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Engineering Design Process in Stem Education: A Systematic Review

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Abstract

Engineering Design Process (EDP) is one of the strategies available to implement STEM education. 37 selected articles we systemically reviewed following the Five Stages framework to extract EDP effectiveness in school setting. Information was arranged in the following sequence: kind of research, designed product, measured variables, effectiveness result and characteristics of STEM teaching and learning. It is hoped that this review provides a guide for STEM education to design their owned classroom lesson using EDP and measure its effectiveness following examples in the comprehensive list analyzed in this paper.

Keywords: Engineering Design Process, Stem Education, EDP, Stem Teaching And Learning, Designed Product

Introduction

In recent years, engineering design process (EDP) has been utilized by many STEM-related subjects' educators as a mean to implement STEM. The mass availability of research that examines the effectiveness of EDP in STEM education definitely proved its significance. Various definitions for engineering design are available. For instance, National Research Council(2009) defined engineering design as "a purposeful, iterative process with an explicit goal governed by specifications and constraints"(p.82). In another study, Dym, Agogino, Eris, Frey, & Leifer, (2005) defined engineering design as a systematic process that require the application of concepts to create a device or system that can fulfill the given objective under specified constraints. Engineering design is about a properly designed process toward achieving a specific learning goal. Specific to the application in STEM education relevant to this review, engineering design process is a pedagogical strategy that requires students to follow a set of steps to create the most effective solution that is iteratively tested and justified by mathematical and scientific concept.

A typical EDP incorporates the following steps: (1) defining problem; (2) systematic selection of solution; (3) modeling and analyzing; and (4) repetition of design process (Berland, Steingut, & Ko, 2014). The steps involved in EDP can enhance student's ability to apply science and mathematics concepts in solving real-world problems significantly (English & King, 2015). While conducting a systematic selection in EDP, students need to apply STEM content to justify the design solution. An effective EDP can also increase students engagement and interest, that is vital to master the content of all disciplines in STEM (National Academy of Engineering and National Research Council [NAE & NRC], 2014). The nature of EDP also enables the connections between all STEM disciplines to be explicitly identified (Estapa & Tank, 2017).

In this study, a review of academic literature on EDP in STEM education at the school level is presented. The aim of this study is to provide the state-of-the-art of empirical work on EDP in STEM education. Furthermore, this study is meant to examine the true potential of EDP to be utilized as STEM teaching and learning approach. The sections of this paper are organized as follows: methodology on carrying this review, results of the literature search guided by research questions and review conclusions as well as suggestion for extended research. The focus of this review are the identification of research design and measured variable to measure the effectiveness of the designed EDP module, designed product of the module, the result of EDP implementation and STEM characteristics fulfillment in the module from reported studies. An attempt was made to search for the relevant studies reported in Malaysia. This review lists an extensive research-based EDP strategy example as a guide for STEM educators to design their own lesson. Various research design employed in these studies provide choices of method for educator to measure effectiveness of their designed lesson in their classroom for example through action research for continuous improvement.

Related Works

To-date, only a limited number of reviews on the utilization of EDP as a mean to implement STEM education in school setting is available. Guzey, Moore, & Harwell, (2016) conducted an analysis on engineering design-based curricular materials that have been developed by teachers to integrate STEM. In another study, Lammi, Denson, & Asunda, (2018) did a literature review on engineering design challenges in secondary school settings to identify the features of EDP. In another similar work, Thibaut et al., (2018) provided a review of instructional practices of integrated STEM education in secondary education. None of the reviews has analyzed the effectiveness and suitability of EDP for STEM education. Therefore, this review is carried out to analyze the current empirical studies embracing EDP to illustrate the potential of EDP to be utilized in STEM education.

Methodology

The Five Stages framework proposed by Arksey & O'Malley, (2005) was employed to perform this review to ensure the reliability of the findings. In Stage 1, research questions were identified. The research questions provide direction and limitation of this review. These are as follow:

Q1 *What kind of research 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 measured variables to prove the effectiveness of EDP in STEM education?*

Q4 *What were the effectiveness results of the studies that have employed EDP in STEM education?*

Q5 *How many STEM teaching and learning characteristics were observed in each of the reported study to EDP in STEM education?*

In Stage 2, relevant studies were identified by keyword search in two academic databases namely Springerlink and MyCite. Springerlink was chosen as the database due to the availability of profuse number of articles related to STEM education. The second database was chosen to provide local insight of the current STEM education practices in Malaysia. It is worth to note that Malaysia is making a transition from English to Malay as medium of instruction in Science and Mathematics in school (Ghani & Ayop, 2018). Thus, reported studies in Malaysia written in Malay language might be available in journals registered in MyCite.

Springerlink database was browsed using combinations of search terms: "STEM education","engineering design" and "school". Meanwhile, for literature in Malay language, the following terms were used: "Pendidikan STEM", "reka bentuk kejuruteraan"and "sekolah". The literature search terms in English lead to 4,417 search hits. The search hits were further refined by using the filter "article only", "education" and "science education". The filtering process resulted in 547 search hits. Unfortunately, there was none search hits returned for the search in Malay.

For MyCite literature search, the same procedure was implemented. The English search terms lead to only 3 search hits and search using Malay returned only one search hit. The single search hit eventually was found to be overlapping with one of the previous three search hits. All the search hits from both databases were selected within the publication year of 2014-2019 to indicate the recentness of reported studies.

In Stage 3, relevant studies were evaluated and selected from the search hits. The search from both databases resulted in the total of 550 search hits. Through title and abstract screening, this number is further decreased to 88 articles. The 462 articles were irrelevant due to the type of article and research focus. For instance, the articles obtained were commentary, review, and most of the articles were focused on teacher's professional development.

Another detailed inclusion criteria were set. First, the entire selected articles must provide a clear description of the instruction of STEM teaching and learning. Second, the article has to clearly describe the methodology that was employed throughout the entire research. Thirdly, the article must focus on the impact of STEM teaching and learning approach within a school setting. Studies involved in tertiary education setting were also omitted. The inclusion criteria resulted in 37 articles.

In Stage 4, all the data acquired were charted to provide ease in obtaining the result. The data were charted in such a way to provide answers to the predetermined research questions.

Finally, in Stage 5, the results obtained thru charting were collated, summarized and reported in an appropriate manner.

Results and Discussion

Table 1 tabulates extracted information from 37 selected articles about the EDP utilization in STEM education to answer Q1, Q2, Q3 and Q4. The articles were categorized to authors, research design, research method, designed product, measured variable (s) and effectiveness.

Table 1
Studies on EDP utilization in STEM education

#	Authors	Research Design	Research Method[#]				Designed Product	Measured Variable(s)	Effectiveness
			T	I	Q	O			
1	(Fan & Yu, 2017)	Quasi experiment	✓	✓		✓	Mechanism toy	Conceptual knowledge, Higher-order thinking skills	Positive
2	(Hernandez et al., 2014)	Causal-comparative design*			✓		iPod docking station	Perception of interconnected STEM content knowledge	Positive
3	(English & King, 2015)	Longitudinal design		✓		✓	3D model plane	Design levels, application of disciplinary knowledge	Mixed
4	(S. Selcen Guzey, Moore, Harwell, & Moreno, 2016)	Correlational design	✓		✓		Loon bird nest	Understanding of engineering and attitudes towards stem	Positive
5	(Barrett, Moran, & Woods, 2014)	Quasi experiment *	✓				Wood house model	Weather knowledge and understanding	Mixed
6	(Fan, Yu, & Lou, 2017)	Design-based research	✓		✓	✓	Crank and cam toy	Mechanical conceptual knowledge, engineering design practice, attitudes towards stem	Mixed
7	(Hathcock, Dickerson,	Case study		✓		✓	Buoy	Creativity in solving ill-	Positive

	Eckhoff, & Katsioloudis, 2015)							structured problem	
8	(Duran, Höft, Lawson, Medjahed, & Orady, 2014)	Case study, quasi experiment *		✓	✓	✓	GPS system, web-based games, mathematical models, robots,	Attitudes towards stem, technology skills, IT STEM usage, understanding of IT usage in STEM, STEM career choice	Mixed
9	(Goktepe Yildiz & Ozdemir, 2018)	Quasi experiment, case study *	✓			✓	Food containers	Spatial abilities	Positive
10	(Lie, Selcen Guzey, & Moore, 2018)	Correlational design	✓		✓		Solution to prevent cross-contamination of GMO corn	Engineering content knowledge, STEM learning attitudes	Mixed
11	(Moreno, Tharp, Vogt, Newell, & Burnett, 2016)	Quasi experiment *	✓		✓		Rocket and space helmets	STEM knowledge	Positive
12	(English, 2018)	Longitudinal, design research study		✓		✓	Shoes	Students learning while designing	Positive
13	(Gomoll, Hmelo-Silver, Šabanović, & Francisco, 2016)	Case study*		✓		✓	Telepresence robot	STEM engagement and interest development	Positive
14	(Strimel, Bartholomew, Kim, &	Case study				✓	Bug box, bug trap, animal shade, carrying	Engineering design cognition and	Positive

	Zhang, 2018)						device, secret message device, and protection device for soldier	achievement	
15	(McFadden & Roehrig, 2018)	Case study		✓		✓	Mining tools model	Student discourse patterns during an engineering design challenge	Mixed
16	(Jackson, Mentzer, & Kramer-Bottiglio, 2018)	Quasi experiment			✓		Soft robot	Perception on self-efficacy, motivation, and interest	Mixed
17	(Miller & Roehrig, 2018)	Case study		✓			Snow snake prototype	Students meaning making, impact on community	Positive
18	(Leonard et al., 2016)	Quasi experiment			✓	✓	Robot, computer game	Self-efficacy in technology, attitude toward STEM, computational thinking strategies	Mixed
19	(Todd & Zvoch, 2017)	Quasi experiment*, case study*		✓	✓	✓	Pinball tables	Science affinities	Mixed
20	(Berland et al., 2014)	Case study*, causal-comparative design*		✓		✓	Pinhole camera, aerial imaging system, wind turbine, robotic	Perception toward engineering design process	Mixed

							vehicles		
21	(Roberts et al., 2018)	Naturalistic inquiry, phenomeno-logical approach		✓		✓	Robotics, multiple shape structure, water flow system	Perceptions towards STEM	Positive
22	(Zhou et al., 2017)	Quasi experiment *, case study *			✓	✓	Marshmallow tower, foil boat, fan boat, trebuchet	Self-efficacy and understanding of engineering design process	Positive
23	(Simpson, Burris, & Maltese, 2017)	Case study*			✓		Torch light, light-up greeting card and bookmark, electrical LEGO models	Engagement in science and engineering practices	Positive
24	(Chittum, Jones, Akalin, & Schram, 2017)	Case study*, quasi experiment *		✓	✓		Better-insulated house model, mini solar powered car	Beliefs about science, motivation and engagement	Positive
25	(Dickerson, Eckhoff, Stewart, Chappell, & Hathcock, 2014)	Case study, causal-comparative design*	✓	✓		✓	Maps, film-making, rocket	Reading and math scores, attitudes and perceptions regarding STEM education and careers	Mixed
26	(Evans, Lopez, Maddox, Drape, & Duke, 2014)	Case study		✓		✓	Solar powered car	STEM interest and motivation	Positive
2	(Barak &	Case	✓	✓	✓	✓	Robot	Working	Mixed

7	Assal, 2018)	study*, quasi experiment *						patterns, achievements in learning, students' motivation to learn STEM	
28	(Christensen, Knezek, & Tyler-Wood, 2015)	Quasi experiment *			✓		Remote controlled robot	STEM dispositions	Positive
29	(Purzer, Goldstein, Adams, Xie, & Nourian, 2015)	Case study				✓	Energy - efficient , passive solar virtual building	Meaningful science learning (Design behaviors and scientific explanations)	Mixed
30	(Julià & Antolí, 2018)	Quasi experiment *			✓		Hand dryer, vehicle model	Four motivational factors: attention, relevance, confidence and satisfaction	Positive
31	(Mentzer, Huffman, & Thayer, 2014)	Quasi experiment *, case study		✓	✓	✓	Playground plan	Engineering identity development, mathematical modelling	Mixed
32	(Capobianco, Yu, & French, 2015)	Quasi experiment		✓	✓		Play dough, LEGO dancing birds, LEGO crawler	Engineering identity development	Mixed
33	(Sullivan & Bers, 2018)	Case study*, quasi experiment *			✓	✓	KIBO robot	Attitudes and interest toward technology and	Positive

								engineering	
34	(Bartholomew & Strimel, 2018)	Case study*, causal-comparative design*		✓	✓	✓	Pill dispenser	open-ended design assignment achievement, perceptions of engineering design	Mixed
35	(Schnittka, Evans, Won, & Drape, 2016)	Case study*, quasi experiment*	✓	✓		✓	Heat resistant structure	Understanding of science concept	Mixed
36	(Bahrum & Ibrahim, 2018)	Case study		✓		✓	Insect puppet, solar system diorama	Usability of STEM in art subject	Positive
37	(Tek, Safiee, Jusoh, Salleh, & Nor, 2017)	Case study*, quasi experiment*		✓		✓	Magnet train carriage model	Attitudes towards science	Positive

#T= Test, I= Interview, Q=Questionnaire, O=Observation
*not explicitly mentioned; classification was made by referring to Piaw, (2016)

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

Table 2 tabulates the frequency for research design used by the reported studies listed in Table 1. Several studies were counted twice due to the combination of research designs being used. It was found that the case study is the most utilized research design. The case study design is employed by researcher to uncover in-depth information on behavior, environment, and changes that might revolve around them (Piaw, 2016). Even though the result of the case study could not be generalized, each individual studies contribute toward the understanding of EDP practice in STEM education. This is followed by quasi-experimental design perhaps due to limitation on selecting random sampling.

Table 2
Frequency of research design used in the reported studies

Research Design	#	Frequency
Case study	7,8*,9* ,11, 13, 14, 15, 17,19, 20*, 22, 23, 24*, 25*, 26, 27*, 29, 31*, 33*, 34*, 35*,36, 37*	23

Quasi experiment	1, 5, 8*,9*, 16, 18,19, 22, 24*, 27*, 28, 30,31*, 32, 33*, 37*	16
Correlational design	4, 10,	2
Causal-comparative design	2, 20*, 25*, 34*, 35*	5
Longitudinal design	3, 12	2
Design based research	6	1
Naturalistic inquiry	21	1
Total number of research design		50

*counted twice

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

EDP requires student to find solutions for a given task, usually regarding a tangible product. Table 3 categorized the designed products in the reported studies. Categorization was made following the Research and Markets website (www.researchandmarkets.com). The website is chosen due to the contemporaneity and variety of industrial category covered. The categories of product were chosen such that it matches the current industrial category to show the relatedness of EDP product with real-world application. The total number of product category was more than 37 because several studies have designed more than one product category.

It is found that robotics is the most commonly designed product category (10 studies).A tangible product or model is one of the measurable outcomes of the EDP. Learning takes place around the existence or improvement of the product .The popularity of robotics as a targeted product in EDP is due the tangibility of robots and the excitement roused by it can certainly create a conducive learning environment (Karim, Lemaignan, & Mondada, 2015). STEM teaching and learning that utilized EDP involved in robotics were also made possible by collaboration with local universities that provided teachers with training and educational materials. The next popular products were consumer electronics (5 studies) and architecture and urban planning (4).

Table 3
Designed product category in the reported studies

Category	#	Frequency
Robotics	8*, 13, 16, 18*, 20*, 21*, 27, 28, 32*, 33	10
Gaming	8*, 18*	2
Consumer electronics	2, 20*, 23*, 25*, 30*	5
Software	8*	1
Electrical hybrid vehicle	24*, 26	2

Automotive manufacturing	30*	1
Maritime	7, 22*	2
Aircraft	3	1
Rail	37	1
Commercial aerospace	11, 25*	2
Infantry equipment	14*	1
Mining	15	1
Renewable energy	20*	1
Pest control product	14*	1
Biotechnology	4, 10	2
Residential construction	5, 24*, 35*	3
Architecture and urban planning	21*, 22*, 29, 31	4
Office supply and equipment	23*	1
Personal care product	34	1
Clothing	12	1
Toys	6, 17, 19, 22*,23*, 32*, 36*	7
Packaging	9	1
Others	8*, 21*, 36*	3
Total number of products		54

*counted more than once

Q3 What were the measured variables to prove the effectiveness of EDP in STEM education?

Table 1 listed various variables were used to prove the effectiveness of EDP in STEM education. These variables were themed according to their original definition in Table 4. Thinking skills, test performance and content knowledge are often measured to illustrate the students' cognitive ability In order to measure effectiveness of EDP in STEM education. It is revealed that thinking was the most measured variable (13 studies).

Apart from cognitive, it is found affinities variables were also popular. In measuring STEM affinities, traits such as student's attitudes, perception, motivation and interest towards STEM were measured in most of the studies. Unfortunately, there are minor presence of studies that were focusing in assessing student's non-cognitive skills and values. Probably, this is due to the fact that skills and values based assessment requires the instructor to constantly monitor the students' behavior during EDP instruction. Furthermore, according to Duckworth & Yeager, (2015), assessment based on observing students behavior while completing a task must be administered under highly controlled conditions and intend to create bias. Hence, most instructors found it complicated to be administered and the validity of assessment can be questioned.

Table 4
Measured variables

Variable (s)	#	Frequency
	Cognitive	
Knowledge	1*, 5*, 6*, 8*, 10, 11,	6
Thinking	1*, 3*, 4*, 5*, 7, 8*, 9, 14* , 15, 18*, 22*, 31*, 35	13
Performance	14*, 25*, 27*, 34*	4
	Non-cognitive	
Skills	3*, 6*, 8*, 27*	4
Values	28	1
Perception towards STEM	2, 20, 21, 24*, 25*, 34*36	7
Interest	8*, 12, 13*, 16*, 33*	5
Identities	19*, 31*, 32	3
Motivation	16, 19*, 27*	3
Engagement	13*, 17, 23, 24*, 29	5
Self-efficacy	16*, 18*, 22*	3
Attitude towards STEM	4*, 6*, 18*, 19, 25*, 33*, 37	7
Total number of variables		61

*counted more than once

Q4 what were the effectiveness results of the studies that have employed EDP in STEM education?

Utilizing the data from Table 1, Figure 1 is charted to show the number of studies that across different results. 21 from the 37 studies employing EDP in STEM education produced positive result and the rest in mixed result.

To determine whether the study have a positive, negative or mixed result, the indication was made based on the keyword or term used by the author in the respective study. Terms such as 'positive impact', 'positively affect', and show increase ', 'show promise', ' significant impact', 'show gains', 'more positive', or 'positive' in the result or findings were considered to have yielded positive results. Keyword such as 'foster' , 'rich' , 'stimulate', 'improve', 'successful' or any other keyword that might suggest a positive outcome were also considered to be positive. On the contrary, the studies that have resulted in a combination of increase, decrease and no significant change across different variables or demographic groups are considered to have mixed results. Finally, in order to classify a negative result, keyword such as 'decrease', 'drop', 'ineffective' and 'negative result' were considered to reflect such outcome. Neutral result is considered if for instance the study resulted in no significant change or equal performance in pre-test and post-test.

More than 50% of the reported studies have shown positive effectiveness. For example, Capobianco et al., (2015) found that students who were involved in engineering design-based science learning activities demonstrated greater improvements in the Engineering Identity Development Subscales (EIDS) compared to those in control group. Similarly, Chittum et al., (2017) have found that participants of an afterschool STEM program that used design approach in problem solving have higher rating of their values for science and science competence compared to the non-participants. The participants also demonstrated higher motivational beliefs about science. In another research, by Goktepe Yildiz & Ozdemir (2018), they have concluded that engineering design-based mathematics activities have positive effect on the development of spatial abilities of grade 8 students. The mean rank scores of spatial abilities obtained by the experiment group were higher than the control group. These findings strengthen the prospect of EDP to be used for STEM teaching and learning approach since it shows huge potential towards development of students' cognitive and non-cognitive attributes.

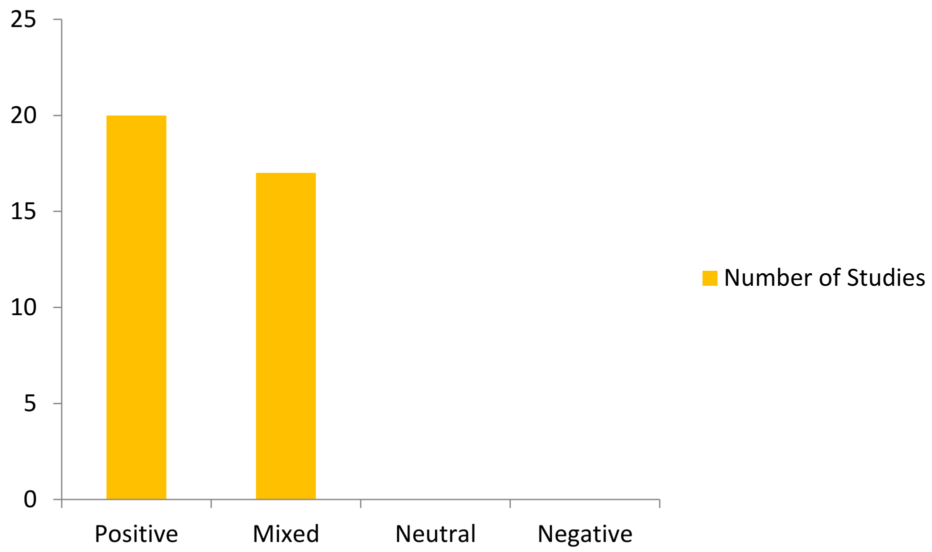

Figure 1. Effectiveness result in 37 reported studies

Q5 How many STEM teaching and learning characteristics were observed in each of the reported study to EDP in STEM education?

Curriculum Development Division Ministry of Education Malaysia, (2016) outlined seven characteristics of STEM teaching and learning. This outline provides guideline for educator to design their lesson so that it fit the aspiration of STEM education. Ideally, effective STEM teaching and learning should "capitalize" on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest" (p.18, National Research Council, 2011).Therefore, STEM teaching and learning should have the following characteristics: (1)

increase students' awareness towards real-world problems and issues; (2) involve students in open inquiry and discovery;(3) involve students in productive group work; (4) requires the students to apply STEM content ; (5) provide the opportunity for students to improve their answer or solution, (6) involve students in applying their designing skills; and (7) requires students to give out multiple answer and solution with justification(p.14, Curriculum Development Divison Ministry of Education Malaysia, 2016).

Table 5 maps the reported studies to those characteristics. Frequency of characteristics in each study was counted. The number of studies which showed number of characteristics is summarized in Figure 2. More than 70% of the study posed at least six out the seven characteristics explicitly in their article.

Table 5
Mapping of the reported studies to the characteristics of STEM teaching and learning.

No	Authors	Real-world	Inquiry/open	Group	Application of STEM	Product improvem	Designing skills	Justification of
1	(Fan & Yu, 2017)	✓	✓		✓	✓	✓	
2	(Hernandez et al., 2014)	✓	✓	✓	✓	✓	✓	✓
3	(English & King, 2015)	✓	✓	✓	✓	✓	✓	✓
4	(S. Selcen Guzey et al., 2016)	✓	✓		✓	✓	✓	✓
5	(Barrett et al., 2014)	✓	✓	✓	✓	✓	✓	✓
6	(Fan et al., 2017)	✓	✓		✓	✓	✓	✓
7	(Hathcock et al., 2015)	✓	✓	✓	✓	✓	✓	✓
8	(Duran et al., 2014)	✓	✓	✓	✓	✓	✓	✓
9	(Goktepe Yildiz & Ozdemir, 2018)	✓	✓		✓	✓	✓	✓
10	(Lie et al., 2018)	✓	✓	✓	✓	✓	✓	✓
11	(Moreno et al., 2016)	✓	✓	✓	✓	✓	✓	✓
12	(English, 2018)	✓	✓	✓	✓	✓	✓	✓
13	(Gomoll et al., 2016)	✓	✓	✓	✓	✓	✓	✓
14	(Strimel et al., 2018)	✓	✓	✓	✓		✓	
15	(McFadden & Roehrig, 2018)	✓	✓	✓	✓	✓	✓	✓
16	(Jackson et al., 2018)	✓	✓	✓	✓	✓	✓	✓
17	(Miller & Roehrig, 2018)	✓	✓		✓	✓	✓	✓
18	(Leonard et al., 2016)	✓	✓		✓		✓	

19	(Todd & Zvoch, 2017)	✓	✓	✓	✓		✓	
20	(Berland et al., 2014)	✓	✓		✓	✓	✓	✓
21	(Roberts et al., 2018)	✓	✓		✓	✓	✓	
22	(Zhou et al., 2017)	✓	✓	✓	✓	✓	✓	✓
23	(Simpson et al., 2017)	✓	✓		✓	✓	✓	✓
24	(Chittum et al., 2017)	✓	✓	✓	✓	✓	✓	
25	(Dickerson et al., 2014)	✓	✓		✓		✓	
26	(Evans et al., 2014)	✓	✓	✓	✓	✓	✓	✓
27	(Barak & Assal, 2018)	✓	✓	✓	✓		✓	
28	(Christensen et al., 2015)	✓	✓		✓		✓	✓
29	(Purzer et al., 2015)	✓	✓		✓	✓	✓	✓
30	(Julià & Antolí, 2018)	✓	✓	✓	✓	✓	✓	
31	(Mentzer et al., 2014)	✓	✓		✓		✓	✓
32	(Capobianco et al., 2015)	✓	✓	✓	✓	✓	✓	
33	(Sullivan & Bers, 2018)	✓	✓	✓	✓		✓	
34	(Bartholomew & Strimel, 2018)	✓	✓	✓	✓	✓	✓	✓
35	(Schnittka et al., 2016)		✓	✓	✓	✓	✓	
36	(Bahrum & Ibrahim, 2018)	✓	✓	✓	✓	✓	✓	
37	(Tek et al., 2017)	✓	✓	✓	✓	✓	✓	✓

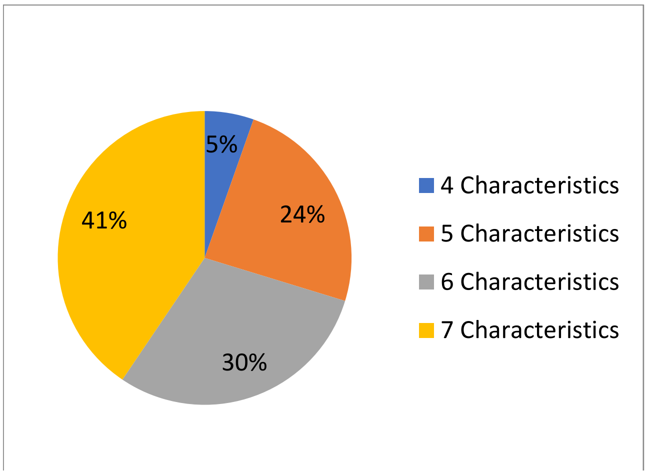

Figure 2. Fulfillment of STEM teaching and learning characteristics

Typically, a STEM teaching and learning that utilizes EDP starts with the introduction of an open-ended design problem. The use of open-ended problems in EDP is to provide real-world industry practices, as well as providing students with more flexibility and choice (Mawson, 2003). In EDP, students are required to work collaboratively in a group. According to English, King, & Smeed, (2017), collaborative group work as well as exchange of ideas plays a significant role in problem solving and can be clearly exhibited in group interactions.

In EDP, the solution to a problem usually will require students to develop models. A model can be in any form that includes graphical, physical, or mathematical representation of the essential features of a system or process that facilitates engineering design (NAE in Mentzer et al., 2014). Thru modeling, students are provided with the opportunity to display an array of STEM skills and knowledge, while iteratively designing and improving their solution. Furthermore, EDP provides the opportunity for students to embark on an inquiry and open discovery. This feature can be further improved by questioning. Questioning by the instructor is crucially important in STEM teaching and learning as part of inquiry process. Apart from being an impeccable assessment tool, the incorporation of questioning in EDP also encourages students to think, analyze, and further justify the design of their solution (Hathcock et al., 2015).

The STEM teaching and learning characteristics fulfillment by utilization of EDP demonstrates the EDP should be used in STEM education. Moreover, EDP can positively affects students STEM cognition and non-cognition traits that is essential in achieving STEM literacy. There is a need to utilize EDP in school not only to increase students' performance but to overcome the limited STEM awareness of STEM among teachers and students. This corroborated the recommendations made by (Meng & Idris, 2016) that encourages EDP to be given greater emphasis in secondary school in order to promote STEM.

Teachers should consider utilizing EDP in teaching and learning; despite the lack of engineering qualifications and professional expertise within the school setting. The most important aspect to utilize EDP is by having the knowledge of the steps involved in EDP and the skills to incorporate the essential content in each steps. Additionally, teachers must take into consideration the practicality of the product to be designed in STEM teaching and learning. The product design is not necessarily have to be popular and expensive, but should engage students with real-world problem solving. Inexpensive things should as recyclable boxes, bottles and papers can be used to carry out EDP, but teachers need to wisely decide the end product to be designed by the students that will fulfill the objective of the STEM lesson.

The utilization of EDP such as in science education, it will create the opportunity for the students to apply science knowledge and scientific inquiry in an authentic context; as well as learning mathematical reasoning to make decision(Kelley & Knowles, 2016). Nevertheless; teachers should have the creativity and discretion to choose the appropriate science and mathematical concepts to be utilized in EDP to ensure the alignment with the standard curriculum. Teachers also encourage incorporating technology in EDP, either as analyzing tools or simply as communication tools that work as a bridge between the group members, parents, and community.

In retrospect, EDP is utilized by many studies mainly because the flexibility in choosing the research design and the variables to assess, as shown in the result. The characteristics of teaching and learning featured enables students to engage in solving real-world problems, by applying the necessary STEM knowledge and skills. There is abundant research related to the utilization of EDP in STEM education. However, there are still a vast array of opportunities to improve the quality and outcome of utilizing EDP in STEM teaching and learning. The review of literature revealed that there seemed to be limited research number of research on the impact of STEM teaching and learning approach towards other attributes; particularly, STEM skills and STEM values. Therefore, there's a need to conduct this study, especially in the Malaysian context; since it is a common belief that STEM literacy can only be achieved thru STEM practice that integrate STEM knowledge, STEM skills and STEM values (Curriculum Development Division Ministry of Education Malaysia, 2016). The proposed research can either assess the effectiveness of EDP as a STEM teaching and learning towards improving these three elements simultaneously or simply to assess the level of students' application of all three elements in a STEM teaching and learning approach.

Conclusions

This study analyzed selected 37 references on STEM teaching and learning approach that utilizes engineering design process (EDP) within the school context from two databases, Springerlink and MyCite. The most employed research design was case study. The popular designed product in EDP implementation was robotics. Cognitive-related variables such as knowledge and thinking were mostly measured to show the effectiveness of the EDP. Implementation of EDP in STEM education showed positive measurable effectiveness. 71% of the reported studies showed more than six out of seven characteristics of STEM teaching and learning.

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