

# Trends of Engineering Design Process in STEM Education: A Systematic Review of the Evidence during 2017-2021

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**Abstract:** The objective is to analyze instructional trends in STEM education throughout 2017-2021 using a meta-synthesis method and use the "Engineering Design Process (EDP)" in the SCOPUS database. Study criteria were identified for inclusion and exclusion. Sixty-two research papers were selected and analyzed for this purpose. Research analysis revealed that researchers mainly use research tools for observing and interviewing to measure the cognitive and non-cognitive learner capacity under the efficacy of EDP in STEM learning. Robotics and architecture & urban planning were the popular category of product design, followed by science. With EDP employed in STEM education, the reported studies were up to 72% effective. Subsequent researchers and professors are expected to be guided by this research in designing and implementing EDP in their classrooms. Over half of the studies reported have shown that EDP is positive for STEM training.

**Keywords:** STEM education, engineering design process, meta-synthesis study

## 1. Introduction

Many countries call for increased science, technology, engineering, and mathematics studies to remain globally competitive at all levels of education. STEM is a framework based on the idea that education should equip learners with science, technologies, engineering, and mathematics knowledge and skills – interdisciplinary approaches to get more involved in science, engineering, and problem-solving by working on problems in the real world (Honey, Pearson, & Schweingruber, 2014). Previous research has recognized that primary and secondary education STEM education can assist students interested in a STEM career and build up a nationwide STEM-trained workforce that can be used in a complex technological economy to meet the needs of business and industry (Dierdorff, Bakker, van Maanen, & Eijkelhof, 2014). 73% of students become interested in pursuing a career in the STEM fields (Maiorca et al., 2021).

Many projects, investigations, lessons, and plans are being developed by the "Design-Based Design Learning Engineering" method. Research also shows that engineering design in education increases the motivation and achievement of the students at university (Park, Park, & Bates, 2018), their ability to resolve practical problems, and their creativity to learners. Thus, one of the strategies available to implement STEM education is an engineering design process (EDP). Identifying limitations is a key factor for defining engineering problems and developing solutions in engineering design procedures. Furthermore, predictive analysis plays an essential role in selecting the best solution, modeling the prototype, evaluating the results of testing, and that efforts in optimization have been made to modify or redesign the results to find the most appropriate solutions (Asunda & Hill, 2007).

This raises concerns about the ability of the education system to generate adequate STEM economic graduates. This paper, therefore, presents the study of academic literature on EDP in STEM education. The review focused on the identification of the methodology for implementation, such as research tools to prove the effectiveness of the designed EDP module, module products, and the result, to choose the method for future professional development and teacher initiatives aimed at enhancing the effectiveness of teachers in the context of integrated STEM approaches.

## 2. Research Questions

The purpose of this study was to explore the current empirical studies in which EDP was utilized and implemented in the field of STEM education to examine the similarities and differences while implementing an engineering design process in different studies. In line with these aims, the research questions are determined as follows:

**Q1:** What kind of research tools was used to prove the effectiveness of EDP in STEM education?

**Q2:** What was the designed product in the reported studies related to EDP in STEM education?

**Q3:** What were the effective results of the studies that have employed EDP in STEM education?

## 3. Methodology

This study is a meta-synthesis study used as a qualitative data analysis method by descriptive analyses. A methodology that utilizes qualitative and quantitative studies as data or units of analysis is meta-synthesis. The focus is on understanding and describing key issues and topics in the research literature on a certain subject (Walsh & Downe, 2004). In this study, the "engineering design process" study aims to be analyzed and evaluated with qualitative insight under the nature of the meta-synthesis. According to Walsh and Downe (2005), a meta-synthesis study has different steps as follows:

- (1) Searching research articles
- (2) Including some criteria for articles to select them on the purpose of the study
- (3) Examining and evaluating the studies
- (4) Conceptualizing and comparing the selected studies
- (5) Synthesizing the findings

The present study follows a similar pathway to search, find and include the articles, and present the research findings. A diagram of the screening process can be seen in Figure 1.

- In stage 1, relevant studies were identified by keyword search in an academic database, namely SCOPUS.
- In stage 2, the SCOPUS database was browsed using two different keywords: "STEM" and "Engineering design process." The literature search terms found 199 search hits. The researchers included only the studies published within the publication year of 2017-2021 to indicate the recentness of reported studies. The filtering process resulted in 101 search hits.
- In stage 3, relevant studies were evaluated and selected from the search hits. The search from the database resulted in a total of 101 search hits. The following criteria were used sequentially against article abstracts:
  - (1) First, the selected articles are the empirical studies embracing EDP.
  - (2) Second, the articles must provide a clear description of STEM teaching and learning instruction.
  - (3) Thirdly, the article has to describe the methodology throughout the entire research clearly.
  - (4) Fourth, the article must focus on the impact of STEM teaching and learning approach within all school levels, i.e., middle included teachers.
  - (5) Fifth, the commentary and review articles and unable to download the full paper were excluded.

According to these inclusion criteria, this number was further decreased to 62 articles. All data gathered in stage 4 had all been diagrammed to help us get the result quickly. The data were so mapped that

the predetermined research questions could be answered. The criteria were identified based on the keyword or term used by the author in the respective studies to determine whether the studies had positive, mixed, harmful, or neutral results:

- (1) Positive result: terms, for instance; “significant increase”, “positive impact”, “positively affect”, “significant impact”, “increase”, in the results were considered to have yielded positive. Furthermore, the keywords, such as “stimulate”, “improve”, “successful” or any other keywords that might suggest a positive outcome, were also considered to be positive.
  - (2) Mixed result: the studies that have resulted in a combination of increase, decrease, and no significant change across different variables are considered to have mixed results.
  - (3) Negative result: keywords, such as “decrease”, “drop”, “ineffective” and “negative result” were considered to reflect the negative outcome.
  - (4) Neutral result: is considered if, for instance, the study resulted in no significant change or equal performance between pre-test and post-test.
- In the last step, the results obtained thru charting were read in detail, summarized, and interpreted appropriately.

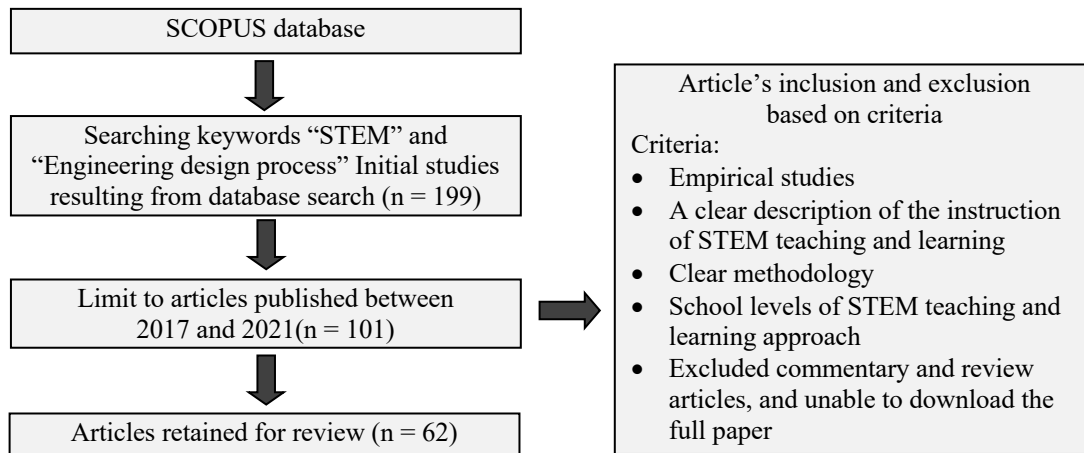


Figure 1. Diagram of the screening process. The diagram shows how the studies were culled down from the initial database search to the final retained studies.

#### 4. Results and Discussion

The classification of the 62 selected articles related to the engineering design process is extracted information in terms of authors, country, school level, research tools, design product categories, and effective results, as shown in Table 1.

Table 1. Classification of the Studies Related to EDP

Articles code	Author	Country	School-level	Research Tool	Effectiveness
A1	(Lin, Wu, Hsu, & Williams, 2021)	Taiwan	Technology teacher	I, O	Positive
A2	(Chuasantia & Sirirat, 2021)	Thailand	H	T	Positive
A3	(Linh & Huong, 2021)	Vietnam	M, H	T, Q, O	Mixed
A4	(Madahae, Pisapak, & Thanyasirikul, 2021)	Thailand	Teacher	O	Positive
A5	(Poonpaiboonpipat, 2021)	Thailand	Technology teacher	O	Mixed

Table 1. *Continue*

Articles code	Author	Country	School-level	Research Tool	Effectiveness
A6	(Bunprom, Boontemsuk, Tupsai, & Yuenyong, 2021)	Thailand	H	I, O	Positive
A7	(Nisa, Yuliati, & Hidayat, 2021)	Indonesia	H	T, I	Positive
A8	(Rusydiyah, Indrawati, Jazil, Susilawati, & Gusniwati, 2021)	Indonesia	Science teacher	I, O	Positive
A9	(Bampasidis et al., 2021)	Greece	M, H	Q, O	Mixed
A10	(Rugh, Beyette, Capraro, & Capraro, 2021)	USA	M, H	T, I, O	Positive
A11	(Dedetürk, Kırmızıgül, & Kaya, 2021)	Turkey	E	T, I, O	Positive
A12	(Firdaus, Wardani, Altaftazani, Kelana, & Rahayu, 2020)	Indonesia	E	T, O	Positive
A13	(Dung, Thu Huong, & Thi Nga, 2020)	Vietnam	H	I, O	Positive
A14	(Zeld, 2020)	USA	Science teacher	T, I	Positive
A15	(Rawat & Asthana, 2020)	USA	M, H	T, Q, O	Positive
A16	(Minken, Macalalag, & Naylor, 2020)	USA	Teacher	T, O	Mixed
A17	(Martin et al., 2020)	USA	Autistic students	T, I, O	Positive
A18	(Pleasants, Olson, & De La Cruz, 2020)	USA	Teacher	T, O	Positive
A19	(Gharib, Benjamin, & Cree, 2020)	Qatar	H	O	Positive
A20	(Long, Yen, & Van Hanh, 2020)	Vietnam	E, M	Q	Positive
A21	(Yen & Chang, 2020)	Taiwan	H	Q, O	Mixed
A22	(Tang Dan & Patel, 2020)	USA	M, H	T, Q, O	Positive
A23	(Li, Chang, & Chiang, 2020)	China	E	T, O	Positive
A24	(Fan, Yu, & Lin, 2020)	Taiwan	Engineering teacher	O	Mixed
A25	(Nurtanto, Pardjono, Widarto, & Ramdani, 2020)	Indonesia	H	T, O	Positive
A26	(Bozkurt Altan & Tan, 2020)	Turkey	M	I, O	Positive
A27	(Bunprom, Tupsai, & Yuenyong, 2019)	Thailand	H	I, O	Positive
A28	(Vela, Caldwell, Capraro, & Capraro, 2019)	USA	M, H	T, O	Mixed
A29	(Silvestri et al., 2019)	USA	Teacher	I, O	Positive
A30	(Traum & Karackattu, 2019)	USA	H	Q, O	Mixed
A31	(Briscoe, McCue, & Lumme, 2019)	USA	M, H	Q	Mixed
A32	(Bowen, Kallmeyer, & Erickson, 2019)	USA	Teacher	I, O	Positive
A33	(Mathiphatikul, Bongkotphet, & Dangudom, 2019)	Thailand	H	I, O	Positive
A34	(Fidai, Barroso, Capraro, & Capraro, 2019)	USA	M	O	Positive
A35	(Dasgupta, Magana, & Vieira, 2019)	USA	M	I, O	Positive
A36	(Mohd Shahali, Halim, Rasul, Osman, & Mohamad Arsad, 2019)	Malaysia	M	I	Mixed
A37	(Butler, 2019)	USA	B	O	Positive
A38	(Fan, Yu, & Lou, 2018)	Taiwan	H	T, O	Mixed
A39	(Rasul, Zahrman, Halim, & Rauf, 2018)	Malaysia	E	Q, O	Positive
A40	(Chien, Chang, Hsiao, & Lin, 2018)	Taiwan	H	O	Positive
A41	(So, 2018)	Hong Kong	Teacher	O	Positive

Table 1. *Continue*

Articles code	Author	Country	School-level	Research Tool	Effectiveness
A42	(Bowen, Kallmeyer, & Erickson, 2018)	USA	Science teacher	I, O	Positive
A43	(Prawvichien, Siripun, & Yuenyong, 2018)	Thailand	H	I, O	Positive
A44	(Douglas, Moore, Johnston, & Merzdorf, 2018)	USA	M	O	Mixed
A45	(Alemdar et al., 2018)	USA	M	I, O	Positive
A46	(Tseng, Tai, Tsai, & Ting, 2018)	Taiwan	H, B	Q, O	Positive
A47	(Lin, Hsiao, Chang, Chien, & Wu, 2018)	Taiwan	H	I, Q, O	Mixed
A48	(Aydin-Gunbatar, Tarkin-Celikiran, Kutucu, & Ekiz-Kiran, 2018)	Turkey	B	T, Q	Positive
A49	(Burns & Lesseig, 2017)	USA	M	I, O	Mixed
A50	(Knop et al., 2017)	USA	M	I, O	Positive
A51	(Teevasuthonsakul, Yuvanatheeme, Sriput, & Suwandecha, 2017)	Thailand	H	I, O	Positive
A52	(McVee, Silvestri, Shanahan, & English, 2017)	USA	E	O	Positive
A53	(Zhou et al., 2017)	USA	M	O	Positive
A54	(Scribner, 2017)	USA	M, H, and Educator	Q	Mixed
A55	(Newman, Parker, Sparks, & Falk, 2017)	USA	E	I	Positive
A56	(White, Alexander, & Prince, 2017)	USA	M, H	Q, O	Positive
A57	(Doddo & Hsieh, 2017)	USA	H	O	Positive
A58	(Sejati, Firman, & Kaniawati, 2017)	Indonesia	M	T, O	Positive
A59	(English, King, & Smeed, 2017)	Australia	E	O	Positive
A60	(Siew, 2017)	Malaysia	H	I, O	Mixed
A61	(Shahali, Halim, Rasul, Osman, & Zulkifeli, 2017)	Malaysia	M	Q, O	Positive
A62	(Barry, Kanematsu, Lawson, Nakahira, & Ogawa, 2017)	Japan	B	Q, O	Positive

Note: E = Elementary school, M = Middle school, H = High school, B = Bachelor's Degree, T = Paper test, I = Interview, Q = Questionnaire, and O = Observation

*Q1: What kind of research tools were used to prove the effectiveness of EDP in STEM?*

Figure 2a shows the proportion of research tools used by the reported studies. It was found that the observation (85.48%, 53 of the total 62 articles) and interview (40.32%, 25 of the total 62 articles) were often used to measure the effectiveness of EDP in STEM education, followed by an interview (40.32%, 25 of the total 62 articles), test (29.03%, 18 of the total 62 articles), and questionnaire (25.81%, 16 of the total 62 articles). It is revealed that thinking skill, which is cognitive ability, was measured in most studies. More than 66%, the combination of research tools was used to measure the effectiveness of EDP in STEM education (Figure 2b). Furthermore, these results revealed that at least two research tools were the most utilized (Inset of Figure 2b). This is probably because only one research tool could not measure students' cognitive and non-cognitive abilities during EDP instruction. Thinking tools, test performance, and content knowledge are often measured to illustrate the students' cognitive ability. Apart from cognitive ability, student's attitudes, perception, motivation, and interest towards EDP-STEM education were measured in most of the studies.

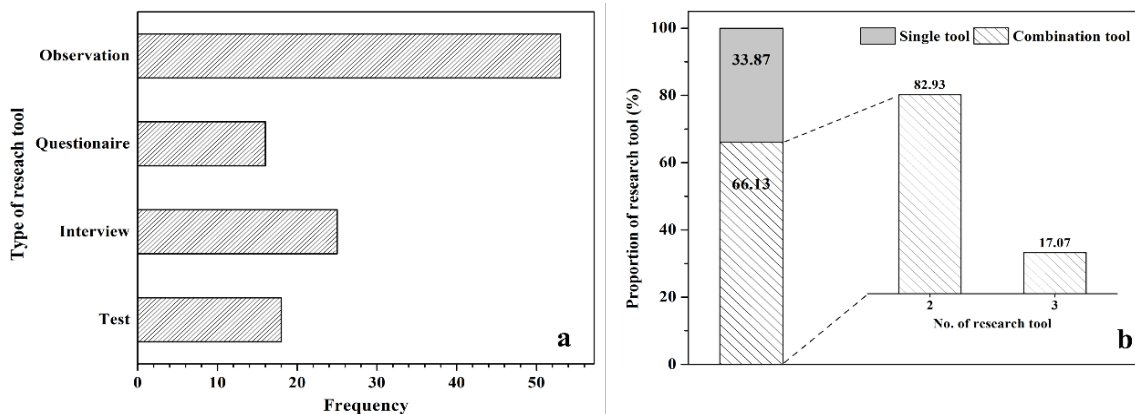


Figure 2. Research Tool Used by 62 Reported Articles; a) Type of Research Tool, and b) the Proportion of Single and Combination Research Tools Used in EDP-STEM Education.

Q2: What was the designed product in the reported studies related to EDP in STEM education?

Table 2 summarizes the design product classes of the 62 articles selected. Product categories were chosen to reflect the relationship between the EDP product and the real-world application in the current industrial category. Note that there were more than 62 product categories in total because more than one product category was designed by multiple studies. The most commonly designed category of products is robotics and architecture/urban planning (11 studies). The popularity of robotics as a targeted product in EDP can undoubtedly lead to a favorable learning environment due to the tangibility of robots and the excitement caused by them. Probably some architectural/urban planning workshop; for instance, the challenge of marshmallow tower and a bridge from straws, no necessary engineering knowledge, reusable and low-cost project material. Sciences in the field of physics, chemistry, and environmental sciences were the next popular category. This may lead to high school pupils learning from such disciplines (physical, chemical, biological, technological, and mathematical), so EDP/STEM education projects or classroom activities can easily be applied.

Table 2. Design Product Categories while Generating EDP

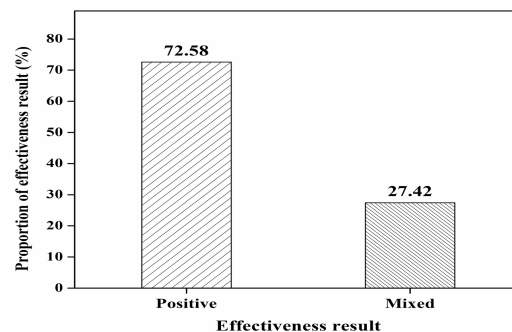
Categories	Articles	Frequency
Robotics	A9, A11, A14*, A15*, A22, A40, A45, A50, A54, A56	11
Gaming	A12, A15*, A17*, A20*	4
Consumer electronics	A17*, A20*, A26, A36, A61*	5
Application/computer hardware	A15, A41, A46, A55*	4
Automotive manufacturing	A16, A23, A24, A25, A34	5
Maritime	A31, A53*	2
Aircraft	A6, A37, A45, A62	4
Commercial aerospace	A30	1
Renewable energy	A3, A20*, A35, A44, A61*	5
Architecture/urban planning	A21, A28, A29, A33, A39, A47, A49, A52, A53*, A59, A61*	11
Toys	A4, A10, A38	3
Pest control product	A1, A14*, A55*	3
Sciences (Physic/Chemistry/Environment)	A2, A7, A13, A21, A27, A51, A53*, A58, A50, A60	10
Others (teaching lesson plans /drawing/mitigation route from flooding areas)	A5, A10, A18, A32, A42, A43	6
Total		74

Note: \* Studies have designed more than one product category.

*Q3: What were the effective results of the studies that have employed EDP in STEM education?*

According to the data summarized in Table 1 and Figure 3, more than half of the reported studies have shown positive effectiveness (72.58%, 45 articles), followed by mixed results (27.42%, 17 articles), respectively. Nevertheless, neutral and negative results had not been reported. These results indicated that the students developed their creative thinking continuously by using learning management through the engineering design process based on STEM education. For example, Mathiphatikul et al. (2019) found that learning management through an engineering design process based on STEM education can promote 10th-grade student's creative thinking in the following three competencies (Mathiphatikul et al., 2019). Similarly, EDP can improve student creativity because students must come up with their respective ideas in making problem-solving plans.

Moreover, it significantly impacts increasing students' mathematics learning outcomes in the cognitive domain (Firdaus et al., 2020). EDP promoted students' creative thinking and positively affected educators' engineering design thinking, as Lin et al. (2021) reported. They found that incorporating the engineering design process into the training of preservice technology teachers is beneficial for refining their cognitive structure in engineering design thinking (Lin et al., 2021).



*Figure 3.* The Proportion of Effectiveness of EDP in STEM Education Results.

## 5. Conclusions

This study selected 62 papers on the STEM learning approach using EDP from the SCOPUS database analyzed in this report. The case study was the most frequently used research design. Robotics and architecture/urban planning were the popular product category developed in EDP implementation. The efficiency of the EDP was mainly measured using research tools that were nearly used in the EDP module, such as observations (85.48%) and interviews (40.32%). In addition, a student's cognitive and non-cognitive skills were measured using at least two types of research tools. Over 70% of the studies reported in the STEM education module showed positive, measurable EDP effectiveness. The results of research have led to the perspective of applying EDP to teaching and learning in undergraduate programs to instill a thought process in research and development.

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