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A Review of Integration of Engineering Design Process (EDP) Learning Model through STEM Approach in Elementary Schools

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Abstract

This study reviews the learning of the Engineering Design Process (EDP) with the Science, Technology, Engineering, and Mathematics (STEM) approach that is operationalised. The review summarised and evaluated research articles published between 2014 and 2024, which specifically focus on the integration of EDP learning models with STEM approaches. This study uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework and follows the CRAAP Test, an evaluation tool used to assess the reliability, relevance, and credibility of the selected paper. After a rigorous search and selection process, 28 unique empirical studies were identified that explored the integration of EDP models with STEM approaches at various levels of education, from elementary school to college. The review revealed that there are only three topics that are suitable for integrating EDP learning models with STEM approaches in elementary schools. Limited research exists about the adaptability, obstacles, and support of STEM-based EDP implementation in primary schools, focussing mostly on identification rather than in-depth studies. In addition, various instruments can be leveraged to facilitate the integration of EDP-STEM learning models in primary education. This result found a gap for further research on STEM-based EDP in elementary schools as a trend of scientific contribution related to the use of STEM-based education in elementary schools.

Keywords: Engineering Design Process, STEM Approach, Elementary School

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Abstrak

Penelitian ini mengulas pembelajaran Engineering Design Process (EDP) dengan pendekatan Science, Technology, Engineering, and Mathematics (STEM) yang dioperasionalkan. Kajian ini merangkum dan mengevaluasi artikel-artikel penelitian yang diterbitkan antara tahun 2014 hingga 2024, yang secara khusus berfokus pada integrasi model pembelajaran EDP dengan pendekatan STEM. Kajian ini menggunakan kerangka kerja Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) dan mengikuti CRAAP Test, sebuah alat evaluasi yang digunakan untuk menilai keandalan, relevansi, dan kredibilitas makalah yang dipilih. Setelah melalui proses pencarian dan seleksi yang ketat, 28 studi empiris unik diidentifikasi yang mengeksplorasi integrasi model EDP dengan pendekatan STEM di berbagai tingkat pendidikan, mulai dari sekolah dasar hingga perguruan tinggi. Hasil tinjauan menunjukkan bahwa hanya ada tiga topik yang cocok untuk mengintegrasikan model pembelajaran EDP dengan pendekatan STEM di sekolah dasar. Penelitian yang ada saat ini masih terbatas mengenai kemampuan beradaptasi, hambatan, dan dukungan implementasi EDP berbasis STEM di sekolah dasar, yang sebagian besar berfokus pada identifikasi dan bukan pada studi mendalam. Selain itu, berbagai instrumen dapat digunakan untuk memfasilitasi integrasi model pembelajaran EDP-STEM di pendidikan dasar. Hasil penelitian ini menemukan adanya celah untuk penelitian lebih lanjut tentang EDP berbasis STEM di sekolah dasar sebagai tren kontribusi ilmiah terkait penggunaan pendidikan berbasis STEM di sekolah dasar.

Kata Kunci: Engineering Design Process, Pendekatan STEM, Sekolah Dasar

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INTRODUCTION

STEM education is a comprehensive approach that combines science, technology, engineering, and mathematics to address human challenges. It focuses on understanding the natural world, creating products to solve problems, designing processes to address issues, and analysing numbers and their relationships. STEM education is crucial in today's rapidly changing world, as it fosters critical thinking and scientific literacy and prepares the next generation of innovators (Marín-Marín et al., 2021). A solid knowledge base in these fields is essential for scientific innovation, leading to new products and processes that support economic growth. A creative classroom structure emphasises hands-on lessons and engagement, which enhances student innovation.

STEM, introduced by the National Science Foundation in 1990, refers to Science, Technology, Engineering, and Mathematics. In Indonesia, STEM encompasses science, technology, engineering, and mathematics. Science involves systematic knowledge gained through observation, research, and experimentation, while technology encompasses human comfort and survival. Engineering focuses on task-executing techniques, and mathematics focuses on numerical concepts and problem-solving methods (Simeon et al., 2022). STEM education aims to improve learning by systematically integrating knowledge, ideas, and skills, not only helping students memorise concepts but also fostering understanding of relevant ideas for daily life (Tseng et al., 2013).

STEM education focuses on replacing conventional teaching strategies with inquiry-based and project-based approaches (Breiner et al., 2020), aiming to optimise students' talents and abilities by focusing on real-world challenges, higher-order thinking, problem-solving skills, cross-disciplinary learning, independent learning, information-sharing, teamwork, and communication skills (Firdaus & Rahayu, 2020). Teachers assist students in the learning process, helping them acquire skills and offer guidance for personal understanding. STEM education aims to develop students into technologically literate, innovative, self-reliant, logical thinkers and effective problem-solvers, making them more technologically literate, innovative, self-reliant, and logical thinkers.

STEM disciplines often overlap, but students often struggle to connect concepts across them due to their familiarity with isolated learning (Honey in Gullberg et al., 2025). Effective methods for integrating these four disciplines to enhance student achievement require research. STEM approaches are often combined with other educational models, such as STEM-Based Project-Based Learning (Samsudin et al., 2020), STEM-Based Problem-Based Learning (Tawfik et al., 2013), and the STEM-Based Engineering Design Process (Nurtanto et al., 2020). One promising approach is implementing engineering experiences in real-world contexts, which contextualise ideas about technology, mathematics, and science (Hertel et al., 2017). The Engineering Design Process (EDP) is crucial for teaching both scientific and engineering concepts. However, many teachers lack strategies for effectively applying the EDP in science instruction. The international education community is interested in using engineering models to connect STEM fields (Schnittka, 2012).

The Engineering Design Process is a vital element of STEM education, as it involves designing a system, component, or process to meet specific needs. The scientific inquiry and engineering design share similarities; both involve investigating a problem or question. However, the processes used in each discipline differ. Scientific research typically begins with an investigative question. In this context, students select appropriate experimental approaches, design and conduct replicable experiments, record results, analyse the data, and draw conclusions based on their findings (Tan & Lee, 2022).

EDP is described in various ways by different experts and educational organisations, but it always includes a repeating series of steps that help improve designs through repeated testing, analysis, and redesign. EDP-based learning integrates engineering concepts with systematic analysis and reasoning (Kelley & Knowles, 2016). The Engineering Design Process (EDP) plays a crucial role in curriculum creation for integrated STEM education, spanning from kindergarten to high school. The objective of EDP is to foster pupils capable of autonomous learning and enhancing design literacy (Hynes, 2012). In primary education, EDP learning prioritises idea formation, but in high school, the emphasis transitions to analysis, testing, and assessment. The focus for educators is to reorganise notions (Lin et al., 2010).

Integrating engineering components into the science curriculum has proven beneficial, improving students' learning experiences and instilling critical design and collaboration skills. Introducing STEM through the Engineering Design Process (EDP) in elective classrooms provides students with a unique opportunity to engage in hands-on learning, regardless of curriculum challenges. This study demonstrates the EDP's ability to provide meaningful STEM learning experiences while also encouraging teamwork and problem-solving skills in students. According to the findings, incorporating engineering activities can significantly improve science lessons while also encouraging students' positive perceptions of engineering.

The recent study reveals that engineering design task-based learning significantly improves students' understanding of scientific and engineering concepts. This approach promotes problem-solving skills, connects theoretical concepts to practical applications, and develops critical thinking, confidence, and adaptability, which are crucial for future careers (Capobianco et al., 2021). Another study found that engineering design tasks, which include collaborative sketching, construction experimentation, and redesign, significantly improved students' comprehension of STEM concepts. These stages structured design, construction, and redesign phases but suggested a flexible approach for advanced applications (King & English, 2016).

Understanding engineering design tasks varies based on age and educational level. Younger students can integrate STEM concepts effectively, while older students need more flexible approaches. Early interest in STEM peaks around age 8 but declines by middle school, requiring tailored interventions to sustain understanding. Primary students develop STEM integration skills, while older students benefit from advanced design processes. Engineering design-based learning enhances problem-solving abilities, interdisciplinary knowledge, and long-term skills for academic and career success. It boosts students' engineering identity and motivation to pursue STEM fields. However, longitudinal research is needed to understand these long-term impacts (Lidinillah et al., 2019).

In elementary education, Engineering Design Process (EDP) learning focuses on the creation of ideas. Teaching engineering in elementary schools helps students develop skills in designing, building, and disassembling objects to understand how they function. The engineering design process is essential for acquiring 21st-century skills (Cunningham & Lachapelle, 2010). As elementary school students become increasingly reliant on engineering and technology, it is crucial for them to grasp the principles of engineering to make informed decisions about the advantages and feasibility of using new technologies. Research indicates that engaging with the engineering design process can enhance literacy among elementary school students.

According to research, the STEM-based Engineering Design Process (EDP) learning model used in elementary schools consists of five key steps: ask (define the problem and identify constraints), imagine (brainstorm ideas and select the best one), plan (draw a diagram and gather materials), create (follow the plan and test it), and improve (discuss possible improvements and repeat the steps) (Lidinillah et al., 2019). The EDP provides a structured framework for introducing fundamental engineering principles in the context of STEM education at the elementary level. Despite the promise, many educators face significant challenges.

A notable concern is the lack of confidence and proficiency among teachers regarding math and science instruction. Additionally, many teachers feel that their university training has left gaps in their content knowledge, making it difficult to nurture young minds effectively. Furthermore, managing and assessing engineering activities within the classroom presents its set of obstacles, complicating the implementation of this valuable learning model (Sürmeli et al., 2018).

Elementary school STEM-based Engineering Design Process (EDP) learning models encounter obstacles including teacher proficiency, insufficient confidence, challenges in managing varied designs, limitations in time and resources, and inadequate institutional support. Creating thematic-integrated learning experiences across disciplines is challenging, and numerous educators lack familiarity with modern STEM pedagogical approaches, particularly in engineering processes.

The efficacy of STEM-based Engineering Design Process (EDP) learning models in elementary schools can be augmented through diverse supports. This encompasses scaffolding in the engineering process, continuous professional development for educators, access to contemporary facilities and technology, assessment guidance for instructors, and collaborative participation in curriculum development. By incorporating these supports, elementary schools can establish a conducive learning environment that fosters STEM education. These support not only enhances students' understanding of engineering principles but also boosts their content knowledge and confidence in teaching STEM subjects. By integrating these supports, elementary schools can create an effective learning environment that promotes STEM education.

The National Research Council believes that limiting science education to rote memorisation can impair children's learning. Instead, students should form knowledge structures through active engagement with complex ideas, discussion, reflection, investigation, experimentation, and other disciplinary practices (Fosmire, 2017). The engineering design process develops skills and attitudes necessary for solving complex problems, such as problem formulation, iteration, alternative testing, and data evaluation (Benenson, 2019).

Persistence and confidence, which should be fostered at a young age, are required for problem-solving abilities. Effective engineering instruction encourages children to take responsibility for their learning and progress. Learning about engineering broadens access to scientific and technical careers, as many scientists and engineers develop an interest in their fields during elementary school (Ferrara et al., 2023).

Early introduction of engineering concepts can inspire children, particularly girls and minorities, to pursue science and mathematics courses in junior and senior high school (Firdaus & Rahayu, 2020). Project-based learning techniques, including hands-on activities, inquiry, teamwork, and critical thinking, help develop essential skills for modern society. Although technical teaching may focus on different stages, the Engineering Design Process remains consistent. Incorporating EDP-based learning within integrated STEM education positively impacts students and enriches the overall learning environment. This approach helps maintain interest in engineering and prepares them for a career in the field.

EDP involves defining the problem, selecting solutions, modelling and analysing them, and iterating through the design process (Hafiz & Ayop, 2019). It enhances students' problem-solving abilities and encourages them to apply STEM content to justify their solutions. An effective EDP can increase student engagement and interest, especially in elementary school, which is crucial for mastering content across all STEM disciplines. (Sneider & Ravel, 2021). Regrettably, the integration of EDP and stem methodologies is infrequently employed in elementary education.

The challenges and supports associated with EDP adoption in elementary schools have not been extensively examined. The two courses are distinct, and the possibility for their application in elementary schools has been minimally explored. It requires a comprehensive analysis to integrate existing best practices for improved model implementation.

This systematic literature review aims to delineate and evaluate STEM-oriented EDP learning models in elementary education. The research enquiries are (1) How does existing research describe the use of STEM-based EDP learning models in elementary schools?; (2) What challenges and obstacles have been identified in the use of STEM-based

EDP learning models in elementary schools?; and (3) What support can teachers and students benefit from when using STEM-based EDP learning models in elementary schools?

METHODS

This research employed a Systematic Literature Review (SLR) and complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Pati & Lorusso, 2017). This review focusses on the STEM-based Engineering Design Process (EDP) learning model for elementary education, including the steps of the STEM EDP and the roles of teachers and students in this learning setup. Protocols were initially established to delineate the criteria for article selection, search methodologies, data extraction, and the procedures for data analysis.

The Publish or Perish (PoP) software was used to perform a comprehensive literature review of pertinent publications, sourcing data from databases including Google Scholar, Scopus, and the Web of Science (WoS). The volume of qualifying research was assessed using the keywords "STEM-EDP", "EDP-STEM", and "elementary school". A manual search was performed to identify eligible articles cited in the electronic search results.

All papers identified through the search engine were collected in Excel tables. The titles and abstracts were then reviewed during the initial screening to determine if the research met the inclusion and exclusion criteria. The inclusion and exclusion criteria for the current SLR are as follows:

1. The full text of the study must be available in English.
2. Studies must be presented as research articles or conference papers.
3. Research must have been published between 2014 and 2024.
4. Research should specifically address the STEM-based EDP learning model in elementary schools, including its stages and the roles of teachers and students.
5. All major academic subjects (science, math, reading, physical education, arts, etc.) in schools are included.
6. The study must provide qualitative and or quantitative primary data on at least one of the four areas examined.
7. Research synthesis, non-empirical studies, and literature reviews (such as meta-analyses, SLRs, and bibliometrics) are excluded.
8. The research sample must focus on students and teachers or prospective teachers who are responsible for implementing classroom learning.

The flowchart illustrating the data search strategy and results is presented in Figure 1 below.

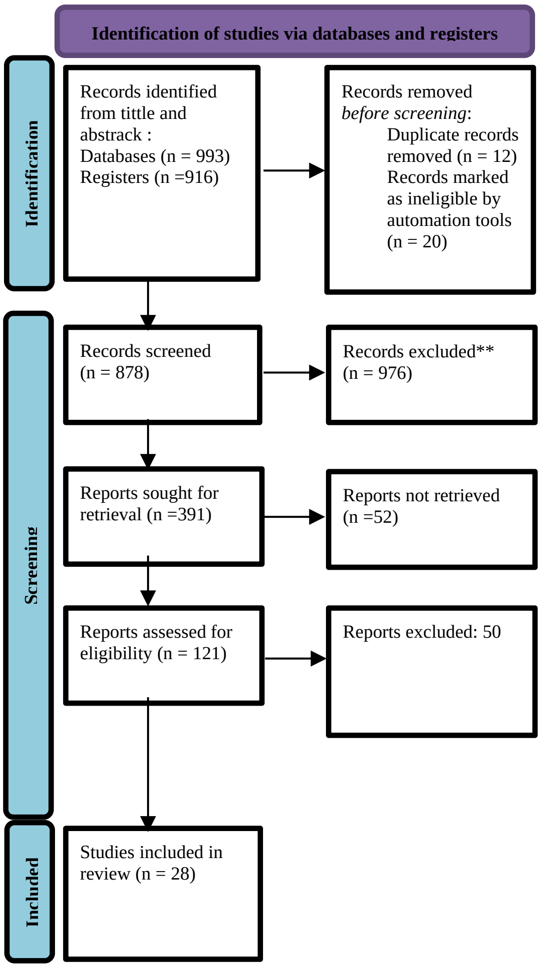

Figure 1. Flowchart of PRISMA Procedure of Studies via Databases and Registers

Using the PRISMA strategy, this search identified 993 databases and 916 registered records, consisting of 701 from Google Scholar, 210 from Scopus, and 5 from Web of

Science. The initial screening yielded 916 unique studies, which included journal articles, book chapters, dissertations, and conference proceedings. A total of 878 texts were screened and evaluated for eligibility after removing duplicates and irrelevant entries. At this stage, we applied inclusion and exclusion criteria, which resulted in the removal of articles that, although eligible, were not accessible. Of the evaluated studies, 42 met the review criteria, and 28 studies met the requirements for the research conducted. In conclusion, 28 references were evaluated.

In this systematic literature review (SLR), we employed the CRAAP Test, a tool designed to evaluate the credibility, relevance, and reliability of the selected articles (Muis et al., 2022). Using a score-based format derived from South Central College's worksheet, our quality assessment was based on the CRAAP (Currency, Relevance, Authority, Accuracy, Purpose) criteria. The final conclusions drawn from the review will summarise key findings and facilitate a discussion of the main results. This study adheres to the PRISMA framework, ensuring a clear, reproducible, and methodologically sound literature review.

The result of this study yield insights into the implementation of EDP's potential strategy in STEM learning within primary schools. This study will also identify potential topics for future research. Table 1 presents the results of the analysis and test of CRAAP evaluation summary of the includes papers.

Table 1. Information on Included Papers (N=28)

Article Code	**Authors**	**Year**	**Research Participant**	**Subject Area**
A1	Shahat et al.	2024	Teacher	STEM and EDP
A2	Yim, Leung, & Woo	2024	Students at Elementary School	STEM and EDP
A3	Ho & Pang	2024	Students at Preschool	STEM
A4	Ozkizilcik & Cebesoy	2024	Teacher at Elementary School	STEM and EDP
A5	Xi et al.	2024	K 12 (Student at elementary and secondary school)	STEM and EDP
A6	Holincheck et al.	2024	Teacher at Elementary School	STEM and EDP
A7	Akpinar & Akgunduz	2022	Students at Preschool	STEM
A8	Kuvac & Koc	2023	Teacher at Elementary School	STEM
A9	Fan, Yu, & Lin	2021	K 12 (Student at elementary and secondary school)	STEM
A10	Lin et al.	2021	Teacher Sains	STEM and EDP
A11	Kelana et al.	2020	Students at Elementary School	STEM and EDP
A12	Widiastuti, Budiyanto, & Ramli	2020	Preservice Teacher	STEM and EDP
A13	Bezuidenhout	2021	Students at Elementary School	STEM
A14	Linh & Huong	2021	K 12 (Student at elementary and secondary school)	STEM and EDP
A15	Tientongdee & Ficklin	2021	Teacher at Elementary School	STEM
A16	Bampasidis et al.	2021	Science Teacher	STEM and EDP
A17	Firdaus & Rahayu	2020	Students at Elementary School	STEM
A18	Li, Chang, & Chiang	2020	Students at Elementary School	EDP
A19	Fidai et al.	2020	K 12 (Student at elementary and secondary school)	EDP
A20	Fan, Yu, & Lou	2018	K 12 (Student at elementary and secondary school)	EDP

A21	Wind et al.	2017	K 12 (Student at elementary and secondary school)	EDP
A22	King & English	2016	Students at Elementary School	EDP
A23	Zhou et al.	2017	K 12 (Student at elementary and secondary school)	EDP
A24	Capobianco & Rupp	2014	Science Teacher	STEM and EDP
A25	Ball, Beckett & Isaacson	2015	K 12 (Student at elementary and secondary school)	EDP
A26	Sürmeli et al.	2017	Students at Elementary School	EDP
A27	Capobianco, Radloff & Lehman	2021	Students at Elementary School	EDP
A28	Lidinillah et al.	2019	Students at Elementary School	STEM

RESULTS AND DISCUSSION

How does existing research describe the use of STEM-based EDP learning models in elementary schools?

The selected article offers helpful observations about the operationalization of STEM-based Engineering Design Process (EDP) learning models across various educational levels. Among the 28 articles reviewed that focused on the implementation of STEM-based EDP learning models, only three specifically addressed their application in schools. This paper highlights the need for integrated learning approaches that combine different subjects, particularly in the areas of science, technology, engineering, and mathematics (STEM). STEM-based education can create engaging experiences and enhance students' interest in mathematics (Firdaus & Rahayu, 2020). Table 2 presents the identification of how EDP learning models are integrated based on STEM approaches.

Table 2. Identified Paper on EDP-STEM Integrated Approaches

Identification Codes	**Articles Code**
Integration of EDP Learning Model through STEM Approach in Elementary Schools	A1, A2, A4, A5, A6, A10, A11, A12, A14, A16, A18, A19, A20, A21, A22, A23, A24, A25, A26, A27
Implementation of STEM Approach in Elementary Schools or at another level.	A3, A7, A8, A9, A13, A15, A17, A28

One key finding of the study highlights the effectiveness of the Engineering Design Process (EDP) in enhancing student engagement and learning in STEM activities. EDP encourages students to identify problems, brainstorm solutions, prototype designs, test their ideas, and iterate on their solutions (Yim et al., 2024). This hands-on approach enhances engagement and understanding of STEM concepts while fostering collaboration and communication among participants. Integrating Bloom's Taxonomy for assessing cognitive development aligns with the EDP, guiding students from knowledge acquisition to higher-order thinking skills like analysis and evaluation. Overall, the underwater robotics competition effectively promotes project-based learning and integrated STEM education, preparing students for future STEM careers (Bampasidis et al., 2021).

In grade 5, students use the Engineering Design Process to learn about STEM by designing and building tools like periscopes, following a step-by-step engineering approach. By examining a rich array of student sketches, observing group dynamics, and noting various interactions, the research draws attention to the significant role of collaborative sketching, hands-on experimentation, and the iterative process of redesign (King & English, 2016). These elements are vital for understanding fundamental scientific principles like light reflection and angles. Students demonstrated a solid grasp of these concepts and successfully created functional models. However, their redesign efforts focused mainly on structural improvements rather than deepening their scientific or mathematical understanding. The findings highlight the value of engaging design-based activities in primary education, suggesting that more flexible instructional methods could enhance STEM learning and creative problem-solving in young learners.

The implementation of EDP learning demonstrates that students gain a deeper understanding of expressing their opinions, planning, and creating prototypes related to their studies. Furthermore, student participation in the epistemic practices of science and engineering is vital, as it involves using both oral and written discourse to grasp the knowledge within these disciplines (Hertel et al., 2017).

The identification indicates that the EDP aligns with elementary school learning objectives. Modern EDP is a "intelligent" and "systematic" process by which engineers design and evaluate practical solutions based on end-user requirements. Engineers analyse and break down complex issues (Bull et al., 2014). They then repeat each step to address each smaller part. STEM project-based learning models promote critical thinking, help teachers understand engineering design concepts, and improve their skills by integrating the engineering design process (Lin et al., 2010). These models encourage critical thinking, connections, questioning, problem-solving, creativity, and persuasion (Sen et al., 2021).

Engineering design improves math and science education by addressing deficiencies. As students' proficiency improves, more can explore technical careers earlier. Engineering design in elementary and secondary curricula may attract minorities and women to engineering careers (Wendell et al., 2010).

What are the identified challenges and obstacles in the implementation of STEM-based EDP learning models in elementary schools?

The findings reveal that teachers learned more about EDP by the end of the course, particularly in the areas of brainstorming, planning, and prototyping as essential EDP steps. This indicates that teachers recognize the importance of explicitly teaching planning and prototyping skills to primary school students as part of their instructional strategies. Additionally, teachers have begun to focus more on data analysis to resolve disputes among students engaged in EDP activities, which enhances their pedagogical knowledge of EDP and leads to evidence-based revisions of student prototypes (Siew, 2022).

Research findings indicate several key points. (1) The engineering design process can serve as an effective alternative for teachers instructing mathematics and science, as it bridges the gap between abstract, numerical learning and its practical applications in daily life. (2) To effectively teach the engineering design process, teachers need foundational engineering skills, particularly female teachers, who may have less interest in engineering fields. (3) The engineering design process can foster students' creativity by encouraging them to propose their solutions and create problem-solving plans. Additionally, it positively impacts students' mathematics learning outcomes in cognitive domains.

The challenges and obstacles in executing the Engineering Design Process (EDP) are complex and can profoundly affect students' learning experiences and outcomes (King & English, 2016). Here are several critical issues.

1. Limited Time for Exploration: Students often face challenges due to insufficient time for thorough exploration and experimentation. Rushed development prevents them from critically assessing their designs and exploring alternative ideas, limiting their understanding and the creativity of their end products.
2. Need for Teacher Support: Effective teacher guidance is essential during project redesign. Without appropriate scaffolding, such as feedback and structured support, students may struggle to identify weaknesses in their designs, hindering their ability to innovate and explore advanced concepts.
3. Lack of Flexibility in the Design Process: Excessive rigidity in the design process can stifle students' creativity. Strict adherence to guidelines may lead them to produce designs that closely reflect their initial concepts, limiting the evolution of ideas.

This can result in similar projects across the board, rather than promoting diverse and complex solutions.

4. Limited Resources and Tools: Access to diverse tools and materials is crucial for effective design development. Many classrooms face resource constraints, limiting students' ability to test ideas and explore innovative solutions. This scarcity hinders experimentation and iteration, which can result in subpar design outcomes.
5. Limitations in Design Drawing and Communication Skills: Effective communication is crucial in the design process, particularly in collaboration and idea presentation. Some students may find it challenging to draw their concepts or articulate their thoughts clearly, which can impede collaboration and feedback exchange.

What support can teachers and students benefit from in using the STEM-based EDP learning model in elementary schools?

Engineering design is a pedagogical approach that integrates STEM (science, technology, engineering, and mathematics) into learning and fosters creative thinking, problem-solving, decision-making, and the consideration of alternative solutions. The Engineering Design Process (EDP) trains students to think creatively and establishes a robust instructional foundation for implementing STEM (Siew, 2022). EDP is a systematic process for generating, evaluating, and defining concepts to achieve learning objectives, marking it as a new concept that guides the development of learning in schools.

The development of the engineering design process encourages students to think critically, view problems from multiple perspectives, and question existing standards. By definition, engineering design involves creating, evaluating, and defining concepts for devices, systems, or processes that meet client goals or user needs while adhering to specific constraints. Recent studies on engineering design thinking have primarily focused on the thought processes of university-level engineering students and experts, leading to various methods of design thinking.

The engineering design process is divided into several steps, including problem definition, information gathering, ideation, modeling, and analysis (Atman et al., 2007). Observations of how engineering teachers comprehend and teach the engineering design process reveal that technology teachers frequently exhibit foresight, particularly during prototyping and redesigning. A study of high school students' performance in engineering design courses found that their ability to perform predictive analysis and testing/revision is an important part of their engineering design thinking (Fan et al., 2018).

Instructing primary school students in engineering design can substantially elevate their engagement with academic disciplines and enhance their overall learning outcomes. Integrating engineering principles into the curriculum enables educators to cultivate an interactive and stimulating environment that engages students' imaginations and fosters curiosity (Sulaeman et al., 2021). This methodology promotes critical thinking, collaborative work, and participation in practical projects addressing real-world issues. Through the exploration of the engineering design process, which includes problem identification, solution brainstorming, prototyping, and testing, individuals cultivate vital skills such as creativity, resilience, and analytical thinking. Furthermore, the early introduction of engineering design promotes enhanced diversity in STEM disciplines by motivating participation from all students, irrespective of their backgrounds or prior experiences. This initiative fosters a lasting passion for learning in young students and facilitates a more diverse and inclusive future workforce in science, technology, engineering, and mathematics (Bowman et al., 2024). A separate study elucidated that engineering design education can utilize engineering notebooks to facilitate student learning in the planning and creation of engineering designs. This study shows how important tools like technical notebooks or practice guidelines are for getting students involved in writing, drawing, redesigning, and sharing their design results to meet learning goals.

This research offers valuable insights into the engineering design behavior of elementary school students utilizing a STEM approach through the Engineering Design learning model. The model involves several key steps: identifying the problem, generating ideas, designing and constructing, evaluating the design, and making necessary redesigns. In the initial stage of STEM learning, students exhibit behaviors typical of beginner designers, while progress into the second stage indicates they are evolving into new designers. These findings suggest that implementing STEM-based learning can significantly strengthen the engineering design capabilities of elementary school students, paving the way for future innovation and creativity in their educational journeys (Kelana et al., 2020).

Discussion

Some of the review's findings require serious consideration by educators, such as the fact that model adoption has not been optimal due to teacher competence. Sequential analyses of fourth-grade students' design thinking revealed that idea generation is an important component of their overall design process (Sung & Kelley, 2019). The findings show that teachers and students prioritise different aspects of the design process: elementary school students prioritise idea generation, whereas high school students prioritise predictive analysis and testing/revision. In contrast, the Engineering Design Process (EDP) allows STEM teachers to guide students through the stages of design, prototyping, and testing before producing the final product (Shahat et al., 2024). Furthermore, there is a growing trend in funded research and the implementation of EDP in teacher training programs, emphasising the importance of providing educators with extensive knowledge and skills in EDP to improve effective STEM education (Ozkizilcik & Cebesoy, 2024).

Teachers play an important role in facilitating this design process by assisting students in developing fine motor skills, resilience, teamwork, ethical awareness, fostering a positive learning disposition, problem-solving abilities, and communication skills, as well as highlighting challenges such as time management and the need for ongoing teacher professional development (Ho & Pang, 2024). Teachers require support and training to improve their perceptions of EDP implementation and STEM understanding (Kuvac & Koc, 2023). Integrating engineering design into curricula promotes critical thinking, teamwork, and 21st-century skills (Sürmeli et al., 2018). Students develop better problem-solving abilities, creativity, and a positive attitude towards STEM. Furthermore, teachers benefit from the development of more interactive and effective teaching methods that promote project-based learning and student collaboration (Yim et al., 2024).

This research highlights the integration of engineering assignments for fifth-graders that encompass science, technology, and mathematics (STEM), particularly in the context of optical engineering. It contributes to primary education by demonstrating effective STEM integration at an early age and introduces a new area of focus in elementary education (Bezuidenhout, 2021). The study encourages teachers to develop innovative, context-rich engineering activities and emphasises the need for flexible design approaches that enhance creativity and understanding of STEM concepts.

The methods and tools for EDP implementation in elementary schools often exhibit a deficiency in diversity. In a study implemented STEM integration via the Engineering Design Process (EDP) by utilising a streamlined six-step engineering design framework, facilitating adoption by students and educators, particularly in Greek educational settings where teachers' engineering expertise was constrained. This process encompasses problem comprehension, solution investigation, and prototype development, enabling students to engage in STEM education in a tangible and innovative manner. This methodology facilitates the practical development of engineering skills and engineering cognition within a formal educational framework (Bampasidis et al., 2021). Furthermore, engineering notebooks are essential for facilitating student engagement in writing, drawing, and redesigning within small groups as a means to enhance their learning (Tientongdee & Ficklin, 2021). Utilising digital storytelling as a pedagogical strategy is an effective method for enhancing engineering process skills. Digital storytelling aids learners, particularly novices in STEM, in cultivating the capacity to formulate and articulate valid problem statements, which are crucial competencies in the engineering process. Digital storytelling enhances participants' ownership and autonomy in learning while fostering the development of active learning communities that link real-world issues with formal knowledge (Ball et al., 2015).

Applying EDP allows instructors to improve their students' problem-solving abilities while also exposing students to specialised areas. With these characteristics, EDP can be integrated into STEM instruction (Linh & Huong, 2021). Students' interests and metacognitive skills influence EDP implementation, which can be important in shaping and presenting various design goals and objectives in engineering design projects (Fan et al., 2018). The Engineering Design Process (EDP) is implemented in K-12 education by developing and using assessment instruments that assess students' conceptual understanding of the engineering design process. The instrument consists of several multiple-choice items designed to reflect the different stages of the EDP model used in the experimental curriculum (King & English, 2016; Wind et al., 2017).

This research offers vital details about the role of hands-on learning in enhancing student engagement and understanding in STEM education. Additionally, the research indicates that collaborative learning environments foster creativity and encourage a sense of community among students, which is essential for constructing knowledge in STEM fields (Fan et al., 2021). The research emphasises the importance of conducting longitudinal studies to assess the long-term effects of integrated STEM curricula on students' outcomes, such as academic performance and engagement. Additionally, it suggests developing comprehensive training programmes for teachers to equip them with the necessary content knowledge and pedagogical skills for effective STEM instruction. For instance, the application of automotive design enhances the understanding and perception of engineering design in elementary school science education. The results found that automotive design experiences improve participants' overall understanding of STEM knowledge, especially in the fields of science and mathematics (Li et al., 2020). This aligns with research findings that indicate the application of engineering design processes can enhance students' learning experiences and boost their academic achievement in science and mathematics (Fidai et al., 2020).

The study's findings have important implications for future research and practical applications in STEM education. More longitudinal studies are required to investigate the long-term effects of integrated STEM curricula on student outcomes such as academic performance, critical thinking skills, and STEM-related field engagement, as well as to provide understudies with current information about the building calling, aptitudes, and have been successful in students' product design/invention objective handle (Akpinar & Akgunduz, 2022).

Moreover, educators are encouraged to thoroughly explore the effectiveness of various teaching methodologies. This includes evaluating the impact of technology-enhanced learning tools, hands-on activities, and interdisciplinary approaches that combine elements from science, technology, engineering, and mathematics (Lin et al., 2021). By fostering a rich and dynamic learning environment, educators can better stimulate students' curiosity and interest in STEM subjects. Furthermore, the insights gained from this research can play a pivotal role in shaping the development of comprehensive training programs for teachers. These programs should ensure that educators are well-equipped with not only the content knowledge necessary for effective STEM teaching but also the pedagogical skills required to implement innovative and engaging instructional strategies (Widiastuti et al., 2020). By investing in teacher training, we can enhance the overall quality of STEM education, ultimately benefiting students and preparing them for future challenges in an increasingly complex and technology-driven world.

It is crucial to continue encouraging the ongoing support and development of Engineering Design Process (EDP) learning models in elementary schools. By investing in these approaches, we can create dynamic and adaptable learning experiences that promote critical thinking and innovation from an early age. Stakeholders, including educators, policymakers, and community members, must collaborate to provide resources and training that enhance EDP implementation. Fostering a culture that values STEM learning will ultimately prepare students for the demands of the future workforce, equipping them with the skills needed to thrive in a rapidly evolving technological landscape.

CONCLUSION

The reviewed papers provide information about how STEM-based EDP learning models have emerged as innovative educational tools, particularly at secondary and tertiary levels. Various stages can be employed to teach students, beginning with problem definition and systematically selecting solutions, followed by modeling, analysis, and iterations of the design process. This approach is a cyclical design sequence aimed at finding solutions to real-world problems, with multiple versions adaptable to different situations.

The most significant conclusion from our systematic literature review (SLR) is that high-quality studies on the application of STEM-based EDP learning models in primary schools are lacking. Most learning models are more frequently implemented at the middle school level, particularly among engineering students and teachers. Research on learning models in elementary schools has not sufficiently demonstrated how teachers facilitate student learning within STEM-based approaches.

However, the implementation of EDP in elementary schools remains limited. This has led to uncertainties that challenge students. Often, teachers restrict the openness of procedures, and many lack an engineering background. Some papers illustrate the application of STEM-based EDP learning models in elementary mathematics and science subjects. These findings indicate that there must be the need for further research into the application of STEM-based learning models and call for teacher training to incorporate these models into daily teaching.

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