Global perspectives and methodological innovations in STEM education: a systematic mapping analysis of engineering design-based teacher training

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Abstract

Purpose – This study investigates a novel educational strategy in science, technology, engineering and mathematics (STEM) teaching that integrates the engineering design process (EDP) as a framework. The strategy aims to help teachers explain STEM concepts in a simplified way. We employed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology to enable a systematic review that evaluated the effectiveness of this approach in improving both teaching and learning in STEM subjects.

Design/methodology/approach – In order to fulfill the objectives of the review, key data were extracted from each of the 400 articles that were reviewed from three databases: Scopus, ProQuest Central and EBSCO. Two types of analysis were conducted, namely descriptive analysis and literature classification.

Findings – This systematic review analyzed 44 articles on the EDP, focusing on 18 detailed studies mainly from ProQuest, SCOPUS and EBSCO. It revealed a limited focus on gender's impact on EDP and a trend toward interdisciplinary use and integrated research approaches. The study underscores the need for further exploration of demographic influences and preparation programs in EDP across various disciplines, aiming to inform future research and educational policies.

Originality/value – The study's value lies in its comprehensive assessment of engineering design (ED) research over the past decade, serving as a key reference point. It highlights progress in the field, consolidates findings and provides insights into the field's evolution, guiding future research directions in ED.

Keywords Pre/in-service teacher, Teaching STEM, Engineering design, Systematic review

Paper type Literature review

Introduction

Science, technology, engineering and mathematics (STEM) education has gained significant attention in recent years as a way to enhance students' critical thinking, problem-solving and analytical skills. STEM approaches emphasize the integration of these disciplines to address

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real-world challenges and promote innovative solutions. Within the realm of engineering design (ED), STEM plays a vital role in providing the foundation and framework for effective and comprehensive problem-solving Zainuddin and Iksan (2019). The ED process is a systematic approach used by engineers and designers to create innovative solutions to problems. This approach guides the construction and development of solutions to problems by applying scientific and engineering processes (Avsec & Szewczyk-Zakrzewska, 2018). ED includes a combination of creativity, critical thinking, analysis and technical knowledge to design and develop products or structures to meet specific STEM education requirements (Marulcu & Barnett, 2013). STEM education utilizes diverse strategies to integrate the disciplines of science, technology, engineering and mathematics. These strategies include project-based learning (Nurtanto, Pardjono, Widarto, & Ramdani, 2020), design thinking, inquiry-based and problem-based learning, maker education, computational thinking and integrated STEM. Students engage in active, experiential learning, and their critical thinking, problem-solving and collaboration are promoted (Widiastuti, Oktavia, Lukad, & Sutrisno, 2022). Each one of these approaches emphasizes different aspects of STEM education to enhance STEM competencies and prepare students for the challenges of the rapidly changing 21st century (Shahat, Al Bahri, & Al-Balushi, 2024).

Utilizing the ED process is a STEM education strategy that is widely used for STEM integration (Yu, Wu, & Fan, 2020). When using the ED process in STEM teaching and learning, students are first introduced to open-ended design problems which offer real-world practice while allowing for greater flexibility and choice (Mohd Hafiz & Ayop, 2019). The key tasks of ED form part of a systematic and iterative process that functions to create innovative solutions to problems (Shahat, Al-Balushi, & Al-Amri, 2022). These tasks include problem identification and definition, research and information gathering, concept generation, concept evaluation and selection, detailed design development, prototyping and testing, analysis and iteration and finalization and implementation. In the initial stages, engineers identify and understand the problem, gather relevant information and generate a range of design concepts. These concepts are then evaluated and the most suitable one is selected for further development. Detailed design involves creating specifications, plans and drawings, followed by prototyping and testing to validate the design. Analysis and iteration are crucial for identifying and addressing design flaws and ensuring continuous improvement. The final design is then documented and the implementation phase begins. Throughout these key tasks, engineers utilize scientific principles and their expertise and collaboration skills to develop effective and functional designs (Yu *et al.*, 2020). Models can take many forms, including graphical, physical and mathematical representations of critical features of processes that support ED (Uzel & Bilici, 2022). Several teaching models that emphasize ED have been developed and used for teaching STEM based subjects (e.g. Donna, 2012; Hynes, Portsmore, Dare, Milto, & Rogers, 2011).

To encourage students to explore and engage in critical thinking, mathematical and computational reasoning about evidence and its design and investigation, it is crucial to integrate ED into science education (Shahat *et al.*, 2022). However, the reason why ED is not yet a widespread practice in many science classrooms is partly because science teachers have not been instructed or trained to create and build physical products during experimental investigations (Shahat, Al-Balushi, & Al-Amri, 2023). There is also a lack of review articles available that investigate the various models used to teach ED or the key issues related to demographic variables, and prior research has failed to consider the pre- and post-service status of preservice STEM teachers in the Middle East (Chen *et al.*, 2020).

This study distinguishes itself from previous research in several key ways. Firstly, it conducts an extensive global examination of studies focused on training both preservice and in-service STEM teachers for ED-based activities. This worldwide perspective sets our research apart. Secondly, it delves into potential future STEM education research paths related to ED based on an in-depth analysis of current findings.

A significant differentiator of this study is its pioneering use of systematic mapping analysis in this specific research field. While this method is gaining recognition for its structured approach to literature reviews and its ability to generate new insights from existing research, it has not been widely applied in the context of ED in STEM education. Thus, our study offers valuable insights and makes a methodological contribution by showcasing the utility of systematic mapping analysis in this area. This approach enhances our ability to systematically analyze and interpret data, providing a fresh perspective in the field of ED and STEM education.

Research aim and questions

Our study maps the recent literature to better understand pre-and in-service STEM teachers' skills in preparing ED-based activities. It presents the findings related to pre-and in-service STEM teachers in higher education institutions (HEI). By considering the importance and impact of ED-based activities in STEM teacher preparation in HEIs, the three research questions that guided the study are as follows:

RQ1. Does the engineering design process (EDP) as an instructional approach in STEM education attract significant interest among researchers?

RQ2. What steps can be implemented for instructing ED in a classroom setting?

RQ3. Which STEM fields most frequently utilize the EDP?

Study structure

The paper is structured as follows: Section 2 provides an overview of the systematic mapping process used in this study. In Section 3, the research results are presented. Section 4 analyzes the literature retrieved and discusses the findings. Finally, Section 5 offers concluding remarks.

Methodology

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodology, which is a well-established framework for conducting and reporting systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff, Altman, & PrismaGroup, 2010), was used in this study. This framework has been extensively used in various scientific fields, including autism spectrum disorder research (Allely, 2018), student performance assessment (Amelia, Abdullah, & Mulyadi, 2019) and medicine (Dong *et al.*, 2015). The framework comprises four main stages: (1) Search Strategy – this initial stage involves developing a comprehensive search plan across two databases to identify relevant studies, (2) Selection Criteria – specific inclusion and exclusion criteria are applied in this stage to filter the studies identified in the search strategy, (3) Quality Assessment – in this stage the relevance and reliability of the selected studies are assessed, ensuring their suitability for the review and (4) Data Extraction – the final stage involves systematically extracting and compiling key data and findings from the chosen studies for analysis. Below, there is a more detailed explanation of how each of the stages was carried out in this study.

Search strategy

We developed a search strategy that aimed to identify the relevant literature. Our search strategy was tailored to three databases: Scopus, ProQuest Central and EBSCO. The databases were selected because they are among the most extensive databases, and they have powerful search capabilities for accessing scientific content. A list of keywords was prepared for the query in the databases that contained the following terms: “Teaching Models”, “ED” and “Pre-and In-service Teacher, STEM disciplines”. The keywords were carefully selected based on their relevance to the core content and themes of the paper, rather than directly from the title. Additionally, we have employed the use of “AND” and “OR” in our search strings to ensure a thorough and relevant literature search. Based on the literature returned from the search attempts, a decision to limit the search to the period 2013–2021 was made.

Selection criteria

The primary objective of the search was to create a systematic map of the current literature concerning the abilities of preservice and in-service STEM teachers to develop ED-based activities. As for the Scopus database, the article selection criteria involved narrowing the search to “publication year”, “source type” and “language”. The search was also narrowed when searching the ProQuest Central database by setting the fields “publication years”, “source type”, “full text”, “subject”, language” and “database”. The same criteria were applied for the EBSCO database search except for the “data” field as this field is not provided by the EBSCO search option list. The search span was from 2013 until 2021 and covered all countries. Studies not published in the English language were eliminated during the screening process, resulting in a total of 400 articles extracted from the databases (see Table 1).

DB	Search string	Filter	Search results
Scopus	(“Teaching Models”) AND	1 No filter	65
	(“Engineering Design”) AND	2. Publication year: Limit to years	55
	(“Preservice Teacher”)	2013–2021	52
		3 Source type: Limit to journal and	51
		conference paper	
		4 Language: Limit to English	
		Number of articles	*51*
ProQuest central		1. No filter	2,460
		2. Publication year: Limit to years	1,827
		2013–2021	1,803
		3. Source type: Limit to scholarly	1,718
		journals	411
		4. Full text only	411
		5. Subject: Limit to mathematics education and science education	
		6. Language: Limit to English	
		7. Database: Education database	
		Number of articles	*334*
EBSCO		1. No filter	26
		2. Publication year: Limit to years 2013–2021	26
		3. Source type: Limit to scholarly journals and conference papers and proceedings	26
		4. Full text only	20
		5. Subject: Limit to education and mathematics education and science education	20
		6. Language: Limit to English	15
		Number of articles	*15*
		Total of articles	*400*

Source(s): Authors’ own work

Table 1.
Selection criteria step

Maintaining quality

To ensure quality of the review, several actions were performed with the initial search results. Firstly, duplicates were eliminated using features available in MS Excel, i.e. the "remove duplicates" function and the "match" function. Initially, duplications were scrutinized separately in each database before being evaluated in all three databases. This resulted in the exclusion of 92 studies – 3 articles were excluded from Scopus, 81 articles were excluded from ProQuest Central and 3 articles were excluded from EBSCO. Secondly, a careful evaluation process was carried out on the studies. This process was implemented by reading and analyzing the abstract to select only studies that investigated STEM, STEM models, science education and pre-and in-service teacher topics. To reduce the time required to analyze a large number of abstracts, the main focus was placed on two important aspects of the abstracts, namely the research objectives and the research problem. Despite the narrowing of focus, this process still took approximately 30 days for the authors to complete. During the quality maintenance stage, a total of 224 articles were excluded due to duplication or a failure to meet the inclusion criteria, including 26 from Scopus, 141 from ProQuest Central and 9 from EBSCO. The remaining 176 articles were subjected to further analysis. Table 2 presents the statistics of the articles remaining after the quality maintenance stage.

Extracting the data

After applying the selection criteria to the 176 remaining articles, a total of 44 research papers from the three databases were included in the final analysis. The selection of research papers was based on the predefined inclusion and exclusion criteria (Figure 1). The filtering steps followed in this research were designed to ensure a comprehensive and accurate reflection of the existing body of research on the topic. Data extraction involved recording information such as the title, abstract, author affiliation, publication details and keywords. The PRISMA guidelines were followed throughout the study, and the inclusion and exclusion process is presented in Figure 1.

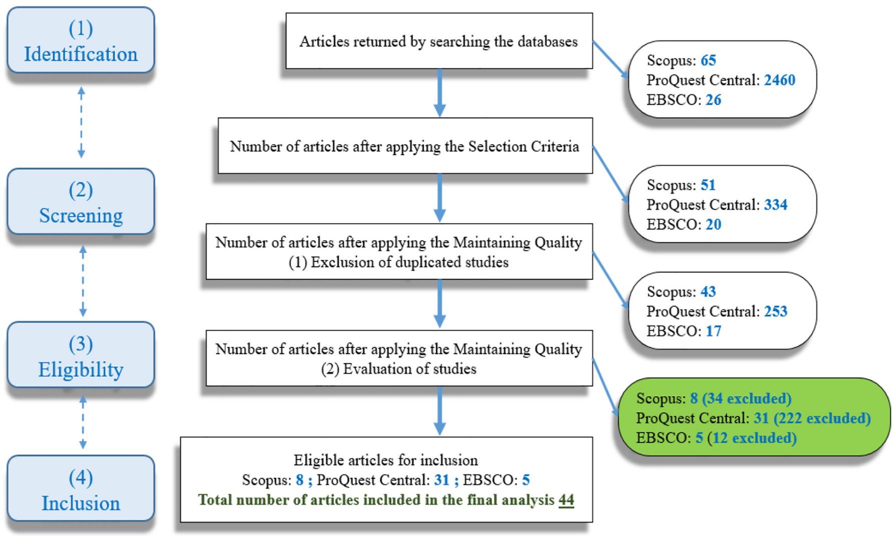
Data analysis

The objective of the data analysis was to identify relevant information pertaining to the review's research objectives and questions. The analysis involved examining the title, abstract, keywords and main text of the 44 articles. The articles were then classified into three categories based on their contributions: (1) conceptual contribution, which described, analyzed, compared, or reviewed ED processes; (2) practical contribution, which presented, proposed, designed, or developed quantitative or qualitative research methods to solve or explore problems related to ED processes for pre- and in-service STEM teachers; and (3) mixed contribution, which included both conceptual and practical contributions. Additionally, the studies were classified based on their scope and the problem they aimed to address, taking into consideration the parameters within which the study was conducted. For example, one researcher addressed the views of preservice science teachers regarding

Task	Scopus	Excluded studies ProQuest central	EBSCO
Exclusion of duplicated studies	8	81	3
Evaluation of studies	26	141	9
Total of remaining studies	8	31	5

Source(s): Authors' own work

Table 2. Maintaining quality stage



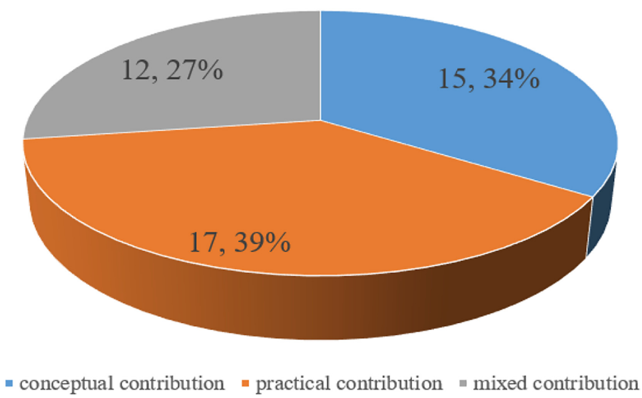
Source(s): Authors' own work

Figure 1.
Flow diagram of study selection

STEM education. We classified this research as a study relevant to ED. Figure 2 shows how the articles were classified based on their contribution type.

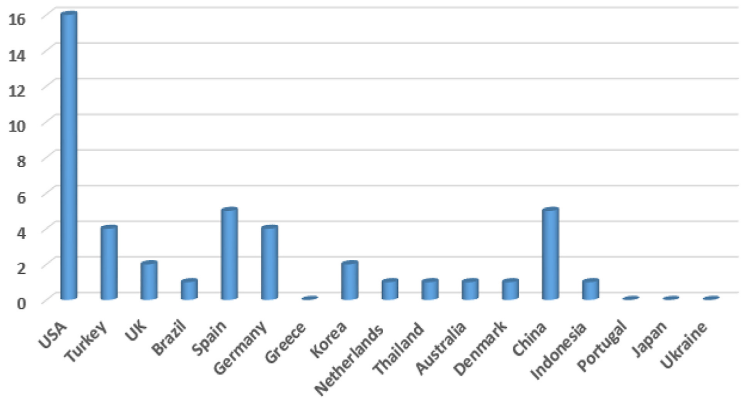
Results

In this section, we present findings from the systematic review of 44 articles investigating the use of the EDP in STEM education. Our research focused on three key questions: the level of research interest in EDP as an instructional approach, its practical implementation in classrooms, and its prevalence across different STEM fields. The results organized by research question are outlined in Figures 3–17 and Tables 3 and 4.



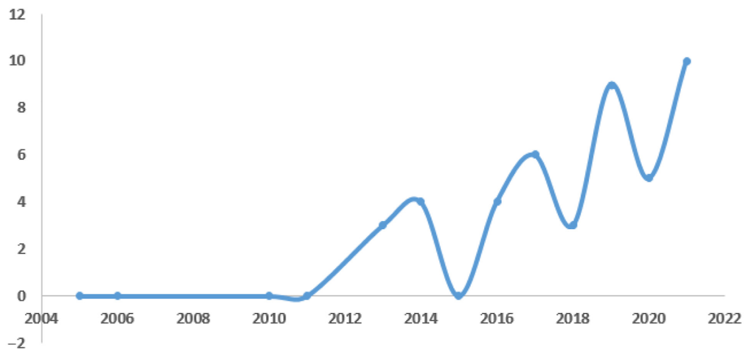
Source(s): Authors' own work

Figure 2.
Distribution of articles according to the three categories



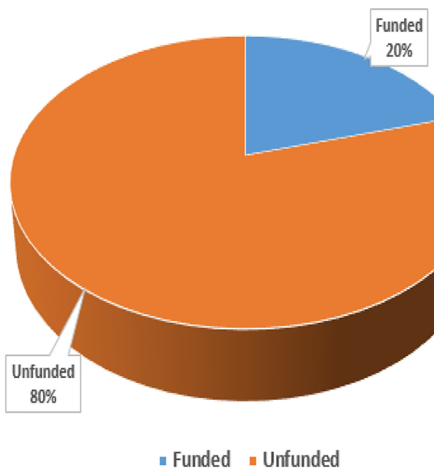
Source(s): Authors' own work

Figure 3.
Number of articles based on author's affiliation



Source(s): Authors' own work

Figure 4.
Number of articles based on publication's year



Source(s): Authors' own work

Figure 5.
Proportions of funded and unfunded research

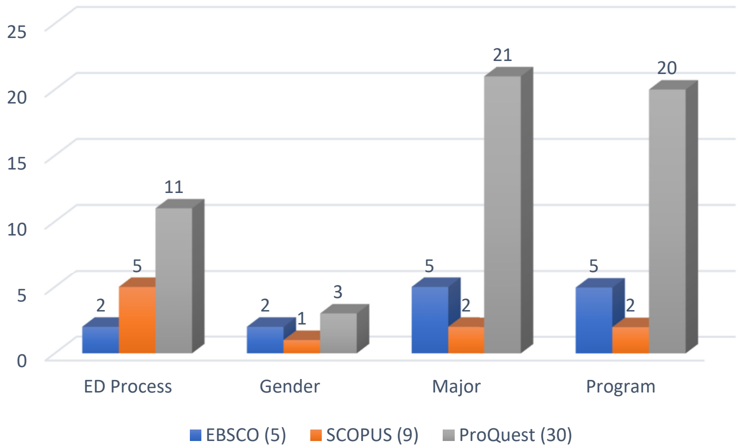


Figure 6.
Overall findings

Source(s): Authors' own work

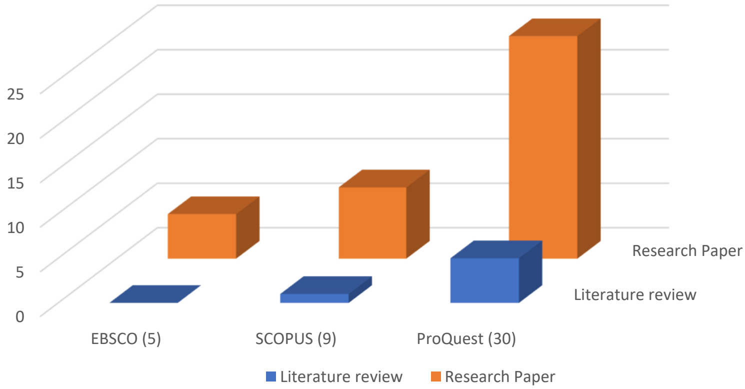


Figure 7.
Type of articles in the three databases

Source(s): Authors' own work

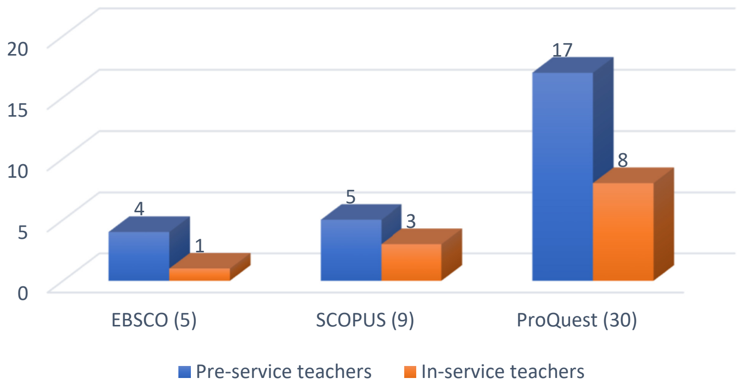


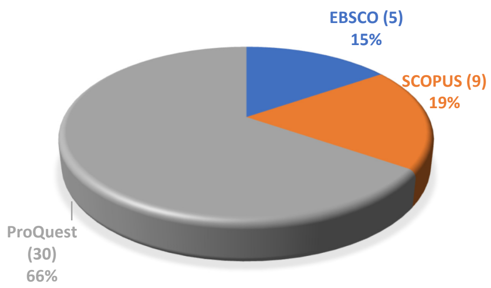
Figure 8.
Targeted sample: pre- and in-service teachers

Source(s): Authors' own work

RQ1. Does the EDP as an instructional approach in STEM education attract significant interest among researchers?

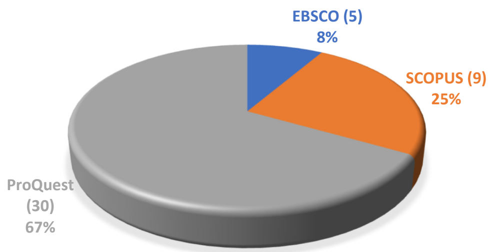
From the sample of 44 articles selected, the following data was obtained.

RQ2. What steps can be implemented for instructing ED in a classroom setting?



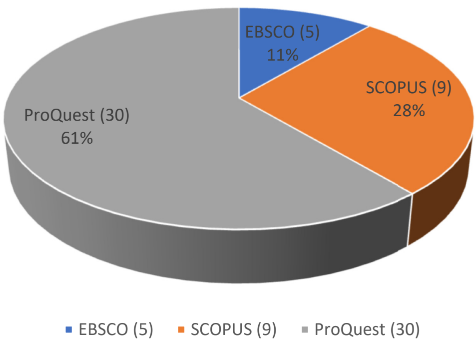
Source(s): Authors' own work

Figure 9. Percentage of articles that targeted preservice teachers



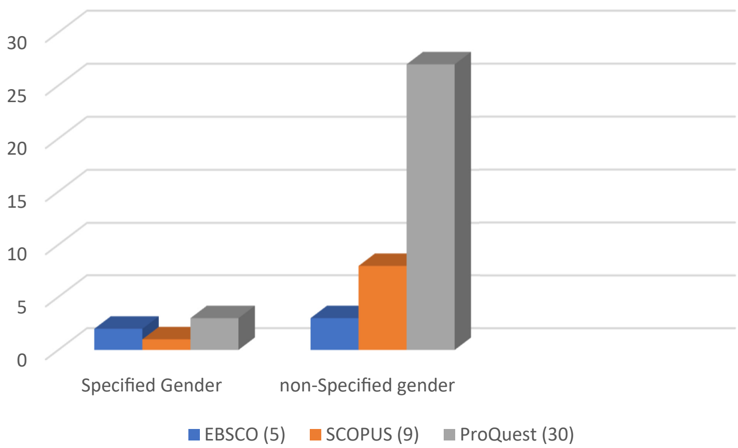
Source(s): Authors' own work

Figure 10. Percentage of articles that targeted in-service teachers



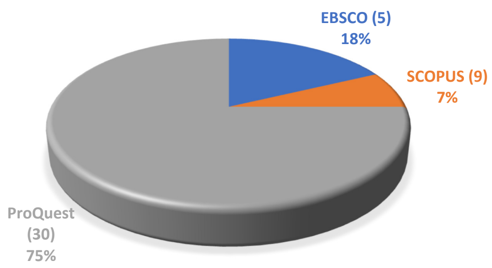
Source(s): Authors' own work

Figure 11. Distribution of engineering design process (EDP) steps found in the databases



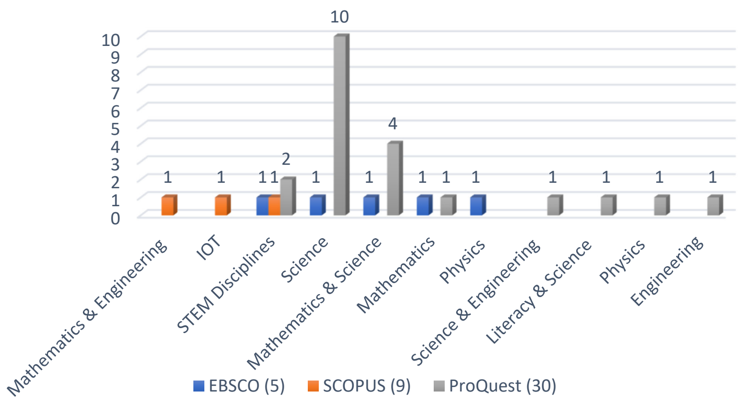
Source(s): Authors' own work

Figure 12.
Gender and EDP



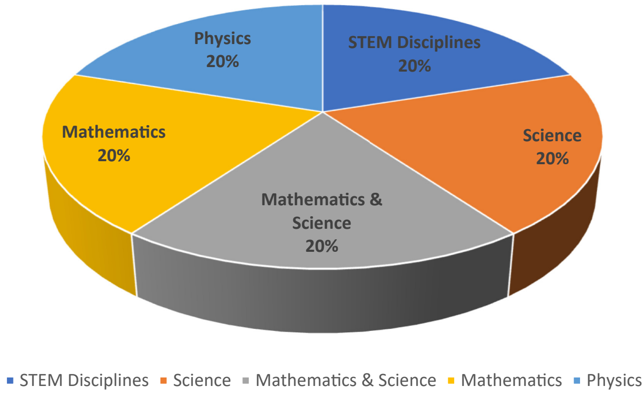
Source(s): Authors' own work

Figure 13.
Distribution of disciplines using EDP in the databases



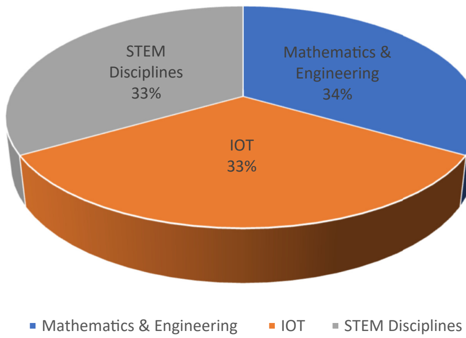
Source(s): Authors' own work

Figure 14.
Disciplines using the engineering design process (EDP)



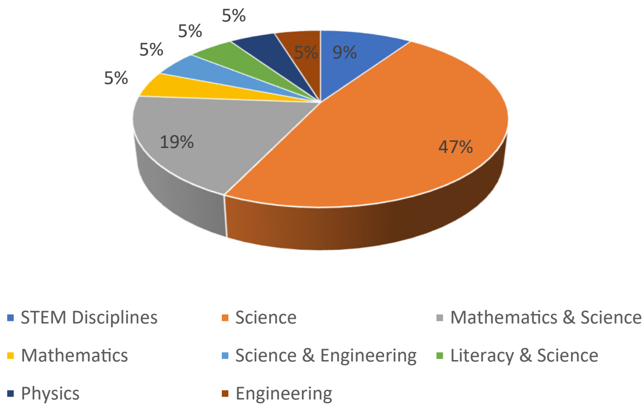
Source(s): Authors' own work

Figure 15.
Disciplines that used EDP in EBSCO



Source(s): Authors' own work

Figure 16.
Disciplines that used EDP in SCOPUS



Source(s): Authors' own work

Figure 17.
Disciplines that used EDP in ProQuest

NO	DB	Author(s)	ED process
1	SCOPUS	Robinson, Kirn, Guy-Gaytán, and Ellis (2021)	1. Identify problem and scenario 2. Research current water filtration devices 3. Draw their own filtration devices 4. Provide labels and measurements for filtration devices 5. Give feedback and receive feedback from peers on their drawings 6. Evaluate their filtration devices 7. Present prototypes to a business member and local engineers
2		Chen *et al.* (2020)	1. Propose Questions 2. Guide Theory 3. Design Plans 4. Comment Plans 5. Implement Plans 6. Display and evaluate
3		Wong, Delagrammatikas and Waters (2019)	1. Identified a problem statement 2. Created a working prototype 3. Collected user feedback 4. Refined their invention to achieve a minimum viable product
4		Lai, Chu, and Chen (2018)	1. Define the problem 2. Find information 3. Develop the program 4. Select the best program 5. Make the prototype 6. Test and evaluate the 7. prototype 8. Communicate the program 9. Redesign the prototype 10. Finish
5		Zeid, Chin, Duggan, and Kamarthi (2014)	1. Start with a problem 2. Conduct research 3. Brainstorm for possible solutions 4. Choose the best solution 5. Design and build a prototype 6. Test prototype 7. Redesign 8. Communicate
6	EBSCO	Tank, DuPont, and Estapa (2020)	1. Problem and background 2. Plan and implement 3. Test and evaluate
7		Maiorca and Mohr-Schroeder (2020)	1. Imagine 2. Plan 3. Create 4. Experiment 5. Improve 6. Ask

(*continued*)

Table 3.
Steps of engineering design process (EDP) in the databases

NO	DB	Author(s)	ED process
8	ProQuest	Yesilyurt, Deniz, and Kaya (2021)	1. Figure out the engineering problem and design specifications 2. Brainstorm and sketch at least three alternative designs on paper 3. Agree upon one viable design option 4. Engaged in constructing prototypes 5. Evaluate designs 6. Refine designs
9		Lawson, Hendrik, and Rosenberg (2021)	1. Collect 2. Analyze 3. Model data to form conclusions
10		Dare, Keratithamkul, Hiwatig, and Li (2021)	1. Plan 2. Design 3. Model 4. Test 5. Evaluate 6. Redesign
11		Antink-Meyer, Arias, Antink-Meyer, and Arias (2020)	1. Empathy 2. Engage 3. Explore I 4. Explain 5. Explore II 6. Elaboration
12		Kim, Chung, Jung, Kim, and Lee (2020)	1. Picking a book 2. Identifying problems 3. Designing solutions 4. Building 5. Feedback 6. Improving solutions 7. Reconstructing stories
13		Kilty and Burrows (2019)	1. Application/Real-world context 2. Creating a product/design/model 3. Experimentation 4. Background research 5. Revision process 6. Challenge/multistep problem 7. Brainstorming 8. Communication
14		Ergün, Kiyici, and Bilgisi Öz (2019)	1. Identification of the problem 2. Researching possible solutions 3. Identifying the most suitable solution 4. Creating prototype 5. Testing prototype
15		Kaya, Newley, Deniz, Yesilyurt, and Newley (2017)	1. Defining the problem(s) 2. Developing and using models 3. Planning and carrying out investigations 4. Analyzing and interpreting data 5. Using mathematics and computational thinking 6. Designing solutions 7. Engaging in argument from evidence 8. Obtaining, evaluating, and communicating information

(*continued*)

Table 3.

NO	DB	Author(s)	ED process
16		Nowikowski (2017)	1. Reaction to the problem 2. Problem research and conceptualization 3. Discovery and discussion 4. Applying a solution 5. Application to teaching practice
17		DiFrancesca, Lee, and McIntyre (2014)	1. Ask (define the problem and identify constraints) 2. Imagine (brainstorm ideas and choose the best one) 3. Plan (draw a diagram and collect materials) 4. Create (follow the plan and test it) 5. Improve (discuss possible improvements and repeat steps 1–5)
18		Pinnell *et al.* (2013)	1. Ideation and brainstorming 2. Product research and conceptual design 3. Decision analysis and embodiment design 4. Final design 5. Prototype building and testing 6. Product redesign 7. Project reporting and presentation

Table 3.

Source(s): Authors' own work

EDP and demographic data

The results of the systematic literature review of the final 44 articles from the three databases (EBSCO 5, SCOPUS 9 and ProQuest, 30) are categorized into two major demographic data based on the overall findings presented in Figure 1. These themes are the steps of the ED Process (EDP) and demographic data including gender, major and preparation program/course. Out of 44 articles, only 18 articles addressed the steps of the EDP. Regarding the demographic data, gender (male/female) was specified in only 6 articles compared to 38 articles which did not specify the gender. Twenty-eight articles specified the major that incorporated the EDP, and 27 articles named the preparation program/course in which the EDP was applied.

Type of articles and target audience

The numbers of the two different types of reviewed articles – research paper articles and literature review articles is presented below in Figure 7.

In addition, research paper articles were categorized as articles that targeted preservice teachers and articles that targeted in-service teachers (Figure 8).

The percentage of pre-and in-service teachers using EDP is presented in Figures 9 and 10 below.

Theme 1: ED process (EDP)

Articles explicitly describing the steps of the EDP were found in all three databases. ProQuest database had 11 articles (61%) that showed the steps of the EDP, followed by SCOPUS with 5 articles (28%) and EBSCO with 2 articles (11%) as illustrated in Figure 11.

Eighteen articles presented different numbers of EDP steps. The least number of EDP steps was three steps, while the largest number of EDP steps was eight. The number of EDP steps used by authors can be seen in Table 3.

NO	DB	Author(s)	Program/course
1	EBSCO	Wong *et al.* (2019)	High school summer outreach course
2		Zeid *et al.* (2014)	Two-week summer professional development program, called CAPSULE
3		Tank *et al.* (2020)	Multi-year project
4		Rinke, Gladstone-Brown, Kinlaw, and Cappiello (2016)	Two traditional mathematics and science methods courses
5		Maiorca and Mohr-Schroeder (2020)	Mathematics methods course
6		Radloff, Guzey, Eichinger, and Capobianco (2019)	Introductory elementary biology content course
7		Ryu, Mentzer, and Knobloch (2019)	STEM education methods course
8	SCOPUS	Yesilyurt *et al.* (2021)	Science teaching methods Course
9		Lawson *et al.* (2021)	A secondary mathematics or science teaching methods course
10	ProQuest	Salar (2021)	University course
11		Dieker, Butler, Ortiz, and Gao (2021)	Teacher preparation program
12		Dare *et al.* (2021)	STEM-focused professional development
13		Nguyen, Antoine-Goeas, Sulman, Tra, Cox, and Gulacar (2021)	University course
14		Nava and Park (2021)	Community focused Stem project-based learning (C-STEM-PBL)
15		Kim *et al.* (2020)	NE-based maker education course
16		Kilty and Burrows (2019)	Two secondary science methods courses
17		Ergün *et al.* (2019)	University course
18		Zimmer, McHatton, Driver, Datubo-Brown, and Steffen (2018)	General education teacher preparation
19		Srikoom, Hanuscin, and Faikhamta (2017)	STEM workshops
20		Kaya *et al.* (2017)	A science teaching methods course
21		Nowikowski (2017)	Middle-level interdisciplinary course in the teaching of mathematics and science
22		Egger, Kastens, and Turrin (2017)	Teacher preparation programs
23		Pelch and Mcconnell (2016)	Introductory college science Courses
24		Singer, Ross, and Jackson-Lee (2016)	Professional development program
25		Conley, Douglass, and Trinkley (2014)	Three semesters course
26		DiFrancesca *et al.* (2014)	The ED methods course, ATOMS A STEM-focused elementary education program
27		Pinnell *et al.* (2013)	Engineering innovation and design for STEM teachers

Source(s): Authors' own work

Table 4. Preparation programs/ course using EDP in the databases

Theme 2: demographic data

Gender and the ED process. The results showed that very few articles focused on the gender of the participants, as can be seen in Figure 12.

RQ3. Which STEM fields most frequently utilize the EDP?

STEM disciplines that incorporated the ED process

Authors of 21 (75%) articles from the ProQuest database mentioned the application of the EDP in various STEM and non-STEM disciplines compared to 5 authors (7%) and 2 authors (18%) who used the EDP with STEM and non-STEM disciplines from EBSCO and SCOPUS databases, respectively (Figure 13).

The most common STEM disciplines and non-STEM disciplines that were mentioned in the selected articles as utilizing the ED process can be seen in Figure 14.

The disciplines covered in the three databases were similar. Articles were found in all three databases that mentioned STEM and non-STEM disciplines, as can be seen in Figures 15–17.

Preparation program

The preparation program results showed that ProQuest mentioned 20 (74%) of articles focused on preparation programs, followed by EBSCO which mentioned 5 (19%) preparation programs and SCOPUS, which mentioned 2 (7%) preparation programs, as presented in Figure 18.

The three databases presented various preparation programs/courses targeting pre-and in-service teachers. Table 4 shows the preparation programs/courses that used EDP.

Discussion

The process of ED involves creating a design solution to a problem, starting with a conceptualization phase and leading to its completion and evaluation. This process is commonly used in various industries to develop innovative products and services, and it is widely used in STEM education. While different articles may describe the ED process using varying numbers of steps, the general consensus is that it is an iterative process. This means that students can repeat the process as many times as necessary, learning from mistakes, discovering new design possibilities and ultimately arriving at effective solutions. Regardless of the exact number of steps, overall the process must start with the identification of the problem, and then students should research possible solutions and identify the most suitable possibility. Then, they should create a prototype of the optimal solution. Finally, they should test and evaluate the prototype.

Gender as a variable in EDP was often not mentioned in the reviewed articles. The articles mostly viewed those involved in the study as participants only, and gender was considered inconsequential. However, knowing the gender of the participants in EDP may, in fact, account for some of the differences in performance, motivation, creativity and quality of teaching STEM fields (Shahat & Al-Balushi, 2023).

STEM disciplines utilize the ED process to create new solutions, products and ideas. The investigation into which disciplines employ the EDP yielded results that are divided into STEM and non-STEM fields. Many articles discussed the EDP in various STEM disciplines.

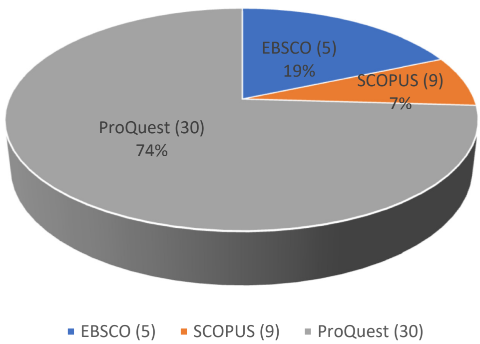


Figure 18. Distribution of preparation program in the databases

Source(s): Authors' own work

However, specific STEM fields such as mathematics and engineering, mathematics and science and science and engineering also utilized the ED process (Shahat *et al.*, 2023). Apart from STEM fields such as literacy and the Internet of Things (IoT) also applied the EDP. All these disciplines require designing, prototyping and testing before the final product is constructed (Shahat *et al.*, 2023). Applying the ED process allows pre-and in-service STEM teachers to train students to develop functional, efficient and cost-effective solutions, resulting in it becoming widely used in STEM education (Shahat *et al.*, 2024).

It was noticeable that mathematics, science and engineering majors applied EDP the most in their studies. At its core, mathematics is a problem-solving tool. Solving mathematical problems often requires an engineering-like design process. For complex equations, students often must break down the problem into smaller pieces and look for patterns before reassembling the equation. This is similar to the design process engineers use to develop solutions to problems. Also, in science classes the ED process is regularly used. Students are often tasked to create experiments to test a hypothesis. This can involve designing and testing and revising and modifying an experiment until students reach a desired result. This approach is often used in more analytical and practical subjects, such as topics in chemistry, physics and biology where students look at problems and develop prototype solutions. After testing their solutions, they revise and refine their designs based on feedback and testing. Engineering is another and perhaps the most obvious, area of STEM that utilizes the ED process. Take civil engineering for example; it is the application of scientific principles to design and construct large-scale infrastructure projects such as bridges, roads, airports and dams. Civil engineers must account for a variety of factors, including environmental conditions, material strength and topography when designing infrastructure projects; they often use computer simulations to efficiently test their designs before construction begins.

Many pre-and in-service teachers apply EDP as part of a preparation program or a university course. The interest in using EDP in teacher professional development programs and university courses reflects the importance of equipping STEM teachers with comprehensive knowledge and skills which will in turn help students in their STEM education.

Conclusion

This systematic review aimed to investigate the literature on the ED process and its application in STEM teacher preparation courses, a topic that has not been extensively explored. The review yielded several significant findings, indicating a positive trend in published research and contributions to the field. For example, one positive sign is the great interest being shown in ED research. In addition, countries increased the percentage of funded research (see Figure 5), reaching 80%. There is a lot of variation in the nature of the research published in this field. There are researchers devoted to addressing research problems, such as steps of the EDP and demographic data including gender, major and preparation program/course and other researchers devoted to reviewing the literature. Further diversity in the nature of the research can be seen in articles addressing preservice and others in-service teacher programs. Another key finding was the STEM and non-STEM disciplines that most commonly use the ED process. The research reviewed revealed that there is similar interest in STEM and non-STEM disciplines by researchers. In order to try and fully understand the EDP process, a lot of the reviewed research presented various preparation programs/courses targeting pre-and in-service teachers with different numbers of EDP steps. The least number of EDP steps was three steps, while the largest number of EDP steps was eight steps. Future research could investigate the extent to which pre- and in-service STEM teachers engage in ED process-based activities. Additionally, it would be beneficial to explore how demographic variables such as gender, teaching experience and major are related to STEM teachers' engagement in ED processes.

Research implications

The findings from this systematic review of the EDP in preparing STEM teachers have profound implications for educational research and practice. The evident global interest and significant funding in this area underscore the critical role of ED in modern STEM education. This growing emphasis suggests that educational policy and curriculum development should continue to focus on integrating EDP into teacher training programs. It is imperative for institutions to align their strategies with this trend to ensure that educators are adequately equipped to teach using ED methodologies.

The diversity in research approaches observed in the literature, which encompasses various aspects like the steps of the EDP, demographic data and the focus on both preservice and in-service teacher programs, reflects the complexity and multifaceted nature of EDP in STEM education. This range of perspectives suggests that future research should adopt an integrated approach, examining how different factors collectively influence the effectiveness and implementation of ED in educational settings. Furthermore, the growing interest in ED among non-STEM disciplines indicates an expanding recognition of its value beyond traditional boundaries. This interdisciplinary interest provides a unique opportunity for educational research to explore how ED principles can be adapted and applied in a variety of academic contexts, potentially leading to innovative teaching practices and cross-disciplinary collaboration.

Future research directions

In terms of future research directions, a deeper exploration into the engagement levels of pre- and in-service STEM teachers with ED-based activities is essential. Such research could reveal insights into the practical challenges of implementing ED in classroom environments, thereby guiding improvements in teacher training and curriculum design. Another vital area is investigating the relationship between demographic variables, such as gender, teaching experience and educational background and their effect on engagement in ED processes. This research could uncover important trends and barriers, informing targeted interventions to enhance EDP integration in diverse educational contexts.

Also, evaluating the effectiveness of different EDP models is crucial for developing a more standardized approach to ED education. Research in this area could lead to the identification of best practices and effective teaching methodologies, contributing to enhanced learning outcomes in STEM education. Exploring the application of ED principles in non-STEM disciplines is a promising area for interdisciplinary research. Such studies could pave the way for innovative educational practices and broaden the scope of ED's applicability, enhancing its impact across a wide range of academic fields. In addition, long-term studies assessing the impact of ED training on various aspects of educational outcomes are essential. These studies should focus on the sustained effects of ED on teaching methodologies, student engagement, learning experiences and overall academic achievement in both STEM and other disciplines. The findings from such research could provide valuable insights into the long-term benefits and potential areas for improvement in ED-focused education.

Lastly, the variability in the EDP models, which range from three to eight steps, indicates a lack of consensus on the most effective approach to teaching ED. This disparity presents a significant research opportunity to standardize and optimize EDP models, ensuring consistency and effectiveness in ED instruction across various educational settings.

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