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STEM-PJBL Model on Development of Technology Engineering Literacy and Student Learning Motivation

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Abstract

This meta-analysis investigates the impact of integrating Project-Based Learning (PjBL) with STEM (Science, Technology, Engineering, and Mathematics) on Technology Engineering Literacy (TEL) and student learning motivation. The study aims to provide valuable insights for educators, curriculum developers, and policymakers, guiding the design of more engaging learning experiences and supporting innovative educational practices. The research followed a systematic meta-analytic approach, including defining the research problem, setting inclusion criteria, devising a literature search strategy, selecting studies, extracting data, performing statistical analysis, and interpreting results. Analyzing 33 articles from international and national journals, the study reveals that PjBL-STEM significantly enhances TEL, particularly at the high school and college levels, and boosts student motivation, with more pronounced effects observed in high school and college compared to junior high and elementary schools. The model shows a strong impact on TEL in Physics but has lower effects in Science and Biology. For student motivation, significant improvements are noted in Science, Mathematics, and Social Sciences, while effects are less in Chemistry and Physics. The research highlights the effectiveness of PjBL-STEM at higher educational levels and underscores its potential to improve TEL and motivation, though further research is needed to refine adaptation strategies for different educational contexts.

Keywords: meta – analysis, STEM – PjBL – TEL - motivation

INTRODUCTION

The rapidly changing global landscape in the 21st century demands adjustments in education, particularly in developing students' potential through learning (Nurramadhani,Riandi, Permanasari & Suwarma, 2023). Education aims to prepare quality students with scientific awareness, values, and attitude skills (Serdyukov, 2017; Thahir, Magfirah & Anisa, 2021). A critical aspect is enhancing potential through science education. Science education is expected to produce young generations equipped with scientific awareness, values, and attitude skills to tackle 21st-century challenges (Dinwiddie, Schillerstrom & Schillerstrom, 2017; Syamsi, Rahmat & Husain, 2021).

In the 21st century, six essential skills are required for human resources based on the 21st-century partnership learning framework, including problem-solving ability, communication skills, creativity, information and communication technology literacy, contextual learning skills, and information and media literacy (BSNP, 2010). These 21st-century skills combine cognitive, interpersonal, and intrapersonal aspects that support deeper learning processes and knowledge transfer (Pellegrino & Hilton, 2012; NRC, 2014; Mentz & Bailey, 2020).

Science education needs to adapt to increasingly complex future challenges. Haleem, Javaid, Qadri & Suman (2022) and Wolff (2021) demonstrate that science and technology are continually evolving to address these challenges. Teachers need to link science content with technology in science education, given the importance of technology engineering literacy (TEL) (Ejikeme & Okpala, 2016; Nikou, De Reuver, Kanafi, 2022). Technology literacy is the ability to understand, use, and make decisions about technology (NETP, 2017). Science education must strengthen students' TEL abilities so they can address real-world problems (Darmaji, Kurniawan, Minarsih & Perdana, 2023).

Technology and engineering are closely related, where technology is the result of engineering processes (NRC, 2012; Moore, Tank, Glancy & Kersten, 2015). Technology and engineering literacy (TEL) helps students understand and design technology to solve complex problems. Integrating STEM (Science, Technology, Engineering, and Mathematics) into science education is an effective solution, allowing students to develop critical and creative thinking skills (Torlakson, 2014). STEM integrates science, technology, engineering, and mathematics, preparing students to solve real-world problems (NAE & NRC, 2014).

One innovative learning model is project-based learning (PjBL), which emphasizes solving significant life problems for students. In PjBL, students engage in designing, planning, and implementing projects that produce outputs such as products, publications, or presentations that can be showcased to the public. Integrated STEM PjBL has been proven effective in improving students' understanding and STEM skills. By emphasizing scientific inquiry and engineering design projects, this model provides engaging and relevant learning experiences for students. Bell (2010) emphasizes that students not only learn scientific and technological concepts but also apply them in real and meaningful contexts in their daily lives. This aligns with the vision of the Ministry of Education (2014), which emphasizes the importance of providing authentic and relevant learning experiences for students.

The integrated STEM-PjBL model in science education not only helps students develop technology engineering literacy but also enhances their learning motivation (Erlinawati, Bektiarso & Maryani, 2019; Rahmania, 2021). Through project-based learning relevant to daily life, students feel more engaged and motivated to learn because they can see a direct connection between what they learn and the real world (Gottschalk, 2019). Moreover, learning that emphasizes exploration, experimentation, and problem-solving provides challenges that stimulate students' interest and motivation to learn more actively (Gottschalk, 2019; Haleem, Javaid, Qadri & Suman, 2022). Thus, the integrated STEM-PjBL model in science education can prepare students to face 21st-century challenges more prepared and skilled in solving complex problems sustainably.

Considering the information provided, the researchers decided to conduct a meta-analysis study to explore the influence of STEM-integrated PjBL on TEL and student learning motivation. This choice was made for several reasons. First, meta-analysis allows researchers to consolidate findings from existing studies, thereby evaluating the consistency of findings from various previous studies. Second, through this model, researchers can involve data from studies covering various contexts and populations, expanding the scope of the analysis. Third, the researchers hope that by conducting meta-analysis, they can arrive at more general or broader conclusions about the influence of STEM-integrated PjBL on TEL and student learning motivation, which can provide deeper insights into the field. Thus, meta-analysis research is seen as a suitable solution to gain a more comprehensive understanding of the topic.

Meta-analysis research has several significant advantages in its application. First, the meta-analysis procedure allows the application of beneficial discipline in the process of summarizing research findings, as mentioned by Stone & Rosopa (2016) and Piggot & Polanim (2019). This means that the research can produce a more systematic and structured synthesis of various existing studies. Second, meta-analysis is a study conducted with a more sophisticated method compared to conventional review procedures that often rely on qualitative summaries. Thus, this research can provide a deeper and more accurate analysis of existing data, in line with the findings of Fagard, Staessen & Thijis (1996) and Borenstein, Hedges, Higgins & Rothstein (2009). Third, meta-analysis can reveal hidden influences or relationships in other approaches to summarizing research. This is consistent with the study conducted by Appel, Marker & Gnambs (2019), which shows that meta-analysis can reveal patterns or trends that are not visible in regular qualitative analysis. Fourth, meta-analysis provides an organized way to handle information from a large number of research findings under study. Thus, this research can help simplify the complexity of data and enable researchers to understand the overall picture of existing research results, in line with the research conducted by Izzah & Mulyana (2021).

The problem statement of this meta-analysis research is how the PjBL-STEM learning model influences TEL and student learning motivation, considering the variables of education level and subjects taught. This research aims to do two things. First, to explore the extent of the impact provided by the PjBL-STEM model on TEL and student learning motivation, considering differences in educational levels. Second, to determine the extent of the influence of the PjBL-STEM model on TEL and student learning motivation, considering differences in the subjects taught, and third, to determine the extent of the influence of the PjBL-STEM model on TEL and student learning motivation, considering differences in the grade levels of the students in the learning process.

METHOD

The research methodology employed in this study is meta-analysis, which adopts a quantitative approach to review existing research. Meta-analysis is quantitative in nature as it involves numerical calculations and statistical analyses to organize and extract information from a large dataset for practical purposes (Juandi & Tamur, 2020). It is used to summarize quantitative data from multiple studies and draw conclusions about the distribution of effect sizes within a set of eligible studies (Juandi & Tamur, 2020).

The utilization of meta-analysis in this study aimed to assess the impact of the STEM-PjBL model in science education on students' technology engineering literacy (TEL) and learning motivation. The random-effects model was chosen to accommodate the diversity among the primary studies, considering factors such as educational level, sample size, integration of STEM-based PjBL, and study year, which could contribute to heterogeneity in TEL and student motivation. Initially, heterogeneity testing was conducted to address this issue.

Typically, meta-analysis involves several stages, including defining the research problem, data collection, coding, applying statistical analysis, and presenting results (Juandi & Tamur, 2020; Retnawati, Apino & Kartianom, 2014). Other literature outlines additional stages such as defining the problem, inclusion criteria, devising a literature search strategy, study selection, data extraction, and interpretation and reporting of findings (Borenstein, Hedges, Higgins & Rothstein, 2009; Cooper, Valentine & Hedges, 2017). In this study, the stages used follow the framework proposed by Borenstein, Hedges, Higgins, and Rothstein (2009). These stages include:

1. Defining the Problem: Identifying the specific research problem to be addressed through the meta-analysis. This involves determining the key variables and formulating clear research questions.
2. Defining Inclusion Criteria: Establishing inclusion criteria to determine which studies will be included in the meta-analysis. These criteria typically consider aspects such as study design, the population studied, interventions, and outcomes measured.
3. Devising a Literature Search Strategy: Creating a comprehensive literature search strategy to find all relevant studies. This includes using various databases and appropriate keywords to ensure a wide coverage of the available literature.
4. Study Selection: Selecting studies based on the defined inclusion criteria. Studies that meet the criteria are included in the meta-analysis, while those that do not are excluded.
5. Data Extraction: Extracting essential data from the selected studies, including information about research methods, sample sizes, outcomes, and statistics required for further analysis.
6. Interpretation and Reporting of Findings: Interpreting the statistical analysis results and reporting the meta-analysis findings. This stage also includes discussing the implications of the results, the limitations of the study, and suggestions for future research.

These stages are depicted in Figure 1 of this study, illustrating a systematic and comprehensive process to ensure the validity and reliability of the meta-analysis findings.

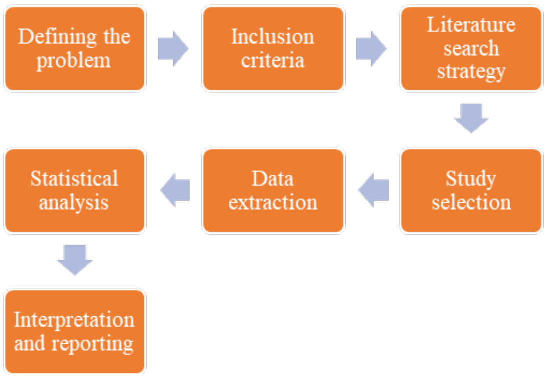

Figure 1. Flowchart of Meta-Analysis Stages

The following calculation formula will be employed in accordance with the following parameters Izzah & Mulyana (2021):

a. Mean and Standard Deviation of Pretest-Posttest

$$ES = \frac{\bar{x}_{post} - \bar{x}_{pre}}{SD_{pre}}$$

with
ES : effect size
$\bar{x}_{post}$: mean of the post-test
$\bar{x}_{pre}$: mean of the pretest
SD : standard deviation

b. Mean and Standard Deviation Two Group Post-test Only

$$ES = \frac{\bar{x}_E - \bar{x}_C}{SD_C}$$

with
ES : effect size
$\bar{x}_E$: mean of the experimental class
$\bar{x}_C$: mean of the control class
SD : standard deviation

c. Mean and Standard Deviation of Two-Group Pre-Post Test

$$\boldsymbol{ES = \frac{(\bar{x}_{post} - \bar{x}_{pre})_E - (\bar{x}_{post} - \bar{x}_{pre})_C}{\frac{SD_{preC} + SD_{preE} + SD_{postC}}{3}}}$$

with
ES : effect size
$\bar{x}_{postE}$: mean of the post-test in the experimental group
$\bar{x}_{preE}$:mean of the pretest in the experimental group
$\bar{x}_{preC}$: mean of the pretest in the control group
$\bar{x}_{postC}$: mean of the post-test in the control group
SD$_E$: standard deviation of the experimental group
SD$_C$: standard deviation of the control group

d. If the Standard Deviation is Unknown, it Can be Determined Using a t-Test

$$\boldsymbol{ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}}}$$

with
ES : Effect size
t : t-test result
n$_E$: number of experimental groups
n$_C$:number of control groups

After obtaining the effect size (ES), the results can be interpreted according to the criteria in Table 1.

Table 1. Effect Size Classification (Cohen's, 1988)

Effect Size (ES)	Standard Category
0 ≤ ES ≤ 0,2	Low
0,2 ≤ ES ≤ 0,8	Moderate
ES ≥ 0,8	High

RESULT AND DISCUSSION

a. Defining the Problem

The rapidly evolving global landscape in the 21st century requires significant adjustments in education, particularly in fostering students' potential through science education (Nurramadhani, Riandi, Permanasari & Suwarma, 2023). Education aims to develop quality students with scientific awareness, values, and essential skills to tackle modern challenges (Serdyukov, 2017; Thahir, Magfirah & Anisa, 2021). Key 21st-century skills include problem-solving, communication, creativity, and technology literacy, which are vital for deep learning and knowledge transfer (Pellegrino & Hilton, 2012; NRC, 2014; Mentz & Bailey, 2020).

To address these needs, science education must integrate technology and engineering literacy (TEL) to prepare students for real-world problems (Ejikeme & Okpala, 2016; Nikou, De Reuver, Kanafi, 2022). Integrating STEM (Science, Technology, Engineering, Mathematics) into education, particularly through Project-Based Learning (PjBL), has proven effective in enhancing TEL and motivating students (Torlakson, 2014; NAE & NRC, 2014). PjBL allows students to engage in real-world projects, fostering critical thinking and creativity (Bell, 2010).

b. Inclusion criteria

During the eligibility assessment, four studies lacked essential statistical information and were consequently excluded. Thus, 23 studies were identified as suitable for meta-analysis. These studies underwent coding and data extraction by two independent coders, capturing key information such as sample size, mean, standard deviation, p-value, t-value, education level, publication year, subjects, and the presence of STEM-PjBL in TEL and learning motivation. The study selection process was visually depicted in Figure 2, providing a comprehensive overview of the stages involved in identifying and selecting relevant primary studies.

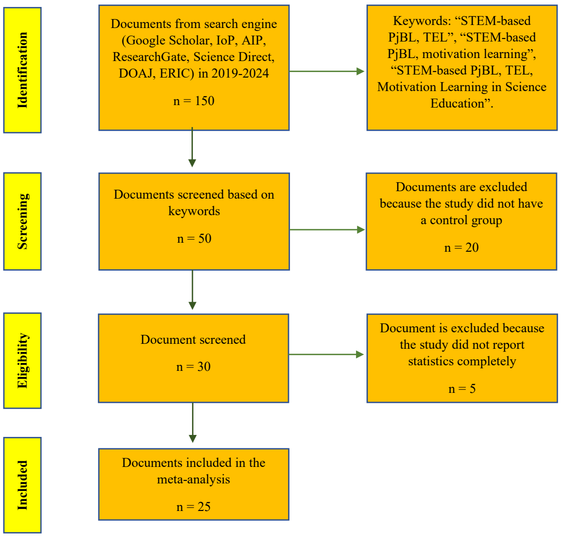

Figure 2. Study Selection Based on the PRISMA Stages

In conducting meta-analysis, it's crucial to follow a systematic procedure for tabulating data. This involves identifying the research variables and organizing them into appropriate columns, determining the mean and standard deviation for both control and experimental groups, and analyzing t-values if standard deviation is unavailable (Borenstein, Hedges, Higgins & Rothstein, 2009; Cooper, Valentine & Hedges, 2017). Finally, data analysis is performed to ascertain effect size values using the provided equation.

c. Literature Search Strategy

To conduct a meta-analysis on STEM-integrated Project-Based Learning (PjBL) and its impact on Technology Engineering Literacy (TEL) and student motivation, a structured literature search was performed. Key academic databases such as Google Scholar, ERIC, DOAJ, Research Gate, and specific publishers' platforms were used. Search terms included "STEM-Project-Based Learning," "Technology Engineering Literacy," and "student motivation," refined with Boolean operators. Studies were filtered for relevance, recentness, and empirical evidence. Initial screenings removed duplicates, followed by abstract and full-text reviews to assess quality and relevance. Reference lists of key studies were also checked. This approach ensured a comprehensive collection of high-quality research for the meta-analysis.

d. Study Selection

The study aimed to explore how the PjBL-STEM model impacts students' TEL and learning motivation. Specific inclusion criteria were set to focus on primary studies meeting certain conditions, including the use of STEM-based PjBL, involvement of students across different educational levels, and outcomes related to TEL and learning motivation. Only experimental or quasi-experimental quantitative research articles published between 2017 and 2023, containing the necessary statistical data for effect size calculation, were considered eligible. A systematic search using various keywords and databases like Google Scholar, ERIC, DOAJ, Research Gate, and specific publishers' platforms was conducted following the PRISMA framework for study selection, which involved identification, screening, and eligibility stages. Out of initially screened 30 studies meeting the criteria, only those with a control group were further analyzed, resulting in 23 eligible studies**.**

e. Data Extraction

For the meta-analysis on STEM-integrated Project-Based Learning (PjBL) and its impact on Technology Engineering Literacy (TEL) and student motivation, a systematic data extraction process was employed. Relevant studies were analyzed to extract key data points, including sample size, effect size, study design, and context. Specifically, each study's effect size, calculated using statistical measures like Cohen’s d, was recorded. Information on educational levels, subjects taught, and demographic details was also noted to assess the impact of PjBL across different contexts. Data extraction ensured consistency and accuracy, enabling a comprehensive synthesis of findings from various studies. This process facilitated a robust analysis of the effectiveness of STEM-PjBL interventions.

f. Statistical Analysis

The selected articles consist of 23 international and national journals, each assigned a code from A1 to A23. The following presents the codes, sources, and effect sizes analyzed from the 23 journals.

Table 2. Journal Code, Journal Sources, and Effect Size

Code	Journal Sources	Research Results	Effect Size
A1	(Anjarsari, Prasetyo & Susanti, 2020)	The analysis revealed a significant difference in technology and engineering literacy skills between the experimental and control classes, with STEM learning having a notable effect on literacy abilities measured at 64.10%.	0.64
A2	(Harpian, Suwarma & Setiawan, 2023)	The research findings indicate that students' STEM literacy has significantly improved, showing a substantial impact following the implementation of STEM learning.	3.10
A3	(Utami, Rochintaniawati & Suwarma, 2020)	In summary, students' STEM literacy showed a satisfactory improvement with a strong effect size following the use of a STEM-based module in their learning activities.	1.24
A4	(Tari, Suwarma & Hasanah, 2023)	The use of STEM-based modules in the physics learning process has a positive impact with a strong effect size on students' STEM literacy, particularly in the knowledge dimension.	1.49
A5	(Ngo, 2021)	A paired sample T-test showed a significant increase in students' motivation scores after STEM activities. Students felt that STEM education boosted their learning motivation and helped prepare them for future careers.	1.75
A6	(Mas'ula, Kusumaningtiyas, Novitasari & Luky, 2023)	The research results suggest that science teachers are encouraged to use the PjBL model as an effective teaching approach.	0.76
A7	(Rahajeng & Suryanti, 2023)	The study shows that the PjBL model significantly boosts student motivation and learning outcomes, with the experimental group showing higher motivation than the control group using conventional methods.	0.72
A8	(Yusuf, Ma'rufi & Nurdin, 2022)	The research shows an improvement in students' critical thinking skills and learning motivation after implementing the STEM approach in learning.	1.07
A9	(Nurhayati et al., 2023)	The STEM-integrated PjBL learning model can be used to enhance students' motivation, scientific literacy skills, and academic performance	2.73
A10	(Noviyani, Maison & Syaiful, 2021)	The findings show that PjBL-STEM and PBL significantly enhance mathematical creative thinking skills ($p < 0.050$), learning motivation levels impact these skills ($p < 0.050$), and there is an interaction between the two approaches and learning motivation ($p < 0.050$).	3.45
A11	(Salikha, Sholihin & Winarno, 2021)	The results of this study indicated that implementing STEM project-based learning significantly enhances students' motivation.	0.44
A12	(Luthfiyani, Widodo & Rochintaniawati, 2019)	This study indicates that STEM-based biology learning does not influence technological literacy or decision-making skills in high school students, as statistical tests revealed no significant differences between STEM and non-STEM class students.	0.53
A13	(Techakosit, 2018)	The results identified STEM literacy as comprising: 1) identifying STEM problems, 2) acquiring new knowledge, 3) applying STEM concepts, 4) solving problems with STEM, 5) communicating STEM-related information, and 6) making decisions based on STEM.	3.39
A14	(Tati, Firman & Riandi, 2017)	The analysis indicated significant improvements in science literacy and mathematics technology-engineering between the experimental and control classes, with a large effect size (over 0.8), attributed to design engineering activities that integrated knowledge from all STEM fields.	0.88
A15	(Aninda, Permanasari & Ardianto, 2019)	The data analysis showed that the experimental class had a moderate average N-Gain in STEM literacy, while the control class's achievement was low. The t-test results indicated that STEM literacy was better in the experimental class than in the control class.	0.18
A16	(Widyatmoko, Nugrahani, Yanitama & Darmawan, 2023)	The research results indicate that VRGBL significantly improves students' STEM literacy in energy concepts, with the experimental class achieving an N-gain of 0.57 (medium category) compared to the control class's N-gain of 0.28 (low category).	0.09
A17	(Samsudin, Jamali, Zain & Ebrahim, 2020)	The results demonstrated that STEM PjBL enhances students' self-efficacy in solving physics problems.	0.29
A18	(Fariasih & Fathoni, 2022)	Based on the analysis of the results, there is a relationship between the implementation of the PjBL learning model and learning motivation in relation to student achievement in civic education subjects in elementary	0.33

Code	Journal Sources	Research Results	Effect Size
		schools.	
A19	(Rachmawati & Rohaeti, 2018)	The research findings reveal significant differences in critical thinking skills and learning motivation between students using the STM model and the 5M model. These differences persist when controlling for initial knowledge, as well as in the motivation levels of students before and after learning about Buffer Solutions at SMAN 1 Godean.	0.57
A20	(Anwar, Yusri & Mantasiah, 2022)	Enhancing students' academic motivation directly affects their learning outcomes. Moreover, the Project-Based Learning model positively influences students' life skills.	2.09
A21	(Batzogiannis, Hatzikraniotis & Papadopoulos, 2018)	The study findings indicate that co-creating an "escape room" helps students uncover the underlying science, connect their informal STEM learning, and enhance their motivation for STEM.	2.83
A22	(Gok, 2021)	Suburban 7th graders had significantly higher STEM values than those in metropolitan areas. No significant differences were found for 6th and 8th graders, except in 5th-grade mathematics. Female students had lower STEM values than males in both regions.	0.12 & 0.39
A23	(Julia & Antoli, 2018)	The hands-on learning activities suggested during the STEM course foster a learning experience that captivates and engages students.	0.04 & 1.53
A24	(Ilafi, Suyanta, Wilujeng & Nurohman, 2024)	The research results indicate a high level of student motivation in learning. Each indicator shows a conformity rate above 50%, suggesting that students generally have a positive perception and greater interest in using science e-books based on STEM-PjBL (Project-Based Learning).	0.66
A25	(Ma'wa, Toto & Kustiawan, 2022)	The study concludes that the implementation of the PjBL-STEM model in science education, particularly in biotechnology topics, has a significant impact on students' learning motivation.	0.20
A26	(Rupnik & Avsec, 2020)	A two-way analysis of variance revealed significant effects of transdisciplinary education on the development of students' technological literacy (TL).	0.10
A27	(Vallera & Bodzin, 2020)	The study found that students in the treatment group gained more knowledge and had more positive attitudes after the curriculum implementation, compared to the control group. It discusses the implications for creating integrated STEM and agriculture curricula with technology-enhanced, project-based learning.	1.04
A28	(Dyrberg & Holmegaard, 2018)	The study found that physics students' motivation differs significantly from biochemistry, molecular biology, and biomedicine students. Some students struggle to see the relevance of the course content, leading them to reconsider their study choice.	0.74
A29	(Şimşek & Hamzaoğlu, 2023)	The data shows that the experimental-I group, using context-based STEM activities, had a stronger positive impact on scientific literacy and STEM motivation compared to the control groups in experiment-II and the science practice curriculum.	0.29
A30	(Vennix, Brok & Taconis, 2018)	Attitudes toward a potential STEM career were positively linked to autonomous motivation and negatively linked to controlled motivation.	0.15
A31	(Argianti & Andayani, 2021)	The analysis of the effectiveness of the STEM approach assisted by Wolfram Alpha, in terms of motivation, showed a t-value of 4.258, with a significant motivation value of 0.001 after the treatment, which is less than 0.05.	0.20
A32	(Higde & Aktamis, 2022)	The results indicated that STEM activities enhanced the science process skills, STEM career interests, and motivation for STEM fields in students from the experimental group, compared to those in the control group.	0.62
A33	(Jasko, Dukala & Szastok, 2019)	The study showed that female STEM students were more motivated when focusing on gender similarities. Highlighting these similarities could encourage women to engage in STEM, though gender stereotypes did not fully explain the effect.	0.17

The data reveals a diverse range of effect sizes across different studies. High effect sizes, such as those reported by Harpian, Suwarma & Setiawan (2023), Noviyani, Maison & Syaiful (2021), and Techakosit (2018), indicate substantial impacts of the interventions, with values exceeding 2.0, suggesting these interventions were particularly effective. In contrast, several studies show moderate to high effect sizes, ranging from 0.5 to 1.75, reflecting a significant but less pronounced impact. These include studies by Ngo (2021), Tari, Suwarma & Hasanah (2023), and Utami, Rochintaniawati & Suwarma (2020). Lastly, studies with small to moderate effect sizes, such as those by Salikha, Sholihin & Winarno (2021), Rupnik & Avsec (2020) and Fariasih & Fathoni (2022), indicate that the interventions had a modest impact, with values below 0.5 suggesting less pronounced effects. This range highlights the variability in intervention effectiveness, with some being highly impactful while others show more modest results.

Indicators of developing technological literacy can be observed through students' ability to understand and effectively use technological tools and resources in the learning process. This includes skills in operating software, analyzing digital information, and applying technology to solve problems (Anjasari, Prasetyo & Susanti, 2020; Harpian, Suwarma & Setiawan, 2023). Additionally, technological literacy is reflected in students' ability to adapt to rapidly evolving technology and utilize it to enhance productivity and creativity.

On the other hand, indicators of increasing learning motivation are evident in the heightened interest and desire of students to actively engage in the learning process. Motivated students tend to exhibit a high level of curiosity, participate in class discussions, and strive to achieve set learning goals (Rachmawati & Rohaeti, 2018; Gok, 2021). Moreover, learning motivation can also be measured by the improvement in students' efforts and perseverance in completing tasks, as well as their ability to overcome challenges encountered during the learning process. Both technological literacy and learning motivation are interconnected and crucial in creating an effective and innovative learning environment.

G. Interpretation and Reporting

1. The Influence of PjBL-STEM Learning Model on Students' TEL Examined by Educational Level

The first outcome of this meta-analysis study concerns the influence of the PjBL-STEM model on students' TEL examined by educational level. The average effect size values based on educational level were obtained from the effect size calculations of each article. The average effect size values examined by educational level, derived from 23 articles from national and international journals, are presented in Table 3.

Table 3. Data on the Effect Size of Students' TEL based on Educational Level

Education Level	Journal Code	ES	Mean	Category
ES	-	-	-	-
JHS	A1	0.64	1.00	High
	A3	1.24		
	A14	0.88		
	A16	0.09		
SHS	A2	3.10	1.32	High
	A26	0.10		
	A4	1.49		
	A12	0.53		
	A15	0.18		
CL	A13	3.39	3.39	High

From the data in Table 3, it can be explained that the meta-analysis results on the influence of the PjBL-STEM model on students' TEL based on educational level found that the PjBL-STEM model has a significant effect on the Junior High School, Senior High School and College levels, with effect sizes of 1.00, 1.32 and 3.39, respectively. This indicates that the PjBL-STEM model is effective when used at all educational levels except for Elementary School, as there is no related research yet on improving students' TEL. Overall, the PjBL-STEM model is beneficial for improving TEL across various educational stages, with the most substantial impacts observed at higher educational levels. Based on overall findings, the implementation of PjBL-STEM is effective in various learning outcomes. This is also supported by research (Suwarma & Kumano, 2019; Maulana, 2020; Harpian, Suwarma & Setiawan, 2023; Suwarma et al., 2023), demonstrating that the application of PjBL-STEM in cognitive domains is categorized as good, while the affective and psychomotor domains also yield positive results.

2. The Influence of PjBL-STEM Learning Model on Student Learning Motivation Examined by Educational Level

The second outcome of this meta-analysis study concerns the influence of the PjBL-STEM model on student learning motivation, examined by educational level. The average effect size values based on educational levels were obtained through the calculation of effect sizes from each article. The average effect size values were analyzed according to the educational level used in the 23 articles from national and international journals, as shown in Table 4.

Table 4. Data on the Effect Size of Students' Learning Motivation based on Educational Level

Education Level	Journal Code	ES	Mean	Category
ES	A6	0.76	0.39	Moderate
	A7	0.72		
	A18	0.33		
	A22	0.12		
	A23	0.04		
JHS	A10	3.45	0.88	High
	A11	0.44		
	A22	0.39		
	A23	1.53		
	A24	0.66		
	A25	0.20		
	A27	1.04		
	A29	0.29		
	A31	0.20		
	A32	0.62		
SHS	A8	1.07	1.27	High
	A9	2.73		
	A17	0.29		
	A19	0.57		
	A21	2.83		
	A30	0.15		
CL	A5	1.75	1.18	High
	A20	2.09		
	A28	0.74		
	A33	0.17		

From the data in Table 4, it can be explained that the meta-analysis results regarding the influence of the PjBL-STEM model on student learning motivation by educational level indicate that the PjBL-STEM model has a significant impact on motivation across different educational levels. Specifically, the PjBL-STEM model shows high effectiveness in middle school, high school, and college, with effect sizes of 0.88, 1.27, and 1.18, respectively. However, for elementary school, the effect size falls into the moderate category, at 0.39. The PjBL-STEM model effectively enhances student motivation across all educational levels. It demonstrates high effectiveness in middle school, high school, and college, with notable effect sizes, while showing moderate effectiveness at the elementary level. This underscores the model's broad applicability in increasing student engagement and motivation throughout different stages of education. The STEM-PjBL learning model enables students to engage in contextual learning through complex activities such as exploring, planning learning activities, collaborative project execution, and ultimately producing a tangible outcome (Jauharriyah, Suwono & Ibrahim, 2017). Therefore, PjBL-STEM is likely to have a positive impact and yield optimal results in the given subjects when implemented effectively. This is consistent with the researcher's findings that PjBL-STEM is effective across various subject areas. The PjBL-STEM learning model helps develop students' thinking skills (Addin, 2014; Suryana, Sinaga & Suwarma, 2018). It can be concluded that integrating STEM education using the PjBL model is highly effective in improving TEL and learning motivation.

3. The Influence of the PjBL-STEM Learning Model on Students' TEL Examined by Subject

The third outcome in this meta-analysis study concerns the influence of the PjBL-STEM model on students' TEL examined by subject. The average effect size values based on subjects were obtained from the calculation of effect sizes from each article. The average effect size values were examined by subject, as derived from the analysis of 23 articles published in national and international journals, as shown in Table 5.

Table 5. Data on the Effect Size of Students' TEL based on Subjects

Subjects	Journal Code	ES	Mean	Category
Science	A1	0.64	0.59	Moderate
	A3	1.24		
	A14	0.88		
	A16	0.09		
	A26	0.10		

Physics	A2	3.10	2.29	High
	A4	1.49		
Biology	A12	0.53	0.35	Moderate
	A15	0.18		

From the data in Table 5, it can be explained that the results of the meta-analysis on the influence of the PjBL-STEM model on students' TEL by subject indicate that the PjBL-STEM model has a significant impact on the Physics subject, with an effect size of 2.29. Meanwhile, for the subjects of Science (IPA) and Biology, the impact is moderate, with effect sizes of 0.59 and 0.35, respectively. This indicates that while the PjBL-STEM model demonstrates the capability to enhance Technology Engineering Literacy (TEL) across various subjects, its effectiveness is not uniform. The model shows particularly pronounced benefits in Physics, where the impact on TEL is significantly greater compared to other subjects like Science and Biology. This variability highlights the model's ability to adapt and provide more substantial improvements in specific subject areas, reflecting its potential for targeted application. Research by Maspul (2023) and Zavalevskyi, Khokhlina, Gorbenko, Fliarkovska and Chupryna (2023) supports this observation, suggesting that the PjBL-STEM model's effectiveness in enhancing TEL is most notable in Physics, thereby emphasizing the need for subject-specific adaptations to maximize the model's impact.

4. The Influence of the PjBL-STEM Learning Model on Students' Learning Motivation Examined by Subject

The fourth result in this meta-analysis study pertains to the effect of the PjBL-STEM model on student learning motivation by subject. The average effect size values based on subjects were derived from the effect size calculations of each article. The average effect size values were examined based on subjects used in the 23 articles from national and international journals, shown in Table 6.

Table 6. Data on the Effect Size of Students' Learning Motivation based on Subjects

Subjects	Journal Code	ES	Mean	Category
Science	A6	0.76	0.64	Moderate
	A7	0.72		
	A9	2.73		
	A11	0.44		
	A22	0.25		
	A24	0.66		
	A25	0.20		
	A27	1.04		
	A28	0.74		
	A29	0.29		
	A30	0.15		
	A31	0.20		
	A32	0.62		
	A33	0.17		
Chemistry	A19	0.57	0.57	Moderate
Physics	A17	0.29	0.29	Low
Mathematics	A8	1.05	2.25	High
	A10	3.45		
Social Humanities	A18	0.33	1.21	High
	A20	2.09		

From the data in Table 6, it can be explained that the meta-analysis results regarding the influence of the PjBL-STEM model on student learning motivation based on subjects found that the PjBL-STEM model has a high influence on the subjects of Mathematics, and Social Humanities, with effect sizes of 2.25, and 1.21 respectively. However, for the subject of Science and Chemistry, the effect size falls into the moderate category, at 0.64 and 0.57, while for Physics, the effect size is low at 0.29. Despite these variations, the consistent effectiveness of the PjBL-STEM model across different subjects underscores its versatility and potential to improve students motivation in diverse educational contexts. The findings align with previous studies, such as those by Sides and Suevas (2020) and Li, Jiang, Liang, Pan, and Zhao (2022), which highlight the model's capacity to enhance students motivation in various disciplinary settings.

5. The Influence of the PjBL-STEM Learning Model on Students' TEL Examined by Grade Level

The fifth outcome in this meta-analysis study pertains to the influence of the PjBL-STEM model on students' TEL, examined by grade level. The average effect size values based on grade levels were obtained through the calculation of effect sizes from each article. These average effect size values, examined by grade level, were derived from 23 articles published in national and international journals, as seen in Table 7.

Table 7. Data on the Effect Size of Student TEL based on Grade Levels

Grade	Journal Code	ES	Mean	Category
VII	A1	0.64	0.66	Moderate
	A3	1.24		
	A26	0.10		
VIII	A14	0.88	0.48	Moderate
	A16	0.09		
X	A4	1.49	1.01	High
	A12	0.53		
XI	A2	3.10	3.10	High
CL	A15	3.39	3.39	High

From the data in Table 7, it can be explained that the meta-analysis results on the effect of PjBL-STEM model on student TEL based on grade levels found that the PjBL-STEM model has a significant effect on grade levels X, XI, and College, with effect sizes of 1.01, 3.10, and 3.39 respectively. Meanwhile, for grade level VII and VIII, the effect size falls into the moderate category, at 0.66 and 0.48. Overall, the PjBL-STEM model proves to be an effective approach for enhancing Technology Engineering Literacy (TEL) across various grade levels. The model shows strong effectiveness in grades VII, X, XI, and College, with significant improvements in TEL, as evidenced by high effect sizes. This indicates that the PjBL-STEM model can substantially boost students' understanding and skills in technology and engineering at these stages. However, the impact varies somewhat, as observed with a moderate effect size for grade VIII. Despite the observed variability in effect sizes across different grade levels, the overall effectiveness of the PjBL-STEM model in enhancing Technology Engineering Literacy (TEL) remains evident. The model's significant positive impact across multiple grade levels, including VII, X, XI, and university levels, demonstrates its robust utility in educational contexts. This consistent performance across diverse grade levels highlights the model's adaptability and effectiveness in improving students' technological and engineering skills, regardless of their specific educational stage. As supported by Rahmawati, Suryani, Akhyar, and Sukarmin (2020) and Alkhawaldeh (2023), the PjBL-STEM model stands out as a valuable educational tool, capable of fostering TEL development and addressing the needs of students at various stages of their academic journey. This underscores the model's potential to contribute significantly to students' readiness for future challenges in technology and engineering fields.

6. The Influence of the PjBL-STEM Learning Model on Students' Learning Motivation Examined by Grade Level

The sixth result in this meta-analysis study pertains to the effect of the PjBL-STEM model on student learning motivation across grade levels. The average effect size values based on grade levels were obtained from the calculation of effect sizes from each article. The average effect size values were examined across grade levels as obtained from 23 articles in national and international journals, as presented in Table 8.

Table 8. Data on the Effect Size of Student Learning Motivation based on Grade Levels

Grade	Journal Code	ES	Mean	Category
IV	A7	0.72	0.42	Moderate
	A23	0.12		
V	A6	0.76	0.44	Moderate
	A23	0.12		
VII	A11	0.44	0.70	Moderate
	A23	1.53		
	A24	0.66		
	A29	0.29		
	A32	0.62		
VIII	A10	3.45	1.34	High
	A22	0.39		
	A31	0.20		
IX	A25	0.20	0.62	Moderate
	A27	1.04		
X	A8	1.07	0.68	Moderate
	A17	0.29		
XI	A9	2.73	2.04	High
	A19	0.57		
	A21	2.83		
CL	A5	1.75	0.73	Moderate
	A20	0.29		
	A28	0.74		
	A33	0.17		

From the data in Table 8, it can be explained that the results of the meta-analysis on the effect of the PjBL-STEM model on student learning motivation across grade levels found that the PjBL-STEM model has a significant effect on grade levels VIII and XI, with effect sizes of 1.34, and 2.04 respectively. Meanwhile, for grade levels IV, V, VII, IX, X and CL, the effect sizes were moderate, with values of 0.42, 0.44, 0.70, 0.62, 0.68, and 0.73. Overall, these findings highlight the versatility of the PjBL-STEM model in improving student learning motivation across a range of educational levels, with varying degrees of effectiveness depending on the specific grade level.

Based on the presented research findings, there are recommendations that can be given to teachers. Among them, teachers can utilize the PjBL model integrated with STEM education in school instruction. Project-Based Learning (PjBL) has significant advantages and benefits for students, yet it is rarely used. Integrating PjBL with STEM education is highly effective in schools because it integrates or combines four disciplines simultaneously: science, technology, engineering, and mathematics, making students more interested in attending classes and making learning activities more meaningful (Shin, 2018; Aslam, Khan, and Joseph, 2021). According to Rustaman (2016), there is a significant intersection between regular APjBL and PjBL-STEM, especially in their application. PjBL-STEM begins with contextual problems and ill-defined issues to find solutions through mastery of STEM concepts and insights, resulting in well-defined outcomes. Therefore, integrating STEM education into the PjBL model can be a supportive tool and can be applied in school instruction.

CONCLUSION

The PjBL-STEM model has a significant impact on students' Technology Engineering Literacy (TEL) at the senior high school and college levels, showing a very high effect, while its impact is moderate at the junior high school level and inconclusive at the elementary level due to insufficient data. It also enhances learning motivation across various educational levels, with strong effects in Science, Mathematics, and Social Humanities, although its impact is lower in Chemistry and Physics. The effectiveness of the PjBL-STEM model varies by grade level, being very high in grades VII, X, XI, and college, but moderate in grade VIII.

To optimize the benefits of the PjBL-STEM model, educators should focus on incorporating practical, hands-on activities, especially in subjects and grade levels where the model has shown significant impact. For elementary and junior high school levels, where effects are moderate or unclear, integrating foundational STEM activities can help build students' confidence and engagement. Tailored models are recommended for subjects like Chemistry and Biology, where the model is less effective, to enhance cross-curricular learning and connections between disciplines. Additionally, ongoing professional development for teachers is crucial to effectively implement the PjBL-STEM model and adapt it to meet diverse student needs.

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