning model is more effective than non-PjBL. Also, studies report large effects, as the magnitude of both summary effect sizes is above 0,6. In order to determine the effect model employed, a heterogeneity test was also performed. Table 3 shows the results of the heterogeneity test.

Table 3. Heterogeneity Test

Heterogeneity				tau-squared			
Q-value	df(Q)	P-value	I-squared	Tau squared	Standard error	Variance	Tau
240.718	28	0.000	88.368	0.368	0.145	0.021	0.607

The I^2 statistic for heterogeneity is 88.368 (88,37%), p = 0.000 (p< 0.05), resulting in accepting of the alternative hypothesis. This demonstrates the notable variation among the papers chosen for the current study. Therefore, it is more appropriate to estimate the mean impact size of the 29 investigated studies using random effects. These findings suggest that it may be worthwhile to investigate moderating factors that influence variable Y.

Figure 2 shows the forest plots for PjBL designs. These forest plots have the line of no effect marked as 0, as the outcome variables are continuous for critical thinking abilities. The means summary effect size is seen on the side of PjBL treatment, towards the positive side of the graph, as per the set direction of effect size. Based on the forest plot in Figure 6, information is obtained that from 29 studies that have been conducted, 7 studies have a less significant effect size or negative z-value, while 22 other studies have a significance <0.05 and a positive z-value. Thus, most studies produce consistent effect sizes.

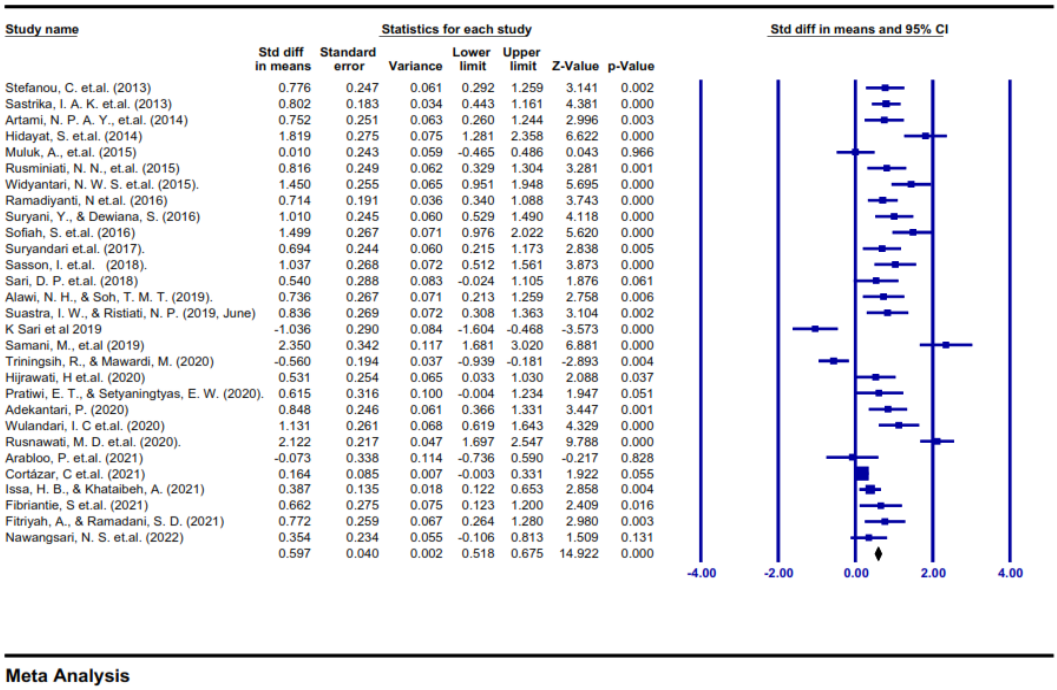

Figure 2. Forest Plot from 29 Studies

Publication bias

The funnel plots for the PjBL designs are shown in Figure 3. Analyzing funnel plots reveals that effect estimates are distributed pretty symmetrically around the central line. This means that pertinent trials may have been included. Whether the funnel plot findings are on the symmetrical axis or not is difficult to say. Therefore, further testing requires Egger's test.

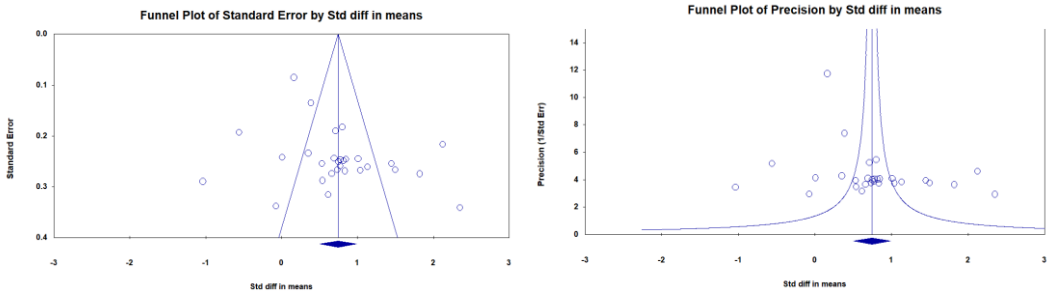

Figure 3. Funnel Plot of Precision by Std diff in means and by Standard Error

The regression test findings show a considerable, albeit less apparent, departure from zero. P values of 0.05 for both the 1-tailed test and the 2-tailed test apply here. The researcher will take into account the 2-tailed p-value, which supports the null hypothesis and denotes the existence of significant asymmetry and, consequently, bias. Researchers also identified publication bias using Begg and Muzambdar rank correlation and classic fail-safe N as shown in table 4 and table 5.

Table 4. Begg and Muzambdar rank correlation result

Kendall`s S statistic (P-Q)	Kendall`s tau without continuity correction				Kendall`s tau with continuity correction			
	Tau	z-value for tau	P-Value (1-tailed)	P-value (2-tailed)	Tau	z-value for tau	P-Value (1-tailed)	P-value (2-tailed)
46	0.1133	0.86287	0.19410	0.38821	0.111	0.84411	0.19930	0.39861

Table 5. The classic fail-safe N result

Z-value for observed studies	The P-value for observed studies	Alpha	Tails	Z for alpha	Number of observed studies	Number of missing studies that would bring p-value to > alpha
16.25997	0.00	0.05	2	1.95996	29	1967

The missing studies value shows the number 1967, which means that there are several studies based on that number that are biased and unpublished. The significance value of Kendall`s tau from Begg and Muzambdar rank correlation is above 0.05 on both the one-tailed and two-tailed side. With these parameters, It may be said that the study utilized for this meta-analysis was not biased.

Moderator analysis

The effect size obtained is known to be heterogeneous based on the analysis that was done. To obtain more complete information, the researchers analyzed the possibility of a moderator. The moderator variable that the researcher took was related to the methodology where some of the research was analyzed as compared to other learning strategies such as problem-based learning, conventional learning, traditional learning, and direct learning. In addition, the moderator's analysis was also analyzed based on the education level of the study samples taken, consisting of Elementary School, Junior High School, Senior High School, and Undergraduate levels. The results of the moderator analysis through this random effect can be seen in table 6.

Table 6. Moderator analysis result

Variable	N	Point estimate	SMD	95% CI		Z-value	p-value
				LL	UL		
Control Group Strategy							
Conventional	11	0.835	0.126	0.588	1.082	6.619	0.000
Direct Learning	2	1.414	0.704	0.034	2.794	2.008	0.045
Discovery	1	0.816	0.249	0.329	1.304	3.281	0.001
Discussion	1	1.499	0.267	0.976	2.022	5.620	0.000
PBL	8	0.176	0.204	-0.224	0.577	0.863	0.388
Scientific	1	0.772	0.259	0.264	1.280	2.980	0.003
Traditional	5	0.997	0.329	0.352	1.642	3.030	0.002
Total Between: Q value: 17.390 ; df (Q): 6 ; P-value: 0.008							
Educational level							
Primary school	7	0.343	0.332	-0.308	0.994	1.034	0.301
Junior high school	2	0.737	0.151	0.441	1.033	4.882	0.000
Senior high school	15	0.960	0.157	0.652	1.268	6.103	0.000
Bachelor	5	0.638	0.226	0.195	1.082	2.822	0.005
Total Between : Q value: 3.496 ; df (Q): 3 ; P-value: 0.321							

N: Number of studies, SMD: Standardized Mean Difference; CI: Confidence Interval; LL: Lower limit; UL: Upper Limit.

Table 6 shows the results of the moderation analysis where the learning strategy in the control group as a comparison for each study (conventional learning, direct learning, discovery learning, problem-based learning, discussion, scientific learning, and traditional learning) shows one of the variables that moderate the effect of the learning model. PjBL on critical thinking skills, with a p-value of 0.008 < 0.05. In table 6 it is also known that several learning strategies as controls show consistent effects on discovery learning, problem-based learning, and scientific learning. While conventional learning, direct learning, discussion, and traditional show less consistent results. Further analysis of each study showed that several studies that compared other scientific learning (PBL, discovery learning, and scientific learning) showed that of the 10 studies, 6 studies reported that PjBL was not better than the other learning strategies in supporting students' critical thinking skills by p-value 0.388, Therefore, it can be concluded that PjBL does not significantly differ from problem-based learning in terms of fostering critical thinking skills. Meanwhile, if PjBL is compared with traditional learning models (traditional, conventional, direct learning, and discussion) it shows that from 19 studies, there is only 1 study that reports PjBL is no different from traditional learning in its effect on students' critical thinking skills (p-value: 0.000 < 0.05).

In table 6, researchers can also see that in terms of the application of the PjBL model at various levels of education, p(value) shows a value of 0.321 < 0.05, so the effect of the PjBL model at various levels of education is no different. However, the study records so far show that using PjBL at the high school level or above produces various effects between studies p(value) < 0.05). Meanwhile, studies that are widely

used at the elementary school level tend to have a more consistent effect on the application of the PjBL model.

Innovation of Project-based Learning

Judging from the implementation of PjBL, several studies have tried to make several innovations for PjBL. Artami, N. P. A. Y. (2014) innovates PjBL by utilizing environmental media so that PjBL can use learning resources from the surrounding environment. Sofiah et al. (2016) innovate PjBL by combining a brainstorming strategy at her PjBL stage. In this model, a combination of question-and-answer and discussion methods is used, as well as efforts to collect opinions expressed by all group members in a structured and systematic manner. Samani et al. (2019) innovate PjBL by emphasizing the idea of contextual PjBL (CPjBL), in which student assignments are adapted to prior knowledge and everyday life. Adekantari et al. (2020), Arabloo et al. (2020), and Rusnawati et al. (2021) implemented innovations in PjBL by utilizing technology integrated into learning, namely the use of Instagram, e-learning, WhatsAppWiki, blogs, and Web 2.0 technology. Fibriantie et al. (2021) also innovates at PjBL by utilizing photonovels. The integration of the PjBL method with photonovel media utilizes learning resources that resemble comics by using photos instead of illustrations. Fitriyah & Ramadani (2021) also innovated PjBL by integrating aspects of STEAM (Science, Technology, Engineering, Art, and Mathematics) and producing an effective PjBL to promote critical thinking skills. In fact Wayan and Ristiati (2019) innovated PjBL by integrating it with authentic assessments, which proved to be effective in encouraging students' critical thinking skills. Therefore, PjBL innovation can be carried out by integrating technology as a PjBL supporting facility, content integration in PjBL (environmental, contextual, and STEAM PjBL), integration of learning strategies in PjBL (brainstorming PjBL), as well as integration with assessment techniques (PjBL with authentic assessment).

DISCUSSION

Based on the analysis of 29 research studies published in scientific journals, it was found that cumulatively, PjBL was able to encourage critical thinking skills for students. In addition, it is also known that various studies in the last ten years on PjBL have found heterogeneous effect sizes related to critical thinking skills. Most studies (22 studies) found that PjBL affects students' critical thinking skills at all levels of education (Alawi & Soh, 2019; Artami, 2014; Hidayat et al., 2014). However, seven studies say that PjBL does not affect critical thinking skills. Of the 29 studies that have been conducted, seven research results report that PjBL is not better than other learning in shaping students' critical thinking skills (Cortázar et al., 2021; Muluk et al., 2015; Nawangsari et al., 2022; Pratiwi & Setyaningtyas, 2020; Sari et al., 2019; Sari et al., 2019; Triningsih & Mawardi, 2020). Overall, the results obtained that PjBL can encourage students' critical thinking skills. The results of this analysis are evidence that many studies have so far provided the successful application of PjBL models in supporting students' critical thinking skills. This aligns with the research results that PjBL interventions have also increased higher-order cognitive skills (Fini et al., 2018). PjBL encourages active students characterized by student autonomy,

goal setting, constructive inquiry, communication, collaboration, and reflection in real-world practice (Kokotsaki et al., 2016). In fact, PjBL combined online with the help of Edmodo can improve students' critical thinking skills (Permana et al., 2020). The effectiveness of PjBL carried out over the last ten years is also known to be moderated by several conditions, namely the application of the model at various levels of education and the application of this model when compared to other forms of learning strategies. The implementation of the learning strategies at several levels of education produces an inhomogeneous effect. The application of PjBL is known to produce more homogeneous effects on primary education. In contrast, the application at the higher education level tends to produce more mixed results. Overall, PjBL is known to effectively support students' critical thinking skills at all levels of education. In higher education, PjBL reinforces research that has been understood to improve higher education student learning (Guo et al., 2020). Therefore, we still recommend that PjBL be applied at various levels of education because this project learning recognizes that PjBL is a cognitive learning strategy that produces elaboration, critical thinking, and good metacognitive self-regulation (Stefanou et al., 2013).

Project-based learning does not significantly outperform problem-based learning in terms of fostering students' critical thinking abilities, according to a moderator analysis of many alternative learning methods. A well-structured problem-based approach also promotes critical thinking, problem-solving, and independent learning skills (Choi et al., 2014). This fits with the research. Anazifa and Djukri (2017) did not find critical thinking skills between PjBL and problem-based learning differ significantly. Other models, such as guided inquiry, have also been believed to significantly affect students' critical thinking skills (Duran & Dökme, 2016). Compared with traditional learning models, such as direct learning, conventional, discussion, lecture, or traditional models, PjBL is known to be significantly superior in achieving students' critical thinking skills. To encourage critical thinking skills, PjBL implementation can also be varied with various innovations, such as integrating technology to facilitate PjBL, integrating content and context in PjBL (environmental, contextual, STEAM PjBL), integrating learning methods, as well as assessment techniques. In fact, PjBL can be integrated with other learning strategies, such as cooperative learning, to encourage student learning outcomes (Tafakur & Suyanto, 2015). Project-based learning integrated with technology significantly encourages critical thinking skills (Arabloo et al., 2020; Sasson et al., 2018).

Through various successes in the application of PjBL summarized in this analysis, the researchers also suggest that learning stakeholders in schools apply this learning strategy in schools to encourage students' critical thinking skills, especially for teachers who still use traditional, direct learning, conventional learning as well as regular discussion (Maros et al., 2021). Critical thinking and problem-solving skills have been defined by the Partnership for 21 Century Skills (P21), demonstrating the ability to utilize various forms of reasoning, analysis, evaluation, and decision-making when dealing with learning and real-life problems specific to the 21st century, thus through engaging students in technology-assisted projects will act as trigger points for students' 21st-century literacy enrichment (Arabloo et al., 2020).

Even PjBL can be done online and has been proven to develop critical thinking skills (Cortázar et al., 2021). The various studies above prove that project-based learning has contributed to supporting the development of students' thinking at various levels of education. Through critical thinking skills, students can have sufficient thinking skills to criticize their plans for systematic practice and solve contextual problems (Mutakinati et al., 2018). Finally, we can assume that PjBL will contribute to future education development, where critical thinking skills as the main ability in the 21st century and support the achievement of 30 SDGs are the most important skills students must master) (UNESCO-Unevoc, 2020). Several innovations to PjBL can also be considered for implementation in future research through the application of technology, the use of the real environment, and the integration of content, context, and other learning strategies into PjBL.

CONCLUSION

Many studies have proved PjBL to support the critical thinking skills of students as compared to other learning approaches. However, compared with other scientific learning (problem-based learning, discovery learning, scientific learning), PjBL strategies do not show significant advantages in promoting critical thinking skills for students at various levels of education. PjBL explicitly promotes students' critical thinking skills compared to traditional learning strategies that highlight lectures, such as conventional, traditional, direct, and learning strategies. This study also concludes that PjBL which is applied seriously will encourage students' critical thinking skills at different educational levels, from basic education to undergraduate level. Therefore, we suggest that teachers still using traditional learning apply this learning model seriously and proportionally. Teachers can also make PjBL more innovative by utilizing information technology, and the contextual environment, as well as integrating various media, content, and other learning strategies. With these findings, we can summarize the research experiences that have been carried out to ensure the effectiveness of PjBL comprehensively.

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Appendix 1. Characteristics of the analyzed studies

No	Author (Year)	Year	N1	N2	Research design	Region/ Country	Education level
1	Sastrika et al. (2013)	2013	64	65	Quasi Experiment posttest only control group	Bali	Senior High School
2	Stefanou et al. (2013)	2013	50	27	Design-based research approach	Northeastern, USA	Bachelor
3	Artami, NPAY (2014)	2014	34	34	Non-Equivalent Pretest-posttest Control Group	Denpasar	Elementary school
4	Hidayat et al. (2014)	2014	36	39	Non-Equivalent Posttest Only Control Group	Mataram, Indonesia	Bachelor
5	Muluk et al. (2015)	2015	34	34	Oneshot study	Central Sulawesi, Indonesia	Senior High School
6	Rusminiati & Suardana (2015)	2015	35	35	Non-Equivalent Pretest-posttest Control Group	Bali, Indonesia	Senior High School
7	Widyantari et al. (2015)	2015	38	40	Non-Equivalent Posttest Only Control Group	Bali, Indonesia	Elementary school
8	Ramadiyanti et al. (2016)	2016	59	58	Non-Equivalent Posttest Only Control Group	Bali, Indonesia	Junior High School
9	Sofiah, S., Peniati, E., & Lisdiana (2016)	2016	36	36	Non-Equivalent Pretest-posttest Control Group	Rembang, Indonesia	Senior High School
10	Suryani & Dewiana (2016)	2016	38	37	Non-Equivalent Pretest-posttest Control Group	Java, Indonesia	Senior High School
11	Suryandari, et.al (2017)	2017	36	35	Non-Equivalent Pretest-posttest Control Group	Semarang, Indonesia	Bachelor
12	D. P. Sari et al. (2019)	2018	25	25	Factorial	Padang, Indonesia	Elementary school
13	Sasson et al. (2018)	2018	38	27	Pretest-posttest Control Group	Israel	IX and X
14	Alawi & Soh (2019)	2019	30	30	Non-Equivalent Posttest Only Control Group	Kelantan, Malaysia	Vocational school
15	I. K. Sari et al. (2019)	2019	27	27	Nonequivalent comparison group	Sumatra, Indonesia	Elementary school
16	Samani et al. (2019)	2019	28	30	Pretest-posttest control group	Java, Indonesia	Vocational school

17	Wayan Suastra & Ristiati (2019)	2019	30	30	Non-Equivalent Posttest Only Control Group	Bali, Indonesia	Senior High School
18	Adekantari et al. (2020)	2020	36	36	Nonrandomized Control Group Pretest–Posttest	West Nusa Tenggara, Indonesia	Senior High School
19	Hijrawati, Muhammad Arsyad (2020)	2020	32	32	Posttest Only Control Group	Makassar, Indonesia	Senior High School
20	Pratiwi & Setyaningtyas (2020)	2020	21	21	Non-Equivalent Pretest-posttest Control Group	Semarang	Elementary school
21	Rusnawati et al. (2021)	2020	67	66	Pretest-posttest control group	Bali, Indonesia	Vocational school
22	Triningsih & Mawardi (2020)	2020	55	56	Posttest Only Control Group	Salatiga	Elementary school
23	Wulandari et al. (2020)	2020	34	34	Nonequivalent control group	West Kalimantan, Indonesia	Senior High School
24	Arabloo et al. (2020)	2021	18	17	Non-Equivalent Pretest-posttest Control Group	Iran	School language
25	Cortázar et al. (2021)	2021	287	266	Pre-post control group	Chile	Bachelor
26	Fibriantie, S. et al. (2021)	2021	29	27	Non-Equivalent Pretest-posttest Control Group	Jember, Indonesia	Elementary school
27	Fitriyah & Ramadani (2021)	2021	32	32	Non-Equivalent Pretest-posttest Control Group	Java, Indonesia	Senior High School
28	Issa & Khataibeh (2021)	2021	111	111	Non-Equivalent Pretest-posttest Control Group	Jordan	Teacher
29	Nawangsari et al. (2022)	2022	37	37	Prepost control group	Bantul, Indonesia	Bachelor

Note: N1: PjBL sample size, N2: Non-PjBL sample size