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Review paper

# STEM-Based Engineering Design Process Models in Physics Learning: Systematic Literature Review

Muhammad Syukri [1]*, Fadiya Haya [1], Siti Maghfirah [1], Fitria Herliana [1], Mohamad S. Rasul [2], Hendri Pratama [3]

[1] *Universitas Syiah Kuala*, INDONESIA
[2] *Universiti Kebangsaan Malaysia,* MALAYSIA
[3] *Sultan Idris Education University,* MALAYSIA

*__Corresponding__ Author: syukri.physics@usk.ac.id

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## ABSTRACT

This study was motivated by the importance of STEM-based education that can competitively meet the needs of the rapidly evolving Industry 4.0. The main objective of this study was to examine the implementation of a STEM-based engineering design process (EDP) model using insights from previous studies documented in academic publications. The research methodology used was a systematic literature review (SLR) in accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analysis). The secondary data sample was collected from journals accessible through Scopus, SpringerLink, and Google Scholar databases. The journals were selected based on the inclusion criteria, coding phase, and study quality assessment. A descriptive analysis was performed on the selected journals. The study generated 23 articles, which were descriptively analyzed. The results showed that the STEM-based engineering design process model had a positive impact on improving creative thinking, critical thinking, and problem-solving skills in elementary, middle, and high school physics courses. The study highlights the potential of EDP models to prepare students for interdisciplinary challenges, promoting lifelong learning and equipping them with skills for STEM-related careers.

**Keywords:** EDP, STEM, physics learning, SLR, PRISMA

Nowadays, Education is increasingly focused on equipping individuals with competencies across multiple domains, enabling them to effectively respond to the challenges of Industry 4.0 (Golitsyana et al., 2021). As the demands of this industrial revolution evolve, contemporary learning methodologies have incorporated approaches that emphasize research-based and scientific learning (Hafeez et al., 2023). In the field of physics education, various instructional methods are available, each aimed at enhancing students' conceptual understanding and their ability to apply these concepts to real-world scenarios (Setiawan, 2020; Hunegnaw et al., 2025). Among these, STEM-based approaches have shown significant potential in developing human resources that are both integrative and competitive, equipping students with the critical skills necessary to thrive in the landscape of Industry 4.0 (Rizakhojayeva et al., 2025).

STEM (Science, Technology, Engineering, and Mathematics) education has emerged as a crucial framework for preparing students to meet the challenges of the 21st century. While STEM contributes to physics education, many individuals encounter challenges when incorporating the Engineering component into STEM integration (Winangun & Kurniawan, 2019; Diana, 2021). This difficulty arises from a need for more understanding regarding how to implement STEM in education and how to create the necessary tools and materials for STEM learning (Nugroho et al., 2019; Wahono & Chang, 2019; Susilo & Sudrajat, 2020). It is crucial to note that when integrating STEM into students' learning experiences, they can independently create a product. STEM education encompasses two main aspects: the scientific process and design. These two processes are then tested, and their outcomes are evaluated to determine the effectiveness of the problem-solving solution. One of the central components of STEM education is the integration of engineering design process (EDP) models, which allow students to engage in problem-solving and hands-on learning experiences (Asimakopoulos et ala., 2024). Within the context of physics education, STEM-based EDP models provide a unique opportunity to enhance understanding of core physics concepts by fostering critical thinking, collaboration, and the practical application of theoretical knowledge.

The Engineering Design Process (EDP) is a model that educators can use to enhance problem-solving skills and introduce students to engineering (Robinson & Mangold, 2013). Integrating STEM through the EDP positively impacts students and the learning environment. EDP actively involves students in the learning process (Guzey et al., 2016). Similarly, it has been observed that EDP-based learning positively enhances students' skills in solving science-based problems (Syukri et al., 2018). With the continuous evolution of technology, EDP has gained popularity as a design process in STEM approaches, contributing to the improvement of creative thinking, critical thinking, and problem-solving abilities (Samad et al., 2023; Arivina & Jailani, 2020; Haryadi et al., 2021; Grewe, 2025).

In recent years, there has been growing interest in understanding how these engineering design processes can be effectively incorporated into physics learning to improve student outcomes. The intended learning outcomes of the study reflect the development of cognitive, practical, and metacognitive competencies that integrate both scientific and engineering reasoning (Türkoğuz & Kayalar, 2021). Students are expected to deepen their conceptual mastery of physics by applying theoretical knowledge to real world design tasks, fostering understanding of abstract concepts such as energy conversion and electromagnetism through hands-on experimentation (Xi et al., 2024; Abdurrahman et al., 2023). Simultaneously, the model emphasizes the application of engineering design skills, including problem identification, ideation, prototyping, and testing, enabling learners to transform abstract physical principles into tangible solutions (Winarno et al., 2020; Guzey et al., 2016). Beyond content knowledge, the EDP nurtures higher-order thinking skills such as creativity, critical thinking, and problem-solving (Safitri et al., 2024; Putra et al., 2023). Overall, this framework represents a pedagogical shift from merely knowing physics to using physics, aligning with interdisciplinary and practice-oriented STEM education goals (Nurtanto et al., 2020).

A systematic literature review (SLR) of STEM-based engineering design process models in physics education is essential to map out existing models, assess their impact on learning, and identify areas where further research is needed. This systematic literature review aims to analyse the existing body of research on EDP models within STEM-based physics learning, highlight best practices, and provide a framework for future instructional design in STEM education. By synthesizing the findings from a wide array of studies, this review informs educators, curriculum developers, and policymakers on effectively integrating engineering design into physics education (Shahidullah & Hossain, 2022). This hopefully enhances students' learning experiences and prepares them for future STEM-related careers.

The systematic literature review (SLR) conducted in this study adopts a structured approach to identify, evaluate, and synthesize research on STEM-based engineering design process (EDP) models in physics learning. The methodology follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure a transparent and rigorous process. The review begins by formulating specific research questions (RQ) that guide the entire research process, ensuring a focused and coherent examination of relevant literature (Haddaway et al., 2022). The research questions are designed to address the key aspects of STEM-based EDP models, including their applications, impacts, and challenges in the context of physics education.

RQ1: How does the STEM-based Engineering Design Process model influence physics education at different levels of schooling?

RQ2: Is the STEM-based Engineering Design Process model more effective than other innovative instructional models for students in physics education?

RQ3: Is implementing the STEM-based Engineering Design Process model more effective than conventional teaching methods for students in physics education?

RQ4: Does the STEM-based Engineering Design Process model enhance creative thinking, critical thinking, and problem-solving skills in physics education?

## METHODS

### Search strategy and criteria

A comprehensive search was conducted across multiple academic databases, including but not limited to Scopus, SpringerLink, and Google Scholar. The following search terms and Boolean combinations were used to ensure the identification of relevant studies: "STEM-based" OR "STEM" AND "engineering design" OR "engineering design process" OR "design process models" OR "EDP" AND "physics learning" OR "physics education". The search targeted peer-reviewed journal articles that focus on STEM-based EDP models in the context of physics learning. **Table 1** shows the keywords and the number of article databases.

Studies for this review were selected based on specific inclusion and exclusion criteria. The inclusion criteria focused on research published in peer-reviewed journals or academic sources. These studies specifically investigate STEM-based engineering design process (EDP) models within physics education between 2020 and 2024, articles written in English, and studies addressing elementary, junior, and senior levels. While this study primarily focused on research published between 2020 and 2024 to capture recent developments aligned with Industry 4.0 and post-pandemic educational transformations, the authors agree that earlier studies provide important historical and contextual insights into the evolution of STEM and EDP models.

During the initial search phase, 164 papers published before 2020 met the basic keyword search but were excluded based on the inclusion criteria, as many lacked explicit integrations of EDP in STEM-oriented physics learning or did not meet methodological rigor standards. On the other hand, exclusion criteria were applied to studies that did not directly relate to engineering design or STEM approaches in physics, papers that lacked measurable learning outcomes, duplicate studies, or articles unavailable in full text. This approach ensured the relevance and quality of the selected literature.

**Table 1**

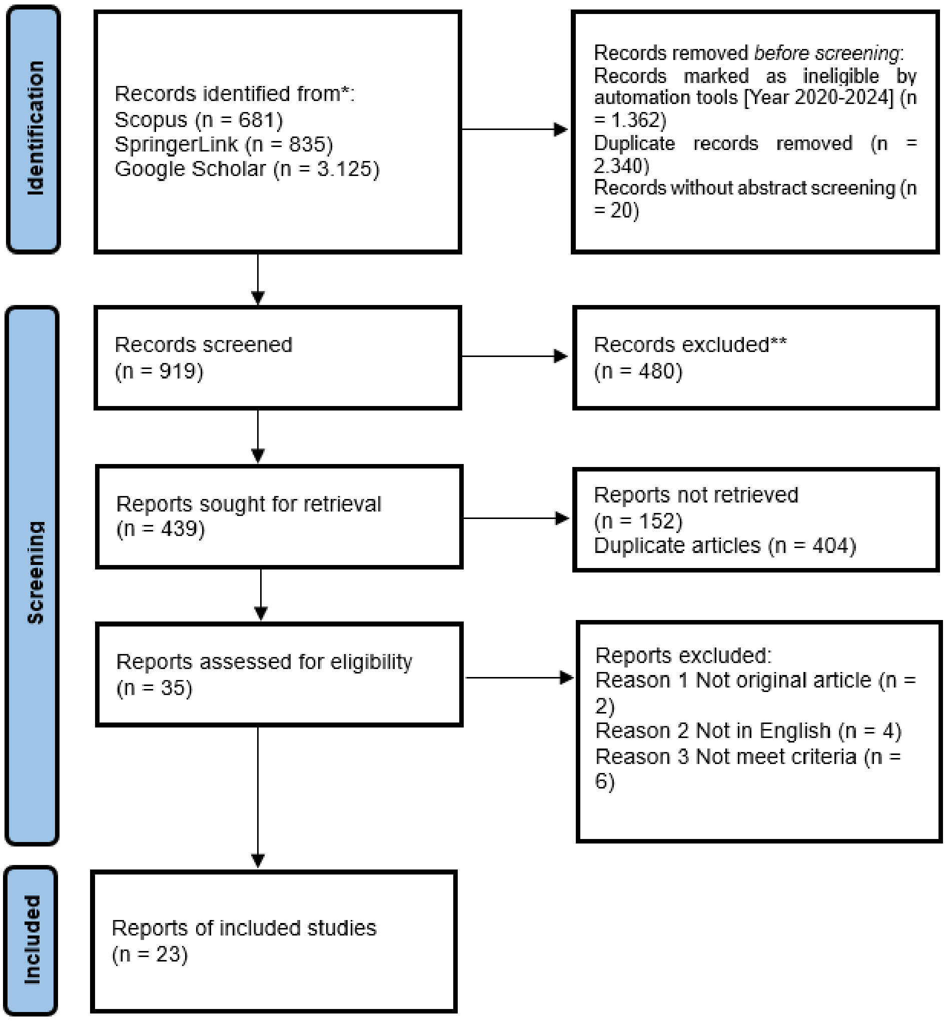
*Keywords and number of article databases*

| Keyword | Source | | |
|---|---|---|---|
| | Scopus | Springer | Google scholar |
| (“STEM-based” AND (“engineering design” OR “engineering design process”) AND "physics learning") | 21 | 84 | 244 |
| (“STEM” AND (“engineering design” OR “EDP”) AND "physics education") | 536 | 341 | 2.220 |
| (“STEM” AND (“design process models” OR “engineering design process”) AND "physics education") | 124 | 410 | 661 |
| Sub total | 681 | 835 | 3.125 |
| Total | 4.641 | | |

### Procedures

The study selection process followed a systematic approach, documented using the PRISMA flow diagram (See Figure 1) to visually summarize the progression from study identification to inclusion. This included listing potential studies, removing duplicates, screening titles and abstracts for relevance, and conducting a detailed review of full-text articles for eligibility. The final selection ensured transparency and replicability, adhering to PRISMA guidelines (Moher et al., 2009). Relevant studies were analyzed using the PICOs framework. This framework is a mnemonic used to formulate clinical and research questions that can be answered by dividing them into four components, namely Patient/Problem/Population, Intervention, Comparison/Control, and Outcome. It helps researchers define the key concepts for a literature search, enabling authors to conduct more focused and effective searches. A qualitative synthesis summarized the findings, highlighting trends, themes, and research gaps. Study quality was assessed based on predefined criteria, focusing on relevance, rigor, and contributions. High-quality studies were prioritized. Extracted data were categorized by EDP model type, educational context, and measured outcomes. This analysis evaluated the effectiveness of STEM-based EDP models in physics learning and identified areas for further research.

**Figure 1**
*Prisma flow diagram*




This study yielded 4.641 results; however, only 23 studies met the inclusion criteria and were analyzed. The studies were published between 2020 and 2024, with the majority published in 2020 and 2024. The sample sizes of the studies varied, and data were mainly collected through pre- and post-tests, interviews, and surveys. The systematic review revealed three main themes related to creative thinking, critical thinking, and problem-solving skills, with a focus on STEM learning based on EDP models in Physics at three different educational levels, namely elementary, junior, and senior high school. Table 2 in Appendix 1 shows the PICOs analysis of these studies.

### Databased on publication years

The data results from the review of STEM-based Engineering Design Process (EDP) model articles are based on the designated five-year publication years, from 2020 to 2024. Based on Table 3, recent studies exhibit a strong emphasis on integrating innovative instructional strategies such as STEM-EDP and PBL with design thinking (Lia et al., 2024; Safitri et al., 2024). These models significantly improve critical thinking, creative thinking, and problem-solving abilities, highlighting the relevance of combining hands-on activities with cognitive skill development. Comparatively, older studies (2020-2021) also demonstrated positive outcomes. Still, they were more diverse in their methods, such as mixed-method approaches (Yuniar et al., 2020; Permana et al., 2021) and qualitative case studies (Ergül & Çalış, 2021).

Additionally, longitudinal progress is seen in adopting interdisciplinary STEM approaches that align better with educational goals, like 21st-century competencies (4Cs). Digital media technology has the potential to enhance teaching and learning, presenting complex subject matter through interactive and up-to-date instructional media in the face of the challenges posed by the modern world, increasingly dominated by technology (Linh & Huong, 2021). This enhancement makes the STEM-based EDP model more interactive and relevant in 21st-century learning. Consequently, numerous studies were conducted in 2020 to support 21st-century skills.

Another factor contributing to the abundance of STEM-based EDP-related research in 2020 is the COVID-19 pandemic. This global crisis has shifted the entire learning process towards digital technology, specifically through remote learning. This transformation has assisted students in accessing educational resources limitlessly through online learning platforms (Zhou et al., 2024). Consequently, implementing the STEM-based EDP model using digital content technology in physics education has emerged as a solution and innovation that both students and teachers can utilize to address the challenges of the 21st century (Winarno et al., 2020; Linh & Huong, 2021). In conclusion, the surge in STEM-based EDP model research in 2020 can be attributed to the necessity of adapting to the challenges posed by subsequent years, particularly in the ongoing pandemic.

**Table 3**

*Research findings based on publication year*

| No. | Year of study | N Article | Codes |
|---|---|---|---|
| 1 | 2024 | 5 | 1, 2, 3, 4, 5 |
| 2 | 2023 | 4 | 6, 7, 8, 9 |
| 3 | 2022 | 1 | 10 |
| 4 | 2021 | 5 | 11, 12, 13, 14, 15 |
| 5 | 2020 | 8 | 16, 17, 18, 19, 20, 21, 22, 23 |

## DISCUSSION

### RQ 1: How does the STEM-based engineering design process model influence physics education at different levels of schooling?

This study was conducted by applying the article selection procedure based on inclusion and exclusion criteria, identifying 23 selected articles. To answer research question 1, the education criteria were examined based on three levels, including elementary school (SD), junior high school (SMP), and senior high school (SMA). The results of the article review in this study revealed that the STEM-based Engineering Design Process (EDP) model can be applied at various levels of education, as described in **Table 4**. The findings indicate that the application of the STEM-based EDP model has a positive impact at the elementary school (SD), junior high school (SMP), and senior high school/vocational school (SMA/SMK/MA) levels. However, research on the STEM-based EDP model has mostly focused on the senior high school/vocational school/MA level in physics education over the past five years.

**Table 4**

*Research findings based on educational level*

| No. | Educational level | N Article | Codes |
|---|---|---|---|
| 1 | Elementary (SD) | 2 | 6, 19 |
| 2 | Junior (SMP) | 3 | 5, 10, 12 |
| 3 | Senior (SMA/SMK/MA) | 18 | 1, 2, 3, 4, 7, 8, 9, 11, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23 |

This pattern is likely influenced by the inherent complexity of physics topics taught at the senior high school/vocational high school/MA level compared to lower educational levels. Consequently, the STEM-based EDP approach proves beneficial in aiding students to connect abstract physics concepts with real-world applications, ultimately enhancing their comprehension (Nurtanto et al., 2020; Abdurrahman et al., 2023; Safitri et al., 2024; Xi et al., 2024). At the senior high school/vocational high school/MA level, students are frequently encouraged to engage in competitive and innovative projects, driving the prevalence of the STEM-based EDP model. This model equips students with essential tools and skills, such as problem identification and design planning, for developing innovative projects and successful participation in higher-level competitions. Given the demand for critical thinking, creativity, and the application of scientific knowledge in real-world scenarios at the senior high school/vocational high school/MA level, the STEM-based EDP model emerges as a valuable tool in cultivating these essential skills (Purwaningsih et al., 2020; Rahmanto et al., 2024).

The results are aligned with the assertion by Ali & Tse (2023) that students have reached a more mature cognitive development stage at the senior high school level, allowing them to develop more sophisticated thinking abilities. However, it is imperative to acknowledge that the STEM-based EDP model holds potential benefits across all educational levels because elementary and junior high school students necessitate an instructional approach tailored to their developmental stage, emphasizing foundational concept understanding and delivering engaging materials (Prasadi et al., 2020; Ab Kadir et al., 2021; Gök & Sürmeli, 2022; Putra et al., 2023; Ramli et al., 2024). Consequently, the STEM-based EDP model contributes to enhanced learning experiences across diverse educational levels, with particular efficacy at the senior high school level.

**RQ 2: Is the STEM-based engineering design process model more effective than other innovative instructional models for students in physics education?**

The data results from the review of STEM-based Engineering Design Process (EDP) model articles on critical thinking, creative thinking, and problem-solving are derived from the analysis of 23 scholarly publications. Each analyzed scholarly publication has at least one dependent variable, with three publications featuring more than one dependent variable. Based on the data findings presented in **Table 5**, it is explained that the STEM-based Engineering Design Process (EDP) model in enhancing students' critical thinking skills was identified in 7 out of 23 articles reviewed in physics education.

**Table 4**

*Research finding based on critical thinking, creative thinking, and problem solving*

| No. | Dependent variables | N Article | Codes |
|---|---|---|---|
| 1 | Critical Thinking | 7 | 1, 5, 9, 11, 19, 21, 22 |
| 2 | Creative Thinking | 6 | 4, 7, 8, 10, 14, 20 |
| 3 | Problem Solving | 11 | 2, 3, 4, 6, 8, 9, 13, 14, 15, 16, 23 |

The research findings suggest that the STEM-based EDP model is most frequently encountered in improving physics education students' critical thinking abilities. The result indicates that STEM-based EDP can significantly enhance students' critical thinking skills in physics learning, as the EDP model serves as a framework used to teach students how to design and develop solutions for engineering problems. Consequently, teachers can develop students' critical thinking skills, such as problem analysis, hypothesis formulation, data collection, and solution evaluation, through the STEM-based EDP model (Prasadi et al., 2020; Yustika et al., 2021; Safitri et al., 2024; Ramli et al., 2024). It can be speculated that STEM learning positively impacts students' critical thinking skills (Oktavia & Ridlo, 2020; Ardianti et al., 2020; Chairunnisya et al., 2023).

The analysis of 23 scholarly publications reveals that 6 articles focus on enhancing creative thinking skills. In contrast, 11 articles emphasize problem-solving abilities within the STEM-based Engineering Design Process (EDP) model. This underscores the importance of these skills for students, such as the capacity to generate innovative ideas when confronted with challenges in the learning process. The application of the STEM-based EDP model emerges as a valuable tool for addressing real-world problems (Nurtanto et al., 2020; Ergül & Çalış, 2021; Abdurrahman et al., 2023; Lia et al., 2024). This model seamlessly integrates physics education with practical and interdisciplinary problem-solving approaches, significantly improving students' problem-solving capabilities.

Furthermore, it equips students with the necessary skills to confront real-world challenges, demanding scientific understanding, technical proficiency, and complex problem-solving insight (Putra et al., 2023; Xi et al., 2024; Lia et al., 2024). The systematic literature review findings on students' critical thinking, creative thinking, and problem-solving skills collectively serve as valuable knowledge to be applied in physics education. This underscores the contribution of the STEM-based Engineering Design Process (EDP) to effective and successful learning, particularly in enhancing students' thinking skills within the context of physics topics.

Numerous studies have demonstrated that the EDP offers a more comprehensive and effective instructional framework than other innovative models, particularly in physics and STEM education. While approaches such as Project-Based Learning (PBL) and Inquiry-Based Learning (IBL) effectively promote engagement and exploration, EDP extends these benefits by integrating systematic design, iterative testing, and optimization processes that mirror authentic engineering practice (Winarno et al., 2020; Guzey et al., 2016). This integration allows learners not only to investigate scientific phenomena but also to apply and refine their understanding through tangible problem-solving and prototype development.

Furthermore, EDP's effectiveness lies in its integration of scientific inquiry with engineering reasoning, providing a dual framework that encourages both conceptual exploration and product-oriented innovation. This dual emphasis aligns with 21st-century competency goals, enabling students to think systematically, adaptively, and collaboratively in addressing complex interdisciplinary challenges (Ramli et al., 2024; Ali & Tse, 2023). Therefore, within the STEM education context, EDP stands out as a superior model because it not only enhances learning engagement but also develops students' higher-order cognitive and metacognitive skills more effectively than other instructional strategies.

**RQ 3: Is implementing the STEM-based engineering design process model more effective than conventional teaching methods for students in physics education?**

Implementing the STEM-based Engineering Design Process (EDP) model in physics education has been increasingly regarded as an effective instructional strategy compared to conventional teaching methods. Research indicates that this model enhances students' cognitive abilities, problem-solving skills, and engagement by integrating science, technology, engineering, and mathematics in a hands-on, inquiry-based framework. Studies have consistently demonstrated that EDP improves students' learning outcomes in physics. For instance, using EDP has fostered higher-order thinking skills such as critical analysis and innovation. This is because students are actively involved in designing and testing solutions to real-world problems, which mirrors the interdisciplinary nature of STEM applications in professional settings. In comparison, traditional teaching methods often rely on rote memorization and lack practical application, limiting their effectiveness in developing these critical skills (Ardianti et al., 2020).

Moreover, EDP-based instruction increases motivation and interest in STEM subjects. By engaging students in collaborative and iterative processes, such as brainstorming, prototyping, and evaluating solutions, the approach not only enhances content mastery but also fosters a sense of ownership over learning. This is particularly evident in studies where students report greater enjoyment and a deeper understanding of physics concepts when engaged in EDP activities compared to traditional lectures or textbook-based learning (Hasanah, 2020; Abdurrahman et al., 2023). In addition, EDP models support the development of transferable skills like teamwork, communication, and adaptability. These skills are crucial for students preparing for future STEM careers. Research highlights that EDP activities often lead to improved student attitudes toward STEM fields and career aspirations, making it a valuable pedagogical approach for long-term academic and professional growth (Xi et al., 2024).

However, the effectiveness of EDP depends on several factors, including teacher preparedness, curriculum integration, and resource availability. Teachers must be adequately trained to facilitate EDP effectively, as it requires guiding students through complex problem-solving processes while aligning activities with curriculum standards. Furthermore, schools need to invest in resources such as lab equipment, digital tools, and professional development to implement EDP successfully (Nurtanto et al., 2020). Despite these challenges, the overall benefits of EDP in physics education are evident. It shifts the learning focus from passive absorption to active exploration, aligns with 21st-century educational goals, and prepares students for interdisciplinary challenges. As such, EDP has emerged as a compelling alternative to conventional teaching methods, making it a transformative model for physics education (Ardianti et al., 2020). This perspective is supported by systematic reviews and meta-analyses, which consistently point to the positive impact of EDP on student engagement, learning outcomes, and skill development across STEM disciplines. Future research could explore strategies to overcome barriers in implementation and further quantify its long-term benefits on academic and career success.

**RQ 4: Does the STEM-based engineering design process model enhance creative thinking, critical thinking, and problem-solving skills in physics education?**

The STEM-based Engineering Design Process (EDP) has been shown to enhance creative thinking, critical thinking, and problem-solving skills in physics education by encouraging students to engage with real-world problems in a structured yet flexible manner (Ergül & Çalış, 2021; Putra et al., 2023; Tiemann et al., 2026). This approach integrates science, technology, engineering, and mathematics to provide an interdisciplinary learning experience beyond traditional rote learning. The EDP fosters creativity by requiring students to brainstorm, prototype, and refine their ideas while solving complex problems. For example, research shows that students participating in STEM-focused curricula significantly improved creativity metrics like fluency, flexibility, and originality (Abdurrahman et al., 2023). These attributes are critical for innovation and are particularly nurtured when students tackle open-ended design challenges that demand novel solutions (Ab Kadir et al., 2021). Activities embedded within the EDP, such as designing physical models or simulations in physics, encourage students to visualize concepts and develop original approaches to problems.

The EDP emphasizes systematic analysis, feasibility testing, and iterative improvement. By engaging in these activities, students learn to evaluate multiple perspectives and apply logical reasoning. This aligns with findings highlighting the EDP's role in helping learners develop the cognitive skills needed for informed decision-making and reflective evaluation of their work. This process is crucial in physics, where understanding abstract concepts often requires analytical thinking supported by empirical evidence (Wahono et al., 2020). STEM-based learning environments centred around the EDP encourage students to view mistakes as learning opportunities. Problem-solving in this context often involves identifying constraints, hypothesizing solutions, and iterating through testing phases. Such experiences prepare students for challenges in both academic and real-world settings by teaching adaptability and persistence. High-quality STEM curricula enable students to connect theoretical physics principles with practical applications, enhancing their ability to address diverse problems (Artika et al., 2024).

The EDP inherently combines knowledge from various disciplines, offering students a comprehensive approach to problem-solving. This integration helps them see the relevance of physics in broader technological and societal contexts. For instance, designing a renewable energy system requires understanding principles of physics, environmental considerations, and technological constraints, cultivating well-rounded problem-solving abilities (Abdurrahman et al., 2023; Lia et al., 2024).

Although all studies included in this review reported positive impacts of STEM-based engineering design process (EDP) models, it is important to acknowledge the potential influence of publication bias. Studies with null or negative findings are often underreported or unpublished in education research (Borenstein et al., 2021, p. 438; Cooper & Meterco, 2017). The authors conducted additional searches to identify studies reporting inconclusive or nonsignificant results, but none met the inclusion criteria. These results suggest that although EDPs generally have positive impacts, the evidence base may be skewed toward positive results. Therefore, future studies should emphasize transparent reporting of neutral or mixed findings to provide a more balanced understanding of EDP effectiveness (Hedges & Maier, 2013; Ioannidis, 2015).

To address this, the authors conducted an additional targeted search for studies reporting neutral, negative, or inconclusive findings regarding the implementation of STEM-based Engineering Design Process (EDP) models in physics education. This search included broader keyword combinations such as “no significant effect,” “ineffective,” “comparison failure,” and “non-significant results,” following recommendations by Cooper & Meterco (2017) and Borenstein et al. (2021) for bias detection. Despite this expanded search, no studies meeting the inclusion criteria explicitly reported negative or null effects of the EDP model. Most retrieved studies highlighted varying degrees of positive impact—some modest and context-dependent, but none demonstrated adverse or insignificant effects.

## CONCLUSION

In conclusion, the STEM-based engineering design process (EDP) model has been shown to significantly enhance critical thinking skills in physics learning, contributing to positive educational outcomes. Additionally, the model also improves creative thinking and problem-solving abilities, demonstrating its overall effectiveness in the physics learning process. The review further concludes that the STEM-based EDP model is applicable and beneficial at all educational levels—elementary, middle, and high school.

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### Ethical statement

Not applicable.

### Conflict of interest

The authors declare that there is no conflict of interest related to this work.

### Author contributions

MS participated in Conceptualization, Methodology, Resources, Writing – Original Draft, Supervision, Writing – Review & Editing, and Project Administration. FH participated in Conceptualization, Supervision, Methodology, Software, Resources, Writing – Original Draft, Writing – Review & Editing, and Project Administration. SM & FH participated in Methodology, Software, and Writing – Original Draft. MSR & HP participated in Methodology, Resources, Writing – Original Draft, and Software. HP participated in Writing – Review & Editing.

 

### Data availability

The data supporting the findings of this study will be available upon reasonable request from the corresponding author.

### AI disclosure

Artificial intelligence tools were used to support language editing and clarity of expression in this manuscript. All scientific content, analysis, interpretations, and conclusions were developed by the authors, who take full responsibility for the accuracy, originality, and integrity of the work.

### Biographical sketch

*Muhammad Syukri* is a senior lecturer in the Department of Physics Education and the master's program in Science Education at Universitas Syiah Kuala. He earned his bachelor's degree in physics education from Universitas Syiah Kuala and completed his Master's and Doctoral degrees in Science Education at the National University of Malaysia (UKM). His teaching and research interests include physics education, STEM education, science pedagogy, curriculum development, and interdisciplinary approaches in science education.

*Fadiya Haya* is a graduate of Physics Education and is currently pursuing a Master's degree in Science Education. She is an independent researcher with a strong interest in problem-based learning, STEM education, and digital learning media. She serves as a journal administrator at the Asian Journal of Science Education (AJSE) and actively contributes to academic writing and research in science education.

*Siti Maghfirah* is an independent researcher in education with a research focus on STEM education and physics education. She holds a Master's degree in Science Education from Universitas Syiah Kuala and has experience as a research assistant in educational research projects. Her scholarly interests center on learner-centered instructional approaches and the development of students' competencies in science learning within secondary education.

*Fitria Herliana* is a Lecturer at the Department of Physics Education, Universitas Syiah Kuala, Aceh, Indonesia, and has been serving as a faculty member since 2019. She is currently pursuing her doctoral degree in Education at the same institution. Her research interests encompass physics education, digital learning environments in physics instruction, and assessment and evaluation in physics education.

*Mohamad Sattar Rasul* is a Professor in the Department of Innovation in Teaching and Learning, Faculty of Education, Universiti Kebangsaan Malaysia. He holds Master's and Doctoral degrees in Industrial Engineering and Systems from Universiti Putra Malaysia and specializes in Technical and Vocational Education and Training (TVET), engineering education, and STEM education. He has served as a university-level STEM coordinator, led and contributed to numerous national and international research grants, and actively engages in academic publishing and community-based STEM initiatives. He is a member of the Asian Academic Society for Vocational Education and Training and serves as an editor of the Journal of the Asian Academic Society for Vocational Education and Training.

*Hendri Pratama* is an independent researcher and academic in the field of Technical and Vocational Education and Training (TVET) with a strong interest in inclusive education, STEM education, and educational technology. He currently serves as Managing Editor of the *Journal of Technology and Humanities* and as an international conference committee member, contributing to the academic publication process and scholarly quality assurance.

### Disclaimer/Publisher's Note



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Appendix 1

**Table 2**
*PICOs analysis*

| Codes | Authors/years | Participant | Intervention | Comparison | Outcomes | Study design |
|---|---|---|---|---|---|---|
| 1 | Safitri et al. (2024) | 142 senior high school students | Quasi-experimental (Pre & Post test) | Creative and critical thinking abilities | The STEM-based EDP model is able to improve creative and critical thinking abilities | Quantitative |
| 2 | Xi et al. (2024) | 64 senior high school students | Quasi-experimental (Pre & Post test) | Knowledge, creative, problem-solving skills, and attitudes | The EDP-CDIO model significantly improved students' STEM knowledge, skills, attitudes and developed more comprehensive epistemic networks in STEM competence | Quantitative |
| 3 | Rahmanto et al. (2024) | 180 vocational high school students | Quasi-experimental (Pre & Post test) | Problem-solving skills | The use of EDP-based student worksheets can improve the problem-solving skills of students | Quantitative |
| 4 | Lia et al. (2024) | 169 senior high school students | Quasi-experimental (Pre & Post test) | Creative thinking and problem-solving capability | The implementation of STEM based PBL with design thinking strategies can improve students' creative problem-solving abilities on renewable energy topics | Quantitative |
| 5 | Ramli et al. (2024) | 30 junior high school students | Pre-experimental (Pre & Post test) | Critical thinking skills | The STEM-EDP learning design has a positive impact on the critical thinking skills of 8th-grade students | Quantitative |
| 6 | Putra et al. (2023) | 17 elementary school students | Case study (Observation & interviews) | Problem-solving skills | The EDP help students to experience real learning and find components that can be used to compound a tool and solve real problems | Qualitative |
| 7 | Putra et al. (2023) | 12 senior high school students | Case study (Group discussion & interview) | Creative thinking skills (CTS) | The EDP facilitated students' collaboration, working in groups, and demonstrated creative thinking, which is one of the goals of effective CTS | Qualitative |
| 8 | Abdurrahman et al. (2023) | 67 senior high school students | Quasi-experimental (Pre & Post test) | Problem-solving and creative thinking skills | Students taught with STEM-EDP outperformed those using traditional STEM approaches, showing greater engagement in EDP processes, enhanced hands-on and mind-on activities, and improved systems | Quantitative |

 

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| | | | | | thinking abilities | |
| 9 | Chairunnisya et al. (2023) | 59 senior high school students | Survey analysis | Numeracy and literacy skills/critical and problem solving | The learning programs can enhance students' numeracy and literacy skills during the learning process | Quantitative |
| 10 | Gök & Sürmeli (2022) | 40 junior high school students | Quasi-experimental (Pre & Post test) | Scientific creative thinking skills | based on The EDP can improved positively with scientific toy design activities | Quantitative |
| 11 | Yustika et al. (2021) | 6 senior high school students | Case study (Observation data, documentation, & interviews) | Critical thinking capabilities | Female students interpret problems more accurately, while male students generate more ideas, some less physics-aligned. Both genders show similar critical thinking skills but struggle with unclear, less logical physics solutions | Qualitative |
| 12 | Ab Kadir et al. (2021) | 60 Junior high school students | Quasi-experimental (Pre and Post test) | Students achievement | The EDP model enhance students' achievements in Physics | Quantitative |
| 13 | Linh & Huong (2021) | 53 senior high school students | Quasi-experimental (Pre and Post test) | Problem-solving skills | Applying EDP helps teachers improve their students' problem-solving ability as well as introduce students to technical fields | Quantitative |
| 14 | Ergül & Çalış (2021) | 28 senior high school students | Case study (Group discussion and interview) | Problem-solving skills and creative thinking | Students effectively addressed real-life problems from multiple perspectives, providing solutions and demonstrating creativity through their drawings | Qualitative |
| 15 | Permana et al. (2021) | 34 senior high school students | (Pre and Post test) and interview | Conceptual understanding/ Problem-solving skills | The model significantly improved students' conceptual understanding | Mixed-method |
| 16 | Nurtanto et al. (2020) | 31 vocational high school students | Pre-experimental (Pre and Post test | Problem-solving skills | The success of the STEM method is influenced by the factors of vocational teachers in measuring the carrying capacity of learning | Quantitative |
| 17 | Hasanah (2020) | 63 senior high school students | Quasi-experimental (Pre and Post test) | Reasoning skills | The STEM group showed improvements in weight and volume conservation, proportional reasoning, CV, and HDR skills, while the traditional | Quantitative |

 

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| | | | | | group improved only in probabilistic reasoning | |
| 18 | Triana et al. (2020) | 126 senior high school students | Quasi-experimental (Pre and Post test) | 4C skills of students | STEM-PJBL are effective on students' 4C skills | Quantitative |
| 19 | Prasadi et al. (2020) | 24 elementary school students | (Pre and Post test) and interview | Critical thinking ability | Student worksheet with STEM and local wisdom is effective to improve of critical thinking ability students | Mixed-method |
| 20 | Yuniar et al. (2020) | 84 senior high school students | (Pre and Post test) and interview | Creative thinking | The application of LSLC-based STEM had a significant effect on the students' creative thinking ability | Mixed-method |
| 21 | Oktavia & Ridlo (2020) | 34 senior high school students | (Pre and Post test) and interview | Critical thinking skills | STEM- PJBL are effective in improving critical thinking of students based on the students' communication skills | Mixed-method |
| 22 | Ardianti et al. (2020) | 27 senior high school students | Quasi-experimental (Pre and Post test) | Critical thinking skills | Blended learning with STEM education approach improved better critical thinking of students than conventional learning | Quantitative |
| 23 | Purwaningsih et al. (2020) | 53 senior high school students | Quasi-experimental (Pre and Post test) | Problem-solving abilities | STEM-PJBL has a significant positive effect on improving students' problem-solving abilities rather than discovery learning | Quantitative |