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The Effect of Project-Based Learning Model (PjBL) with STEM Approach to Promote Students' Critical and Creative Thinking Skills: A Meta Analysis

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Abstract
Critical and creative thinking skills are essential 21st century competencies needed to prepare students for global challenges and an evolving workforce. Despite their importance, the 2018 PISA results indicate that Indonesian students still exhibit low critical thinking skills, underscoring the need for more effective learning approaches. This take a look at goals to investigate the effect of the STEM-based Project-Based Learning (PjBL) model on critical and creative thinking skills through a meta-analytic approach. The analysis included 20 articles published between 2018 and 2024, covering two variables: subject domains and learning materials. The findings discovered that STEM-based PjBL had a big impact, with excessive average impact sizes for essential questioning abilities, in particular in dynamic fluid topics, and for creative wondering talents in biodiversity subjects. PjBL combined with the STEM method effectively enhances students' analytical, communication, and collaboration skills through active engagement in real-world problem-solving. Therefore, the STEM-based PjBL model is a relevant approach to fostering critical and creative thinking skills in 21st-century education.

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1. Introduction

Vital and innovative questioning are complementary competencies that are essential for hassle-solving and selection-making in lots of factors of lifestyles. Important questioning includes the potential to objectively examine facts, compare arguments, and draw conclusions based on valid proof. Critical thinking ability enables individuals to consider information, arguments, and evidence critically and objectively [1].On the opposite facet, innovative thinking is the capability to generate new and revolutionary thoughts which are applicable to a selected context.This creative process involves the ability to look at problems from different perspectives, develop new ideas, and explore alternative options to achieve better results. Creative thinking enables individuals to generate new ideas and creative solutions to problems encountered [2].

The combination of critical thinking and creative thinking is crucial in the present day generation of demanding situations and uncertainties. Critical thingkingand creative thinking skills are essential in the professional and academic world, and are often qualities sought after in potential employees or students [1].

In addition, creative thinking helps one see opportunities in complex or confusing situations. As such, these two abilities complement each other and encourage the development of individuals who are both innovative and reflective, thus making a significant contribution to society.

The critical thinking and creative thinking skills are lots-desired talents inside the 21st century to put together students for global challenges and evolving international of labor. These skills play an important role in solving complex problems and innovating [3]. However, despite its importance the results of the 2018 PISA evaluation show that Indonesian students still struggle to reach the level of critical thinking required in the modern era [4]. This finding confirms the need for more effective learning approaches to develop these skills. Another one important element that motive critical and creative thinking skills to not develop optimally is the education system that still focuses on traditional learning methods. This system provides little opportunity for students to practice higher-order skills. Much classroom teaching is still rote-based and de-emphasizes problem-solving that requires critical thinking skills [5]. Therefore, a more interactive learning technique primarily based at the improvement of twenty first century abilities is wanted to task college students to suppose critically and creatively.

One approach that can be applied to overcome this problem is the PjBL integrated with the STEM method. PjBL version integrated STEM technique is an powerful method to promote college students' skills in organizing ideas, ideas, and techniques in an incorporated way in gaining knowledge [6]. The software of the PjBL with STEM technique version provides enjoyment for students to connect the understanding they have gotten with real existence, thus making the mastering revel in greater significance [7]. Similarly, STEM integration in PjBL can enhance college students' hassle-solving and vital wondering abilities [8]. Thus, the PjBL model with a STEM approach can be an appropriate alternative in learning to develop various student competencies that are applicable to the wishes of the twenty-first century.

Various studies have assessed the impact of PjBL and STEM on student skills. The primary examine confirmed that the application of PjBL incorporated with STEM had a full-size effect on improving the vital and innovative thinking competencies of XII grade excessive faculty college students [9]. The consequences of this take a look at confirm that this getting to know version is extra powerful than traditional learning methods in growing student creativity. in addition, another study located that the use of STEM-primarily based PjBL model can enhance students' essential questioning abilties on warmth and its transfer in grade V elementary college [10]. Results of this study suggest that these gaining knowledge of models are effective in improving students' critical wondering capabilities. However, although many studies help the effectiveness of those fashions, there are nonetheless few that systematically integrate these effects to comprehensively describe their impact on crucial and creative thinking talents.

In practice, many students still face difficulties in developing critical and creative thinking skills, particularly at the research site mentioned in the selected article. One of the main challenges faced is the traditional, teacher-centered teaching method. As a result, students often struggle to analyze a problem in depth. Moreover, the lack of integration between knowledge and real-world contexts is also a significant issue. The implementation of the Project-Based Learning (PjBL) model with a STEM approach provides recommendations on the effectiveness of this strategy in improving students' critical and creative thinking skills. Therefore, the findings of this research can serve as a reference for educators in developing more innovative and relevant learning models that meet the needs of the 21st century.

This examine is critical due to the fact, even though many previous studies have assessed the effect of PjBL with a STEM approach on critical and innovative thinking capabilities, there has been no take a look at that integrates those effects inside the form of a meta-evaluation. This method is expected to offer a greater entire and complete photo of the effectiveness of the mastering version in enhancing essential and creative questioning talents. Consequently, this take a look at goals to discover the impact of imposing PjBL model integrated with the STEM technique on improving college students' crucial and creative thinking capabilities. This research uses a meta-evaluation approach to accumulate and analyze facts from diverse preceding research associated with the effectiveness of PjBL and STEM models in mastering. By way of studying facts from the most latest length, this research is predicted to offer a comprehensive clarification of the outcomes of implementing the version in numerous fields of training and advocate evidence-based implementation to improve twenty first century competencies in students.

2. Methods

This research uses the meta-analysis method. Meta-evaluation is research performed by summarizing, reviewing and analyzing records from numerous studies that have been carried out as an entire on empirical information on a specific topic. records collection on this observe changed into performed by means of trying to find articles on line using of Google schoolar, Turkish education magazine, IOP, number one college journal, JPII, IJSR inside the 2018-2024 time span. The research variables are dependent variables, namely PjBL with a STEM approach, critical thinking skills, creative thinking skills and moderator variables, namely the field of science and subject matter. The research was carried out using 3 stages, namely: First, collecting data through literature sources from various sources. Second, reading and analyzing research articles to see the suitability of the content with predetermined problems and summarizing the results of the collection of articles in several categories. Third, determine the amount of influence (effect size) of each research article obtained. The way to determine the amount of Effect Size is as follows Table 1.

Table 1. A Way to Decide The Effect Size

Statistics Data	Formula	Frm
Common data on one organization	$ES = \frac{\bar{x}_{post} - \bar{x}_{pre}}{SD_{pre}}$	$Frm - 1$
Common information on each organizations (*two organizations post-test best*)	$ES = \frac{\bar{x}_E - \bar{x}_C}{SD_c}$	$Frm - 2$
Common facts on every organization (*organizations pre-post take a look at*)	$ES = \frac{(\bar{x}_{post} - \bar{x}_{pre})E - (\bar{x}_{post} - \bar{x}_{pre})C}{\frac{SD_{preC} + SD_{preE} + SD_{postC}}{3}}$	$Frm - 3$
Statistic *Chi-Square*	$ES = \frac{2r}{\sqrt{1 - r^2}}; \sqrt{\frac{x^2}{n}}$	$Frm - 4$
Statistic *t* count	$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}$	$Frm - 5$
Statistic *P*advantage	CMA (Comprehensive Meta Analysis Software)	$Frm - 6$

Based on the way to determine the effect size as shown in Table 1, it can be explained that: ES = Effect size, X_{post} = Common post-test, X_{pre} = Common pre-test, SD = Standard Deviation, XE = Common of experimental organizations, XC = Common of control organizations, X_{postE} = Common post-test of experimental organizations, X_{preE} = Common pretest of experimental organizations, X_{postC} = Common post-test of the control organizations, X_{preC} = Common pretest of the control organizations, SDE = Standard Deviation of the experimental organizations, SDC = Standard Deviation of the experimental organizations, t = Results of the t test, n_E = Number of experimental organizations, n_C = Number of control organizations, r = Correlation value. To determine the criteria for effect size, we can use Table 2.

Table 2. Effect Size Class

Effect Size	Class
$0 \leq ES \leq 0{,}2$	Low
$0.2 \leq ES \leq 0.8$	Medium
$ES \geq 0.8$	High

3. Results and Discussion

This study changed into carried out to peer the effect of implementing PjBL with a STEM method from two moderator variables, namely the level of the sector and concern count on vital and innovative wondering competencies. After collecting sixteen articles and reading it, two moderator variables have been obtained that could be found for his or her impact length. The effects of the effect size of the two moderator variables have various outcomes. This meta-analysis makes a speciality of the impact of PjBL with a STEM technique on students' essential and creative wondering skills. PjBL with a STEM approach, students have important and innovative questioning competencies that may be seen from the potential to read, write, observe, and do technology practicum so they can be used as provisions for residing in society and fixing issues faced in ordinary life related to the sphere of natural technological know-how.

The articles reviewed were from 2018-2024, out of 16 articles only 1 article was published in 2018 and 2023, mostly in 2019, 2020, and 2021 as presented in Figure 1. The year of publication shows the novelty of research results and research updates. PjBL studies with a STEM method to vital and creative wondering abilties from yr to year has extended courses which display the significance in gaining knowledge of Physics to be studied in accordance with the abilities wanted within the 21st century.

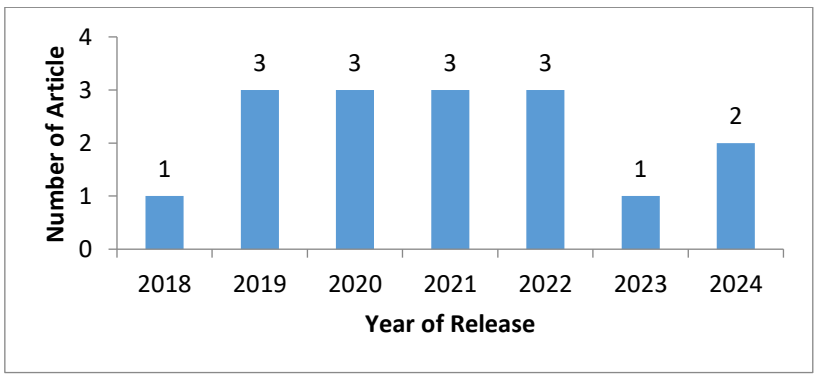

Figure 1. Numerate And Year of Article Release

Based totally on Figure 1, the findings of the articles have various results for each vital and innovative questioning talents in college students. The results of the analysis of articles in 2018 obtained the impact of applying PjBL with a STEM method, specifically on innovative questioning competencies in college students in biology topics with environmental pollution fabric, there is a big distinction among the experimental magnificence and the manipulate magnificence, where pupil creativity inside the experimental magnificence is better than the manage class. Moreover, the effects of the thing findings in 2019-2022 acquired the very best wide variety of articles on the impact of applying the PjBL with the STEM method, with three articles for each yr of booklet.

The outcomes of the analysis inside the article received that critical and creative thinking talents in college students have a big effect if learning is performed the usage of PjBL with a STEM method. The consequences of the analysis of articles in 2023 received one article on enhancing students' creative wondering competencies in biology topics with environment cloth where if PjBL with the STEM method is implemented not only pupil learning consequences within the cognitive area will boom, however innovative wondering competencies may also boom. In 2024, two articles had been received regarding the effect of the PjBL with the STEM method. The article additionally stated that scholars' critical and innovative wondering abilities improved in biology and chemistry topics. Consequently, the application of the PjBL model with the STEM method is very crucial to be applied in gaining knowledge of, this is because the studying version has a full-size impact on twenty first century competencies, namely vital and innovative wondering abilities which can be very crucial for college students at this time.

The second one result in this observe is related to the effect of PjBLwith STEM method on vital and creative questioning capabilities based on science disciplines on the excessive faculty stage. The average price of the impact size of the influence of the PjBLwith the STEM method is supplied within the statistics in desk 3 suggests the overall article records, particularly based on the level of the sector, the scale of the item, the number of samples, the situation rely, the effect size and the integration of the method into PjBL with the STEM method. Based on Table 3, 16 articles had been obtained concerning the effect of applying PjBL with a STEM method on improving essential and creative questioning capabilities. studies on efforts to improve critical and creative thinking skills is presently being accomplished due to the fact those abilities are twenty first century capabilities that need to be possessed by students nowadays. A twenty first century studying emphasizes four skills that must be possessed via a scholar, which includes important and innovative questioning capabilities [26]. The vital questioning capabilities possessed by using students can assist a person's capability to clear up troubles with know-how that enables them analyze, examine, and make decisions approximately ideals or actions taken [27]. The innovative questioning abilities equip students to compete inside the generation of globalization [28]. Therefore, there are many research on improving critical and innovative thinking talents in technology topics, one of which uses PjBL with a STEM method, due to the fact those skills are very important and may be implemented in everyday existence.

The third result of this meta-evaluation studies is the impact of PjBL version with STEM method primarily based on difficulty and scholar competencies. For important wondering skills articles are coded with the letter S, whilst for creative wondering abilities articles are coded with the letter F. furthermore, for each problem, the effect length is divided into 2 categories, namely important thinking competencies and innovative questioning abilities. For more info, it could be visible in under desk 4.

Table 3. General Grouping of Articles

Identity	Subject	Scale	N	Subject Matter	ES	Frm	Model
Azis et al. (2018) [10]	Biology	National	60	Environmental Pollution	1.48	Frm-5	PjBL-STEM
Desi et al. (2023) [11]	Biology	National	58	Ecosystem	1.08	Frm-3	PjBL-STEM
Mamahit et al. (2020) [12]	Biology	National	133	Biodiversity, bacteria and fungi	0.64	Frm-5	PjBL-STEM
Afifah et al. (2020) [13]	Biology	National	36	Plantae	0.75	Frm-3	PjBL-STEM
Novitasari et al. (2024) [14]	Biology	National	60	PencemaranLingkungan	1.26	Frm-3	PjBL-STEM
Allanta&Puspita (2021) [15]	Biology	National	50	Environmental Pollution	1.93	Frm-5	PjBL-STEM
Oktaviani et al. (2022) [16]	Chemistry	National	30	Electrolyte and nonelectrolyte solutions	1.54	Frm-2	PjBL-STEM
Annisa et al. (2019) [17]	Chemistry	National	30	Acids and Bases	0.63	Frm-5	PjBL-STEM
Ilmiah (2024) [18]	Chemistry	National	30	Voltaic cell	0.75	Frm-2	PjBL-STEM
Triastuti (2020) [19]	Chemistry	National	28	Decreasing the freezing point of solutions role in making ice cream	0.75	Frm-3	PjBL-STEM
Cholisoh (2019) [20]	Physics	National	36	Thermodynamics	1.78	Frm-3	PjBL-STEM
Safriana et al. (2022) [21]	Physics	National	72	Optical devices	0.53	Frm-5	PjBL-STEM
MoammarQadafi et al. (2022) [22]	Physics	National	34	Optical devices	1.40	Frm-2	PjBL-STEM
Fiteriani et al.(2021)[23]	Physics	International	52	Optical devices	0,72	Frm-5	PjBL-STEM
Sumardiana et al. (2019) [24]	Physics	National	35	Temperature and Heat	0.43	Frm-2	PjBL-STEM
Rosyidah et al. (2021) [25]	Physics	National	32	Static Fluid	1.05	Frm-3	PjBL-STEM

Based on the facts within the Table 4, the impact of PjBL with the STEM method on important and creative questioning competencies primarily based on the situation region within the science circle of relatives. In vital questioning abilities, it's far said that there are articles within the Biology problem place with an impact length of 1.00 in the excessive class, then one article in the Chemistry challenge vicinity with an effect length of 0.636 and three articles at the level of the Physics problem area with an impact length of 1.08. Then on creative thinking talents it changed into stated that there have been four articles within the Biology subject vicinity with a median effect length of 0.28 within the high class. Then three articles in the area of Chemistry subjects with a mean impact size of 0.01 are in the excessive category and three articles in Physics subjects with an average effect size of 0.88 with a high class.

Table 4. The Effect of PjBL on Critical Thinking and Creative Thinking Based on Subjects

Subject	Article Code	Critical Thingking		Desc.	Article Kode	Creative Thingking		Desc.
		Effect Size	Effect Size Average			Effect Size	Effect Size Average	
Biology	S4	0.75	1.00	High	F1	1.48	1.28	High
	S5	1.26			F2	1.08		
					F3	0.64		
					F6	1.93		
Chemistry			0.64	Medium	F7	1.54	1.01	High
	S8	0.64			F9	0.75		
					F10	0.75		
Physics	S11	1.78			F12	0.53	0.88	High
	S15	0.43	1,08	High	F13	1.40		
	S16	1.05			F14	0.72		

The software of the PjBL version with the STEM method has a huge have an impact on on vital and creative wondering in all 3 subject; because college students within the excessive faculty technological know-how organization are already able to be age unbiased. If students are independent, then the software of the PjBL is genuinely no longer tough for college students. Consequently, the application of PjBL with a STEM method has a high common effect length. So, it could be concluded that the software of PjBL with a STEM method to studying can enhance studying results abilties, one among that is critical and innovative thinking skills. The application of PjBL with a STEM technique can boom motivation, assist recognize coaching materials, and form a innovative attitude [29]. Integration of PjBL version with STEM method is powerful and top to enhance the competencies that novices need to have inside the twenty first century [30]. For this reason, it can be stated that the PjBL model is powerful for improving college students' critical and creative thinking abilities.

The fourth result of this look at is the impact of PjBL version with STEM method on important and innovative thinking capabilities based totally on issue remember. Based of totally the records (Table 5) for critical wondering talents, it's far stated that there are two articles on environmental pollution fabric in the Biology subject with a mean impact length of 1.37 within the high class. Two articles on atmosphere fabric in the Biology problem with an average impact size of one 50 are within the high class. Then three articles on the fabric of optical devices inside the discipline of Physics subjects with an effect size price of 0.88 which is inside the high category. For other materials there's one article for every fabric and is inside the medium and excessive impact length categories which may be seen in Table 5.

The software of PjBL with the STEM method has the most huge effect on important questioning skills while carried out to Thermodynamics fabric. This occurs because of the lively involvement of students when getting to know takes region. The lively involvement of college students in experimental research could make a directed classroom environment and be capable of receive studying well [31]. Thus, students come to be easier to understand the material and are able to improve college students' important thinking abilties. For innovative thinking abilties, it's far said that there are 3 articles on optical gadgets fabric which has a median effect size of 0.88 inside the excessive category. Among the 12 substances, thermodynamic cloth has a tremendous effect on important wondering abilties in students with an impact size of one seventy eight.

This takes place due to the fact in this material college students are capable of increase person abilties in the usage of their thinking method to generate new thoughts. In addition, college students also are active newcomers, able to express critiques, and manner statistics easily. Consequently, the PjBL mastering model with a STEM method is really worth considering in the utility of gaining knowledge of in the study room.

Table 5. Effect of PjBL on Critical and Creative Thinking Based on Subject Matter

Subject Matter	Article Code	Effect Size	Effect Size Average	Descrption
Environmental Pollution	F1	1.48	1.37	High
	S5	1.26		
Ecosystem	F2	1.08	1.50	High
	F6	1.93		
Biodiversity, bacteria and fungi	F3	0.64	0.64	Medium
Plantae	S4	0.75	0.75	Medium
Electrolyte and nonelectrolyte solutions	F7	1.54	1.54	High
Acids and Bases	S8	0.64	0,.64	High
Voltaic cell	F9	0.75	0.75	Medium
Decreasing the freezing point of solutions in their role in ice cream making	F10	0.75	0.75	Medium
Thermodynamics	S11	1.78	1.78	High
Optical Tools	F12	0.53	0,88	High
	F13	1.40		
	F14	0.72		
Temperature and Heat	S15	0.43	0.43	Medium
Static Fluid	S16	1.05	1.05	High

Primarily based on the consequences of the meta-evaluation on sixteen articles from 2018-2024 that have been found, it can be said that the utility of PjBL with a STEM method can improve vital and innovative wondering competencies in students. that is consistent with the motive of the PjBL, that's to hyperlink the potential of many college students' wondering skills [32]. Students' creativity, critical thinking, and skills improved over mastering with out the challenge [33]. The PjBL version may be used as a reference for teachers to use as a gaining knowledge of version to determine college students' critical questioning capabilities [34]. The outcomes of articles in the last five years display that many school room research are running on crucial and innovative wondering skills in the current era of globalization. with a view to face the demanding situations of life these days, particularly within the discipline of schooling, important thinking skills are very crucial in studying [32]. In addition, the STEM method additionally performs an essential function in improving vital and creative questioning abilties. Integrating STEM into mastering can help college students hone their talents and multiply their know-how in lifestyles [35]. The STEM method has a advantageous effect on twenty first century abilities which includes essential questioning, trouble solving and creativity [36]. STEM-primarily based learning is one of the capacity gaining knowledge of alternatives used to build 21st century competencies [37].College students may be guided and skilled to think severely, creatively, and rationally via the use of the STEM method [38].

The PjBL model with a STEM method may be very relevant if applied to study room gaining knowledge of inside the science situation family to enhance crucial and creative questioning capabilities. The integrative nature of STEM allows diverse studying fashions for use to assist its utility [39]. PjBL and STEM getting to know can teach students' abilities and skills to face twenty first century issues [40]. Consequently, the application of the PjBL with the STEM method in the discipline of technological know-how problem clumps is very effective and has a large effect in improving crucial and innovative questioning talents while facing the present day twenty first century technology. This is due to the fact the PjBL and the STEM method have sports that can cause essential and creative wondering abilities at every step inside the learning procedure so that it's miles very beneficial for the improvement of pupil talents.

Critical and creative thinking skills can be improved by implementing the project based learning (PjBL) learning model with a STEM approach. Because, each syntax of the PjBL learning model can trigger an increase in these skills. The syntax of the PjBL model includes: 1) determining basic questions, in this activity students can ask questions that can improve students' critical and creative thinking skills; 2) create a project design, in this activity students' creative skills will increase because students are required to create a project; 3) arrange scheduling; 4) monitor project progress; 5) assessment of results; and evaluation of experience. Therefore, the PjBL learning model with STEM can be applied in learning so that students' critical and creative thinking skills can improve.

Based totally on the results and dialogue that have been described, the shortcomings in this newsletter are the confined range of articles discovered concerning the impact of PjBL with a STEM technique on students' crucial and creative wondering talents. similarly, there are several articles with mild impact length. So the suggestion from this studies is that it's miles was hoping that in writing the subsequent article greater articles will be acquired about the PjBL with a STEM approach and the effect length price with a excessive category.

4. Conclusion

Based on the analysis of 16 articles published between 2018-2024, the results of the effect size vary but the majority are in the high category, indicating that STEM-based PjBL effectively improves critical and creative thinking skills. The highest average effect size for critical thinking was found in thermodynamics, while for creative thinking in biodiversity. This significant effect is mainly due to the active involvement of learners in project-based learning that allows them to think critically, creatively, and be able to relate learning to real life. Therefore, STEM-based PjBL is an effective learning alternative to prepare students to face the challenges of the 21st century.

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