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# 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 (Dierdorp, 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.

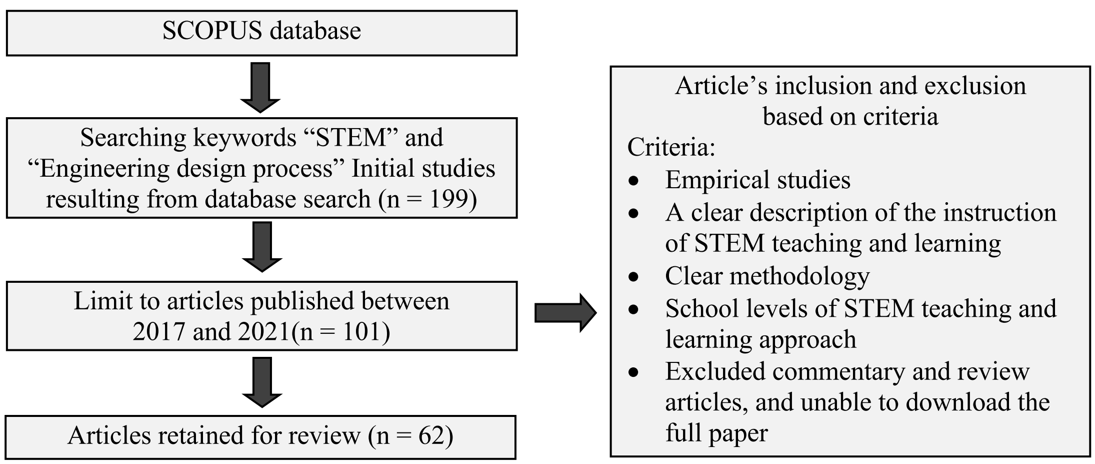


*Figure 1.* Diagram of the screening process. The diagram shows how the studies were culled down from the initial database search to the final retained studies.

## 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 | (Chuasontia & 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 | (Zeid, 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, Zahriman, 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-Celikkiran, 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.

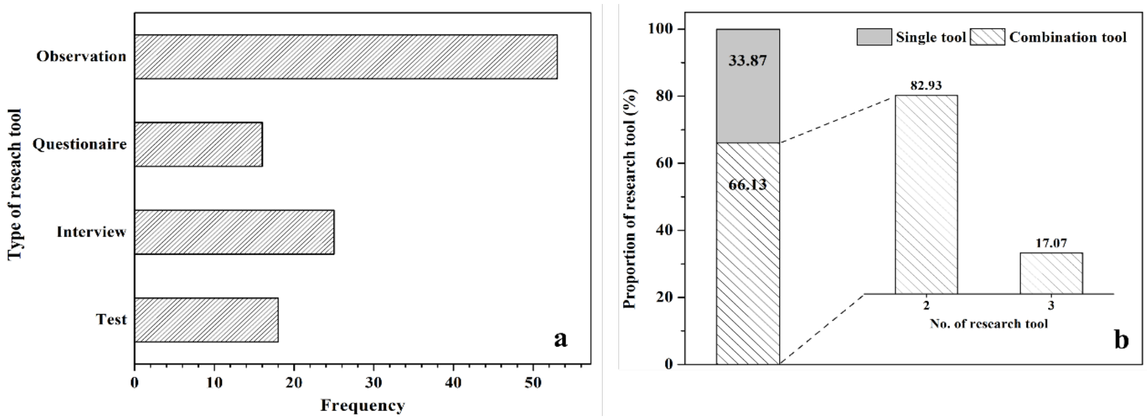


*Figure 2.* Research Tool Used by 62 Reported Articles; a) Type of Research Tool, and b) the Proportion of Single and Combination Research Tools Used in EDP-STEM Education.

*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 strokes, 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).

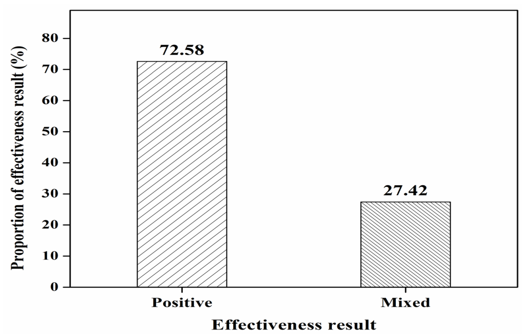


*Figure 3.* The Proportion of Effectiveness of EDP in STEM Education Results.

## 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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## References


Alemdar, M., Moore, R. A., Lingle, J. A., Rosen, J., Gale, J., & Usselman, M. C. (2018). The impact of a middle school engineering course on students' academic achievement and non-cognitive skills. *International Journal of Education in Mathematics, Science and Technology, 6*(4), 363-380.

Asunda, P., & Hill, R. (2007). Critical Features of Engineering Design in Technology Education. *Center Studies*.

Aydin-Gunbatar, S., Tarkin-Celikkiran, A., Kutucu, E. S., & Ekiz-Kiran, B. (2018). The influence of a design-based elective STEM course on pre-service chemistry teachers' content knowledge, STEM conceptions, and engineering views. *Chemistry Education Research and Practice, 19*(3), 954-972.

Bampasidis, G., Piperidis, D., Papakonstantinou, V., Stathopoulos, D., Troumpetari, C., & Poutos, P. (2021). Hydrobots, an Underwater Robotics STEM Project: Introduction of Engineering Design Process in Secondary Education. *Advances in Engineering Education, 8*(3), 1-24.

Barry, D. M., Kanematsu, H., Lawson, M., Nakahira, K., & Ogawa, N. (2017). *Virtual STEM activity for renewable energy.* Paper presented at the Procedia Computer Science.

Bowen, B., Kallmeyer, A. R., & Erickson, H. H. (2018). *Research experiences for teachers in precision agriculture and sustainability for solitary STEM educators.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Bowen, B., Kallmeyer, A. R., & Erickson, H. H. (2019). *The impact of research experiences for teachers program in precision agriculture and sustainability for rural stem educators.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Bozkurt Altan, E., & Tan, S. (2020). Concepts of creativity in design-based learning in STEM education. *International Journal of Technology and Design Education*.

Briscoe, M., McCue, L. S., & Lumme, D. A. (2019). *Implementing and integrating an engineering video game into a variety of educational contexts.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Bunprom, S., Boontemsuk, C., Tupsai, J., & Yuenyong, C. (2021). *Examining Grade 11 students' existing ideas of the engineering design process of fluid and Bernoulli's principle through Predict-Observe-Explain (POE).* Paper presented at the Journal of Physics: Conference Series.

Bunprom, S., Tupsai, J., & Yuenyong, C. (2019). *Learning Activities to Promote the Concept of Engineering Design Process for Grade 10 Students' Ideas about Force and Motion through Predict-Observe-Explain (POE).* Paper presented at the Journal of Physics: Conference Series.

Burns, H. D., & Lesseig, K. (2017). *Empathy in middle school engineering design process.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE.

Butler, W. M. (2019). *Introducing engineering design through an aerospace-based design project.* Paper presented at the AIAA SciTech 2019 Forum.

Chien, Y. H., Chang, Y. S., Hsiao, H. S., & Lin, K. Y. (2018). *STEAM-oriented Robot Insect Design Curriculum for K-12 Students.* Paper presented at the Proceedings - 2017 7th World Engineering Education Forum, WEEF 2017- In Conjunction with: 7th Regional Conference on Engineering Education and Research in Higher Education 2017, RCEE and RHEd 2017, 1st International STEAM Education Conference, STEAMEC 2017 and 4th Innovative Practices in Higher Education Expo 2017, I-PHEX 2017.

Chuasontia, I., & Sirirat, T. (2021). Designing an instructional module to teach light diffraction by a grating to secondary students applying a STEM-integrated approach. *Physics Education, 56*(4).

Dasgupta, C., Magana, A. J., & Vieira, C. (2019). Investigating the affordances of a CAD enabled learning environment for promoting integrated STEM learning. *Computers and Education, 129*, 122-142.

Dedetürk, A., Kırmızıgül, A. S., & Kaya, H. (2021). The effects of stem activities on 6th-grade students' conceptual development of sound. *Journal of Baltic Science Education, 20*(1), 21-37. doi:10.33225/jbse/21.20.21

Dierdorp, A., Bakker, A., van Maanen, J. A., & Eijkelhof, H. M. C. (2014). Meaningful statistics in professional practices as a bridge between mathematics and science: an evaluation of a design research project. *International Journal of STEM Education, 1*(1), 9.

Doddo, M., & Hsieh, S. J. T. (2017). *MAKER: A study of multi-robot systems recreated for high school students.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Douglas, K. A., Moore, T. J., Johnston, A. C., & Merzdorf, H. E. (2018). Informed designers? students' reflections on their engineering design process. *International Journal of Education in Mathematics, Science and Technology, 6*(4), 443-459.

Dung, T. M., Thu Huong, V. N., & Thi Nga, N. (2020). Teachers and STEM education: collaboration across disciplines and implementation of lessons in two subject areas. *Universal Journal of Educational Research, 8*(9), 4122-4128.

English, L. D., King, D., & Smeed, J. (2017). Advancing integrated STEM learning through engineering design: Sixth-grade students' design and construction of earthquake-resistant buildings. *Journal of Educational Research, 110*(3), 255-271.

Fan, S. C., Yu, K. C., & Lin, K. Y. (2020). A Framework for Implementing an engineering-focused STEM Curriculum. *International Journal of Science and Mathematics Education*. doi:10.1007/s10763-020-10129-y

Fan, S. C., Yu, K. C., & Lou, S. J. (2018). Why do students present different design objectives in engineering design projects? *International Journal of Technology and Design Education, 28*(4), 1039-1060.

Fidai, A., Barroso, L. R., Capraro, M. M., & Capraro, R. M. (2019). *Can Building an Electric Bicycle Build an Engineering Identity?* Paper presented at the Proceedings - Frontiers in Education Conference, FIE.

Firdaus, A. R., Wardani, D. S., Altaftazani, D. H., Kelana, J. B., & Rahayu, G. D. S. (2020). *Mathematics learning in elementary school through engineering design process method with STEM approach.* Paper presented at the Journal of Physics: Conference Series.

Gharib, M., Benjamin, T. K. G., & Cree, C. B. (2020). *AN INTEGRATED ENGINEERING AGRICULTURE STEM PROGRAM.* Paper presented at the ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE).

Honey, M. A., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: status, prospects, and an agenda for research*.

Knop, L., Ziaeefard, S., Ribeiro, G. A., Page, B. R., Ficanha, E., Miller, M. H., Mahmoudian, N. (2017). *A human-interactive robotic program for middle school STEM education.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE.

Li, L., Chang, C. H., & Chiang, F. K. (2020). Investigating how children learn and perceive engineering design knowledge through automotive design practices. *International Journal of Engineering Education, 36*(5), 1480-1491.

Lin, K. Y., Hsiao, H. S., Chang, Y. S., Chien, Y. H., & Wu, Y. T. (2018). The effectiveness of using 3D printing technology in STEM project-based learning activities. *Eurasia Journal of Mathematics, Science and Technology Education, 14*(12).

Lin, K. Y., Wu, Y. T., Hsu, Y. T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education, 8*(1).

Linh, N. Q., & Huong, L. T. T. (2021). *Engineering design process in STEM education: An illustration with the topic "wind energy engineers".* Paper presented at the Journal of Physics: Conference Series.

Long, N. T., Yen, N. T. H., & Van Hanh, N. (2020). The role of experiential learning and engineering design process in k-12 stem education. *International Journal of Education and Practice, 8*(4), 720-732.

Madahae, S., Pisapak, P., & Thanyasirikul, C. (2021). *Learning Design of STEM Education through Workshop Training for Thai Teachers.* Paper presented at the Journal of Physics: Conference Series.

Maiorca, C., Roberts, T., Jackson, C., Bush, S., Delaney, A., Mohr-Schroeder, M. J., & Soledad, S. Y. (2021). Informal Learning Environments and Impact on Interest in STEM Careers. *International Journal of Science and Mathematics Education, 19*(1), 45-64.

Martin, W. B., Yu, J., Wei, X., Vidiksis, R., Patten, K. K., & Riccio, A. (2020). Promoting Science, Technology, and Engineering Self-Efficacy and Knowledge for All With an Autism Inclusion Maker Program. *Frontiers in Education, 5*.

Mathiphatikul, T., Bongkotphet, T., & Dangudom, K. (2019). *Learning management through an engineering design process based on STEM education for developing creative thinking in equilibrium topics for 10th-grade students.* Paper presented at the Journal of Physics: Conference Series.

McVee, M., Silvestri, K., Shanahan, L., & English, K. (2017). Productive Communication in an Afterschool Engineering Club with Girls Who are English Language Learners. *Theory into Practice, 56*(4), 246-254.

Minken, Z., Macalalag, A. Z., & Naylor, N. (2020). *What will you do to help elementary students who struggle in the engineering design process? Analysis of teachers' reflections. (fundamental).* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Mohd Shahali, E. H., Halim, L., Rasul, M. S., Osman, K., & Mohamad Arsad, N. (2019). Students' interest towards STEM: a longitudinal study. *Research in Science and Technological Education, 37*(1), 71-89.

Newman, C. A., Parker, C., Sparks, A. N., & Falk, M. L. (2017). *Student-driven engineering design projects.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Nisa, I. K., Yuliati, L., & Hidayat, A. (2021). *Exploration of students' analyzing ability in the engineering design process through guided inquiry learning for STEM education.* Paper presented at the AIP Conference Proceedings.

Nurtanto, M., Pardjono, P., Widarto, W., & Ramdani, S. D. (2020). The effect of STEM-EDP in professional learning on automotive engineering competence in vocational high school. *Journal for the Education of Gifted Young Scientists, 8*(2), 633-649.

Park, D.-Y., Park, M.-H., & Bates, A. B. (2018). Exploring Young Children's Understanding About the Concept of Volume Through Engineering Design in a STEM Activity: A Case Study. *International Journal of Science and Mathematics Education, 16*(2), 275-294.

Pleasants, J., Olson, J. K., & De La Cruz, I. (2020). Accuracy of Elementary Teachers’ Representations of the Projects and Processes of Engineering: Results of a Professional Development Program. *Journal of Science Teacher Education, 31*(4), 362-383.

Poonpaiboonpipat, W. (2021). *Pre-service mathematics teachers' perspectives on STEM-based learning activities.* Paper presented at the Journal of Physics: Conference Series.

Prawvichien, S., Siripun, K., & Yuenyong, C. (2018). *Developing teaching process for enhancing students' mathematical problem-solving in the 21st century through STEM education.* Paper presented at the AIP Conference Proceedings.

Rasul, M. S., Zahriman, N., Halim, L., & Rauf, R. A. (2018). Impact of integrated STEM smart communities program on students scientific creativity. *Journal of Engineering Science and Technology, 13*(Special Issue on ICITE 2018), 80-89.

Rawat, K. S., & Asthana, C. B. (2020). *Students in the engineering design process and applied research.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Rugh, M. S., Beyette, D. J., Capraro, M. M., & Capraro, R. M. (2021). Using DIME maps and STEM project-based learning to teach physics. *Interactive Technology and Smart Education*. doi:10.1108/ITSE-07-2020-0109

Rusydiyah, E. F., Indrawati, D., Jazil, S., Susilawati, & Gusniwati. (2021). Stem learning environment: Perceptions and implementation skills in prospective science teachers. *Jurnal Pendidikan IPA Indonesia, 10*(1), 138-148.

Scribner, J. A. (2017). *A comparative study of educator backgrounds and their effect on student understanding of the engineering design process and engineering careers, utilizing an underwater robotics program (RTP).* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Sejati, B. K., Firman, H., & Kaniawati, I. (2017). *STEM-based workbook: Enhancing students' STEM competencies on a lever system.* Paper presented at the AIP Conference Proceedings.

Shahali, E. H. M., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2017). STEM learning through engineering design: Impact on middle secondary students' interest towards STEM. *Eurasia Journal of Mathematics, Science and Technology Education, 13*(5), 1189-1211.

Siew, N. M. (2017). Fostering students' scientific imagination in stem through an engineering design process. *Problems of Education in the 21st Century, 75*(4), 375-393.

Silvestri, K. N., McVee, M. B., Jarmark, C. J., Shanahan, L. E., Pytlak-Surdyke, M., & English, K. (2019). Teacher identity in an after-school engineering club: Navigating border crossing in an unfamiliar community of practice. *Elementary School Journal, 120*(1), 1-31.

So, S. (2018). *Developing the STEM experience for in-service primary teachers through micro-controlling hardware and coding.* Paper presented at the 2018 17th International Conference on Information Technology Based Higher Education and Training, ITHET 2018.

Tang Dan, R. B., & Patel, M. (2020). *Development of an advanced robotics program for middle and high school VEX robotics students.* Paper presented at the Proceedings of the LACCEI International Multi-conference for Engineering, Education and Technology.

Teevasuthonsakul, C., Yuvanatheeme, V., Sriput, V., & Suwandecha, S. (2017). *Design Steps for Physic STEM Education Learning in Secondary School.* Paper presented at the Journal of Physics: Conference Series.

Traum, M. J., & Karackattu, S. L. (2019). *'It's nothing like October sky!': Spurring 9th & 10th graders to think like engineers via rockets custom-designed for maximum altitude.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Tseng, T. H., Tai, Y., Tsai, S. P., & Ting, Y. L. (2018). Students’ self-authoring mobile App for integrative learning of STEM. *International Journal of Electrical Engineering Education*. doi:10.1177/0020720918800438

Vela, K., Caldwell, C., Capraro, R. M., & Capraro, M. M. (2019). *The Nexus of Confidence and Gender in an Engineering Project-Based STEM Camp.* Paper presented at the Proceedings - Frontiers in Education Conference, FIE.

Walsh, D., & Downe, S. (2004). Meta-synthesis method for qualitative research: a literature review. *Methodological Issues in Nursing Research, 50*.

White, V. M., Alexander, J. H., & Prince, D. (2017). *Mississippi BEST robotics: An analysis of impact and outcomes on student performance and perceptions towards earning STEM degrees.* Paper presented at the ASEE Annual Conference and Exposition, Conference Proceedings.

Yen, W. H., & Chang, C. C. (2020) How Engineering Design Ability Improve via Project-Based Truss Tower STEM Course? In*: Vol. 12555 LNCS. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (pp. 567-575).

Zeid, A. (2020). Deploying engineering-based learning in high school students stem learning. *Athens Journal of Education, 7*(3), 255-272.

Zhou, N., Pereira, N. L., George, T. T., Alperovich, J., Booth, J., Chandrasegaran, S., Ramani, K. (2017). The Influence of Toy Design Activities on Middle School Students’ Understanding of the Engineering Design Processes. *Journal of Science Education and Technology, 26*(5), 481-493.