

## Synthesizing Results from Empirical Research on Engineering Design Process in Science Education: A Systematic Literature Review

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### Abstract

We reviewed 48 articles related to the engineering design process in science education published from 2010 to 2020. There are several previous literature review studies that analyzed the engineering design process in science education. However, we have not found any that investigates projects, discussed topics, as well as the benefits of the implementation of the engineering design process in science education. The research method used was a systematic literature review. This study analyzed the characteristics of the content based on year of publication, type of publications, countries that implement it, research approach, educational stage, and science content. The findings show that the projects used in the implementation of the engineering design processes in science education varied according to the discussed topics. The benefits of the implementation of the engineering design process in science education include cognitive benefits, procedural (skills) benefits, attitudinal benefits, and a combination of the three benefits.

**Keywords:** engineering design process, STEM education, science education, systematic reviews

### INTRODUCTION

The implementation of Science, Technology, Engineering, and Mathematics (STEM) education through the engineering process has become more acknowledged in the field of education (Fan & Yu, 2015). Banko, Grant, Jabot, McCormack, and O'Brien (2013) assert that the Next Generation Science Standards (NGSS) can be used as an alternative in the reform of science education as of now. The implementation of the NGSS emphasizes the integration between engineering and science learning in schools. In addition, engineering design in the implementation of NGSS can increase student motivation, creative thinking skills, and the ability to connect science with engineering. Moreover, the engineering design process is one of the crucial parts of STEM education (Lin, Hsiao, Chang, Chien & Wu, 2018). Atman et al. (2007) state that engineering design is

one of the competencies needed by students in engineering education. According to Nurtanto, Pardjono, Widarto, and Ramdani (2020), the engineering competence of students in vocational high schools can be improved by incorporating the engineering design process in their learning. Based on the results of these studies, the current K-12 reform of education emphasizes science education that is integrated with engineering design (Guzey, Ring-Whalen, Harwell, & Peralta, 2017). Many countries have underlined the account of engineering in science education (Crotty et al., 2017). Furthermore, Guzey, Moore, Harwell, and Moreno (2016) also claims that the engineering design process is a new vision in science education. In addition, according to Lie, Aranda, Guzey, and Moore (2019), the engineering design process implemented in science learning can improve students' creative thinking and interdisciplinary abilities. Thus, the engineering design

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### Contribution to the literature

- Previous literature review study focused on the implementation of the engineering design processes in the K-12 science classrooms. However, this study aims to investigate projects, topics, and benefits of the implementation of the engineering design process in science education. This research is not limited to K-12 science classrooms, but this study investigates various levels of education, such as students, undergraduate or graduate students, and teachers.
- This research can be used as a reference for all stakeholders involved in science education.
- The results of this study can encourage science educators and other fields to implement the engineering design process in their learning.

process is not only applicable in engineering education, but it can also be implemented in science education.

Studies that integrate the engineering design process in science education have been carried out in several countries. Many of the aforementioned studies use various research approaches, such as mixed methods, quantitative, and qualitative. With the use of mixed-method research approach, some studies aim to investigate: the influence of the engineering design process on students' situational interest (Dohn, 2013); students' perceptions of engineering and technology (Hammack, Ivey, Utley, & High, 2015); efficacy (Maeng, Whitworth, Gonczi, Navy, & Wheeler, 2017); content knowledge (Marulcu, & Barnett, 2013); students' conceptions (Schnittka & Bell, 2011; Dankenbring & Capobianco, 2016); and students' ability in handling the complexity of a task (English, King, & Smeed, 2016). In addition, some studies related to the engineering design process are also used to investigate some variables in the research. The aforementioned studies aim to investigate: the influence of the engineering design process on students' achievement and interest (Guzey, Ring-Whalen, Harwell, & Peralta, 2017); students' understanding and self-efficacy (Zhou et al., 2017); as well as content knowledge, STEM conceptions, and engineering views (Aydin-Gunbatar, Tarkin-Celikkiran, Kutucu & Ekiz-Kiran, 2018). Furthermore, Berland et al. (2013) attempt to examine the way students implement science and mathematics to their engineering work.

In a quantitative research approach, some studies aim to investigate: the influence of the engineering design process on problem-solving skills (Syukri, Halim, Mohtar & Soewarno, 2018) and teachers' response (Pleasants, Olson, & De La Cruz, 2020); the influence of the engineering design process on engineering content and attitudes towards STEM (Lie, Guzey, & Moore, 2019); interest towards STEM subjects and career (Shahali, Halim, Rasul, Osman, & Zulkifeli, 2016); curiosity and scientific disciplines (Ward, Lyden, Fitzallen, & León de la Barra, 2016); as well as science attitudes, and science content knowledge (Wendell & Rogers, 2013). In addition, Fan and Yu (2015) examines the influence of the STEM approach within engineering design practices on conceptual knowledge, higher-order thinking skills, and design project activity. Yu, Wu, and

Fan (2019) also look into the influence of the engineering design process on science knowledge and critical thinking within the delivered design product.

With the use of the qualitative research approach, some studies intend to analyze: the application of the engineering design process as well as its influence on students' understanding (Park, Park, & Bates, 2016; Schnittka, 2012), on teachers' understandings (Mesutoglu, & Baran, 2020), on reflective decision-making (Wendell, Wright, & Paugh, 2017), on students' views of design (Lie, Aranda, Guzey, & Moore, 2019), the classroom discourse (McFadden & Roehrig, 2018), and on problem-solving skills (English, Hudson, & Dawes, 2013). Some researches also examine the influence of the engineering design process on the generation of ideas and design thinking (English, Hudson, & Dawes, 2012), on the subject matter and pedagogical content knowledge (Hynes, 2012), as well as on mindful planning and students' modeling practices (Bamberger & Cahill, 2013). Capobianco, DeLisi, and Radloff (2018) also explain the development of elementary science teachers when implementing the engineering design process. Additionally, Chiu and Linn (2011) delve into how students integrate mathematics and science into their engineering design work.

In addition to using a mixed-method, quantitative, and qualitative research approach, we also found some studies related to the engineering design process that uses the systematic literature review (meta-analysis) method. One literature review study found is intended to summarize information on learnings with the engineering process through project-oriented capstone courses (Dutson, Todd, Magleby, & Sorensen, 1997). In addition, Lammi, Denson, and Asunda (2018) review articles related to engineering design challenges in secondary school settings. A review of articles on the engineering design process in science learning is also carried out by Arik & Topçu (2020). Their review investigates the steps of design in the engineering design process that are used for learning. Although we have managed to find literature reviews that analyze the implementation of the engineering design process in science education. However, we have not found any previous literature review studies that aim to investigate which projects and topics are used in the

implementation of the engineering design process in science education. Furthermore, studies investigating the benefits of implementing the engineering design process in science education have also not been carried out by previous researchers.

Based on this explanation, there have been innovations in education that integrate the engineering design process in science education. However, students still experience difficulties in connecting the design projects that they develop with Science (Chao et al., 2017). Berland et al. (2013) also state that although students are able to apply science and mathematics to their engineering projects, the implementation in itself is still rather inconsistent. In addition to students, teachers also claim that teaching science using the engineering design process is challenging and, still, leads to several problems (Capobianco, 2011). These problems are most probably caused by the fact that engineering design is a new, unfamiliar concept to some teachers. Due to the newness of engineering design, science teachers may feel challenged when implementing engineering in science education (Guzey, Harwell, Moreno, Peralta, & Moore, 2016). In addition, science learning, as of now, still encounters several problems in various countries. The problems in learning science are that students regard science as difficult, less interesting, and have too many formulas (Zhang & He, 2012; Winarno, Rusdiana, Riandi, Susilowati, & Afifah, 2020). Ogunkola and Samuel (2011) also explain that students' perceptions of science lessons are abstract; this arises in spite of the fact that science lessons are closely related to everyday life so that students can observe science directly in their environment. Furthermore, according to Sun, Wang, Xie, & Boon (2014), they argue that the implementation of science learning in schools still does not meet the expected standards; that said, there is a need for learning innovations to improve the quality of learning.

From the aforementioned explanation, it can be concluded that the implementation of the engineering design process in science education has not achieved its expected merit. This is mainly due to the implementation process in the field that is still faced with challenges (Berland, Martin, Ko, Peacock, Rudolph, & Gulobski, 2013; Capobianco, 2011; Chao et al., 2017) as the engineering design process is a new, unfamiliar concept to most science teachers (Guzey, Harwell, Moreno, Peralta, & Moore, 2016). According to Dankenbring and Capobianco (2016), the current reform of education is based on the integration of science learnings through engineering practices. Based on these problems, learning innovations that are based on the engineering design process are expected to be an alternative solution to solve various problems in science education.

This research explains the characteristics of its content, such as year of publication, type of publication, countries that implement the engineering design process, research approach, educational stage, and

science content. The purpose of analyzing the characteristics of the content is to provide an overview of the articles analyzed in this study. Furthermore, we also investigated which projects and topics are used in previous studies in implementing the engineering design process in science education (Science, Physics, Chemistry, and Biology). In addition, the results of this study can provide a comprehensive explanation for stakeholders in the field of science education who will implement the engineering design process into their learning. For example, to teach the topic of "energy" by using the engineering design process, we will mention some alternative projects that are suitable for use on the topic of energy based on the results of the previous studies. Furthermore, this study also explains the benefits of the engineering design process in science education. The elaboration of the benefits of the engineering design process in science education is based on cognitive, procedural/skills, attitudinal benefits, and a combination of the aforementioned three benefits. Therefore, the results of this study are not only useful for stakeholders in the field of science education who will implement the engineering design process, but also for future researchers. We served the data in the form of tables so that readers will find it easier to comprehend. The results of previous research reveal that learning with the engineering design process had a positive effect on students (Kim, Oliver, & Kim, 2019).

Thus, a literature review study that discusses the engineering design process in science education is essential to be carried out. The results of this study are expected to be beneficial as reference for all stakeholders involved in science education, especially teachers, lecturers, or future researchers. In addition, the engineering design process can be used as an alternative learning approach in science education. The aim of this study was to review 48 articles related to the engineering design in science education that are published from 2010 to 2020. There are three research questions used to guide the process of this study:

1. How is the distribution of research based on the characteristics of the content?
2. What are the projects and discussed topics in the implementation of the engineering design process in science education?
3. What are the benefits of the engineering design process in science education?

## METHODS

### Research Design

The research method used in this study was a systematic literature review (Petticrew & Roberts, 2008). We chose 48 articles from highly-regarded journals published from 2010 to 2020. All journals chosen are indexed by Scopus and Web of Science (WoS). Scopus

**Table 1.** The stages of the review process

NO	Stages	Actions
1	Determining the research questions	Discussing the research questions among the writers based on the research theme that is the engineering design process in science education
2	Determining the criteria	We are determining the criteria of the articles to be shortlisted for review. The articles must be related to the engineering design process in science education and must be indexed by Scopus and Web of Science or just Scopus. The articles selected to be indexed by Scopus have at least a quartile 2 (Q2) category so that the quality of the articles is classified as excellent. In addition, we selected articles that are in English only.
3	Producing the protocol for the review	Generating a research framework for each section, starting from the title, introduction, method, results, discussion, and conclusion
4	Searching, screening, and selecting	Looking for journals from the highly-regarded publishers with the following keywords: engineering design process, engineering design, engineering design in science education, or STEM through the engineering design process. We were shortlisting articles based on the predetermined criteria. All articles must be published by international highly-regarded journals and related to the engineering design process in science education. If the articles did not meet these criteria, they were exempted from review. Discussing the validity and the reliability of the articles among authors Choosing articles that are relevant to the engineering design process in science education
5	Analyzing and interpreting	Reading and understanding the content of the chosen articles Analyzing the chosen articles for review according to the predetermined research questions Interpreting the results of the analysis in the form of tables and figures Discussing the results of the analysis as well as synthesizing it with the results of the previous studies
6	Producing the article	Writing a literature review article following the intended journal's format
7	Dissemination	Publishing the article to international journals

and Web of Science (WoS) were used as the basis for selecting articles because they are both reputable journal indexers. The articles published on Scopus and the Web of Science (WoS) are also of good quality and can be accounted for. This study aims to review 48 articles related to engineering design in science education.

### Research Procedure

In carrying out this study, there were seven stages of the review process: (1) Determining the research questions; (2) Determining the criteria; (3) Producing the protocol for the review; (4) Searching, screening, and selecting; (5) Analyzing and interpreting; (6) Producing the article; and (7) Dissemination (Bennett, Lubben, Hogarth, & Campbell, 2005; Borrego, Foster, & Froyd, 2014). The stages of the review process are elaborated in [Table 1](#).

### Data Collection

The articles chosen for review were published from January 2010 to April 2020. The highly-regarded publishers that were chosen are Taylor & Francis, Springer, Wiley, Cambridge, Elsevier, Emerald, Oxford, Sage, etc. We also looked for articles directly on the website of international journals. The keywords used were: "STEM approach", "STEM education", "engineering design", "engineering design process", "engineering design in science education" or "STEM through the engineering design process". There were about 393 articles found. However, only 48 articles met

our research criteria. The number of articles is symbolized by the letter "f" in the table. The shortlisted journals for review are to be found in [Table 2](#).

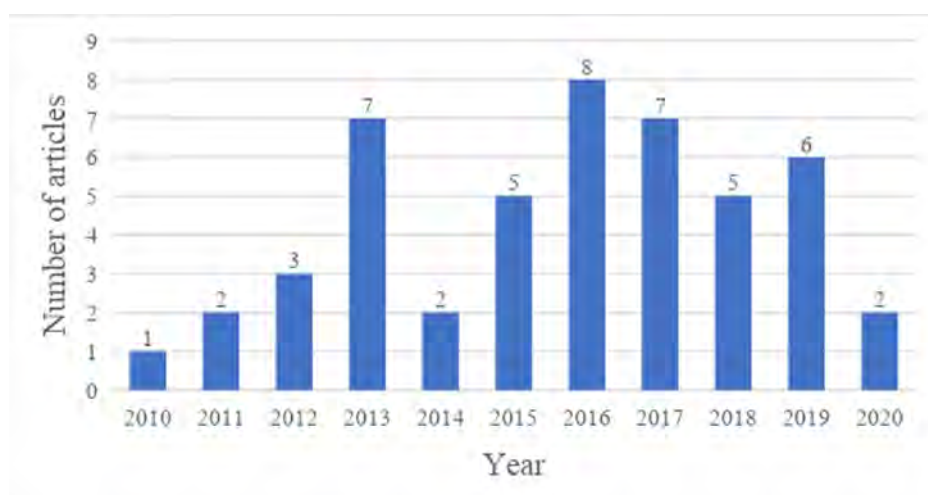
From [Table 2](#), it shows that out of 19 international journals, 15 journals are indexed by both Scopus and WoS, and the remaining four are indexed by Scopus only. Out of the 48 chosen articles, 38 articles are indexed by both Scopus and WoS, and the remaining ten are indexed by Scopus only. All chosen journals can be found in Scimago Journal & Country Rank ([Scimagojr.com](http://Scimagojr.com)). Scimago Journal & Country Rank states that the journals have high H-index. Also, most of the journals are indexed by Web of Science based on Clarivate Analytics. Therefore, it can be concluded that the articles chosen for this study are of good quality.

### Data Analysis

The data obtained in this study were analyzed with a descriptive approach. We classified the data in the form of tables and figures based on the predetermined research framework. The data was then discussed comprehensively and synthesized with the previous research. The focus of this study is to investigate the distribution of research based on the characteristics of the content, projects and discussed topics, and the benefits of the engineering design process in science education.

**Table 2.** The shortlisted articles for review

No	Name of journal	f	(%)	Indexed By	H-Index 2019 (SJR)
1	Journal of Research in Science Teaching	2	04.17	Scopus (Q1) & WoS	121
2	Science Education	2	04.17	Scopus (Q1) & WoS	108
3	International Journal of Science Education	6	12.50	Scopus (Q1) & WoS	102
4	Journal of Engineering Education	3	06.25	Scopus (Q1) & WoS	101
5	Journal of Educational Research	1	02.08	Scopus (Q1) & WoS	71
6	Instructional Science	1	02.08	Scopus (Q1) & WoS	68
7	Journal of Science Education and Technology	6	12.50	Scopus (Q1) & WoS	56
8	Research Science Education	3	06.25	Scopus (Q1) & WoS	50
9	European Journal of Engineering Education	1	02.08	Scopus (Q1) & WoS	41
10	Journal of Science Teacher Education	1	02.08	Scopus (Q1) & WoS	40
11	Chemistry Education Research and Practice	1	02.08	Scopus (Q1) & WoS	40
12	International Journal of Technology and Design Education	3	06.25	Scopus (Q1) & WoS	37
13	International Journal of Science and Mathematics Education	6	12.50	Scopus (Q1) & WoS	35
14	Computer Applications in Engineering Education	1	02.08	Scopus (Q1) & WoS	26
15	Journal of Baltic Science Education	1	02.08	Scopus (Q2) & WoS	14
16	Journal of Pre-College Engineering Education Research	7	14.58	Scopus (Q1)	8
17	Jurnal Pendidikan IPA Indonesia (Indonesian Journal of Science Education)	1	02.08	Scopus (Q2)	12
18	Eurasia Journal of Mathematics Science and Technology Education	1	02.08	Scopus (Q2)	31
19	Australasian Journal of Engineering Education	1	02.08	Scopus (Q2)	5
Total		48	100		



**Figure 1.** The distribution of research based on year of publication

**RESULTS**

**Research Question 1: How is the Distribution of Research Based on the Characteristics of the Content?**

The distribution of research is divided based on the following characteristics: year of publication, type of publication, countries that implement the engineering design process, research approach, educational stage, and science content.

*The distribution of research based on year of publication*

The distribution of research chosen for review ranged from 2010 to 2020. The complete data can be seen in [Figure 1](#).

From [Figure 1](#), it can be seen that the distribution varied each year: 1 article (02.08%) was published in

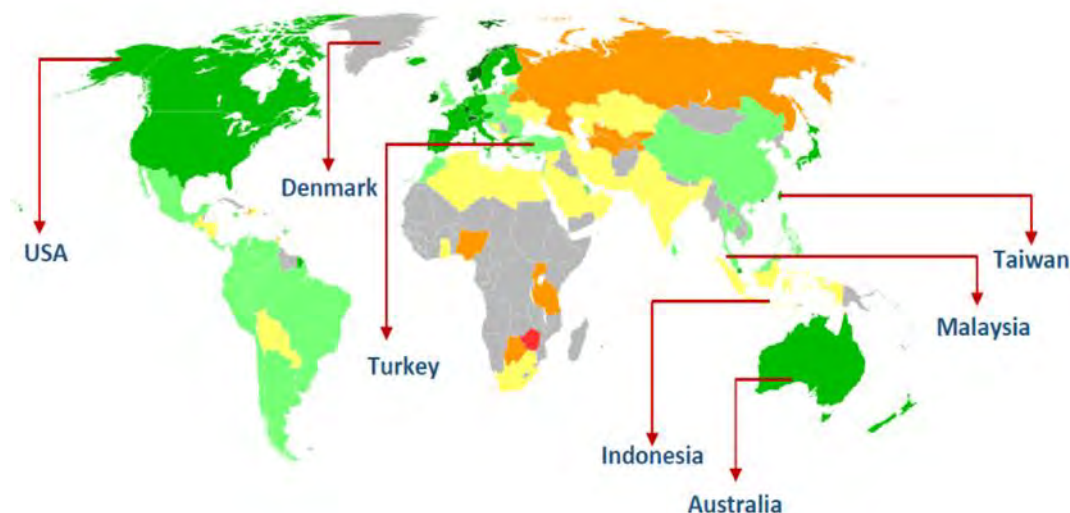
2010; 2 articles (04.17%) were published in 2011; 3 articles (06.25%) were published in 2012; 7 articles (14.58%) were published in 2013; 2 articles (04.17%) were published in 2014; 5 articles (10.42%) were published in 2015; 8 articles (16.67%) were published in 2016; 7 articles (14.58%) were published in 2017; 5 articles (10.42%) were published in 2018; 6 articles (12.50%) were published in 2019; and 2 articles (04.17%) were published in 2020. In conclusion, the highest number of reviewed articles was published in 2016, and the lowest number of reviewed articles was published in 2010.

*The distribution of research based on the type of publication*

The distribution of research based on the type of publication is divided into journal, proceeding, and thesis. The data can be seen in [Table 3](#).

**Table 3.** The distribution of research based on the type of publication

NO	Type of Publications	f	%
1	Journal	48	100
2	Proceeding	0	0
3	Thesis	0	0
Total		48	100

**Figure 2.** The map of the countries and regions that implement the engineering design process in science education**Table 4.** The distribution of research based on the countries that implement the engineering design process in science education

No	Country	f	(%)	E.g., (only first author cited)
1	USA	34	70.83	Apedoe (2013); Bamberger (2013); Berland (2013); Berland (2014); Berland (2016); Capobianco (2014); Capobianco (2018); Chao (2017); Chase (2019); Chiu (2011); Crotty (2017); Dankenbring (2016); Egbue (2015); Guzey (2017); Hammack (2015); Hertel (2017); Hynes (2012); Johnston (2019); Lie (2019); Lie (2019); Maeng (2017); Marulcu (2013); McFadden (2018); Park (2016); Pleasants (2020); Schnittka (2011); Schnittka (2012); Valtorta (2015); Wendel (2010); Wendell (2013); Wendell (2017); Wendell (2019); Xie (2018); Zhou (2017)
2	Australia	5	10.42	English (2012); English (2013); English (2016); King (2016); Ward (2016)
3	Taiwan	3	06.25	Yu (2019); Mesutoglu (2020); Fan (2015)
4	Turkey	2	04.17	Aydin-Gunbatar (2018); Korur (2015)
5	Malaysia	2	04.17	Shahali (2016); Siew (2016)
6	Denmark	1	02.08	Dohn (2013)
7	Indonesia	1	02.08	Syukri (2018)
Total		48	100	

Based on [Table 3](#), it can be seen that all articles for review were chosen from 48 international journals (100%). Although many articles on the engineering design process in science education have been published in proceedings and theses, we did not choose the articles from these proceedings and theses. We aim that the articles selected for review are articles of excellent quality and can be accounted for. In addition, the selection of articles from journals indexed by Scopus or Web of Science (WoS) is more stringent and has been through a peer review. Based on the given data, it can be concluded that the articles chosen for this study are of good reputation and quality.

#### *The distribution of research based on countries and regions that implement the engineering design process in science education*

The data of the countries and regions that implement the engineering design process in science education were obtained from the affiliation of the writer of the chosen articles. The complete data can be seen in [Figure 2](#).

Based on [Figure 2](#), the countries that implement the engineering design process in science education are the United States of America (USA), Australia, Taiwan, Turkey, Malaysia, Denmark, and Indonesia. The distribution of research can be seen in [Table 4](#).

**Table 5.** Research Approach

No	Research Approach	f	(%)
1	Quantitative	15	31.25
2	Qualitative	20	41.67
3	Mixed Methods	13	27.08
Total		48	100

**Table 6.** The distribution of research based on the educational stage

Participants/sample	Educational Stage (Level)	f	(%)	Total (%)
Student	Elementary/Primary school	10	20.83	37 (77.08)
	Middle school	15	31.25	
	High school	7	14.58	
	University/undergraduate	2	04.17	
	Elementary and middle school	2	04.17	
	Middle and high school	1	02.08	
Teacher	Elementary	6	12.50	10 (20.83)
	Middle School	4	08.33	
Others	Undergraduate and graduated students	1	02.08	1 (02.08)
Total		48	100	48 (100)

Based on [Table 4](#), it can be seen that the United States of America had the highest number of articles with 34 articles (70.83%). Denmark and Indonesia were the lowest in the number of articles with 1 article (02.08%), respectively. From the data, it can be concluded that there are very few countries that implement the engineering design process in science education.

#### *The distribution of research based on the research approach*

The research approach was determined by the research method used in the articles. The complete data can be seen in [Table 5](#).

Based on [Table 5](#), it can be seen that there were three research approaches: quantitative, qualitative, and mixed methods. The most used research approach was qualitative with 20 articles (41.67%), and the least used approach was mixed methods with 13 articles (27.08%).

#### *The distribution of research based on the educational stage*

The sample of participants in the articles was analyzed to determine the distribution of research based on the educational stage. This aims to provide an overview of the distribution of previous studies related to engineering design process in science education based on the level of education. Elementary school level consists of students aged around 6-12 years. Middle school level consists of students who have graduated from elementary school within an age of around 12-15 years. High school level consists of students who have graduated from middle school within an age of 15-18 years. Undergraduate level consists of students who have graduated from high school and continue their studies to university level within the age of around 18-22 years. Meanwhile, graduate students are students who have graduated from university level around the

age of 22 years or more. The complete data can be seen in [Table 6](#).

Based on [Table 6](#), it can be seen that there were 37 articles (77.08%) which sample or participant consisted of students; 10 articles (20.83%) with teachers as the sample or participants; and 1 article (02.08%) with undergraduate/graduate students as the sample of participants. The distribution of research based on the educational stage was found the highest in middle school students with 15 articles (31.25%). The lowest came from undergraduate/graduate students with only 1 article (02.08%). From the data, it can be concluded that the engineering design process is implemented in science education of various educational stages (level). However, the implementation in the undergraduate/graduate level is still rather scarce when compared to the elementary school, middle school, and high school levels.

#### *The distribution of research based on science content*

This study divides the science content into 5: Science, Physics, Biology, Chemistry, and the integration of science with other subjects. The selection of articles containing the integration of science with other subjects aims to investigate fields other than science that use one of the topics of science in their research. The discussion of the results of this study is broader and more comprehensive because interdisciplinary fields related to science are also described in this study. The science content was divided based on school subjects or research topics. The complete data can be seen in [Table 7](#).

From [Table 7](#), it can be seen that the implementation of the engineering design process was mostly found in the subject of science, with the least found in the integration of science with other subjects. Based on the data, it can be concluded that the engineering design process is implemented in Science, Physics, Biology,

**Table 7.** The distribution of research based on the science content

Science Content	Information	f	(%)
Science	-	18	37.50
Physics	-	17	35.42
Biology	-	3	06.25
Chemistry	-	3	06.25
The integration of science with other subjects	Science and Mathematics	4	08.33
	Physics, Biology, and Chemistry	1	02.08
	Science, Mathematics, and Computers	1	02.08
	Physics and Biology	1	02.08
Total			48

**Table 8.** The projects and discussed topics in science

No	Project	Topic	E.g., (only first author cited)
1.	- A better play dough. - Birds busting a beat - Crawler creations (Lego crawler)	- States of Matter - Simple machines - Forces affect the motion and speed	Capobianco (2014)
2.	Musical instrument, door alarm, compost column, and solar panel tracker	Energy and matter	Capobianco (2018)
3.	A prototype of a structure that will provide shade over a picnic table during noontime in both the summer and winter.	Solar system	Dankenbring (2016)
4.	A catapult, produce the most carbon dioxide, to measure salt content in water, wind generator, wind-powered vehicle, vehicle and a glider that can soar	The topic is not explained	Dohn (2013)
5.	Bridge construction	Measurements	English (2012)
6.	The earthquake design	Earthquake	English (2016)
7.	Teacher's engineering talk	Genetically modified organisms	Guzey (2017)
8.	Alarm circuits, cleaning an oil Spill, evaluating a landscape, plant packages electricity, the effects of oil spills on ecosystems, erosion and landforms, plants and functions of packages	Electricity, the effects of oil spills on ecosystems, erosion and landforms, plants and functions of a package	Hertel (2017)
9.	Nesting platforms	Ecology	Lie (2019)
10.	- Circuit building, instrument, bridge, tower, submersible, roller coaster, and rocket - Water filter, rover, watershed, ocean floor model, ways to contain/clean up oil spills, hurricane-proof building, and weather instrument environmental science - Gardens, ecosystems, and habitats	- Electricity, simple machines, sound, and force, motion, and energy - Human impacts on the environment, space, erosion, watersheds, oceans, weather - Ecosystems, homeostasis, and plants	Maeng (2017)
11.	A mining extraction tool	Renewable and non-renewable resources	McFadden (2018)
12.	Wind turbine	Energy	Mesutoglu (2020)
13.	Building, road, dam, or other civil structure	A chemical technology	Pleasant (2020)
14.	Building a submarine	Fluid	Siew (2016)
15.	Musical instrument, model house, people mover, an animal model	Simple machines	Wendell (2013)
16.	Bridges, water filters, maglev vehicles, knee braces, windmills, pollinators, knee Braces, circuits	Energy	Wendell (2017)
17.	Automatic plant watering device	Energy transfer	Wendell (2019)
18.	A three-dimensional model of the toy	The topic is not explained	Yu (2019)

Chemistry, and the integration of science with other subjects.

### Research Question 2: What are the Projects and Discussed Topics in the Implementation of the Engineering Design Process in Science Education?

The design projects and discussed topics in the implementation of the engineering design process were

mostly found in Science, Physics, Biology, Chemistry, and the integration of science with other subjects.

#### *The projects and topics in science*

The data of the projects and discussed topics in science can be seen in [Table 8](#).

[Table 8](#) shows that there were 18 projects related to the implementation of the engineering design process in



**Table 9.** The projects and discussed topics in Physics

No	Project	Topic	E.g., (only first author cited)
1.	Wind Turbine	Energy	Bamberger (2013)
2.	Energy-efficient home design	Energy/Heat transfer	Chao (2017)
3.	Cantilevers	Center of mass	Chase (2019)
4.	Electric vehicle electric vehicles' batteries	Sustainability and alternative energy	Egbue (2015)
5.	Catapult	Simple machines	English (2013)
6.	Virtual computer-aided design and simulation	Mechanics lever scales, Cam toy, Gear wheeled range finder, Gear set.	Fan (2015)
7.	Optical instrument	Mirror and lens	King (2016)
8.	Toy crane	Simple machines	Korur (2015)
9.	People Mover	Simple machines	Marulcu (2013)
10.	The save the penguins engineering design	Thermal energy and heat transfer	Schnittka (2011)
11.	The save the penguins engineering design	Thermal energy and heat transfer	Schnittka (2012)
12.	Solar car	Energy	Shahali (2016)
13.	Free electricity energy	Electricity and magnetism	Syukri (2018)
14.	Camera	Optics	Valtorta (2015)
15.	A stable, quiet, thermally comfortable model house.	Strength, elastic modulus, density, heat capacity, thermal conductivity, and expansion.	Wendell (2010)
16.	A Cost-effective rooftop solar power system for their home buildings.	Energy	Xie (2018)
17.	A foil boat, trebuchet, fan boat, and marshmallow tower,	Energy transfer	Zhou (2017)

**Table 10.** The projects and discussed topics in Biology

No	Project	Topic	E.g., (only first author cited)
1.	A Simple hydroponic system, a fish fitness-testing device, a barrier that effectively reduces the cross-contamination of non-GMO cornfields from GMO cornfields.	Plants and Space, Fit Fish, Genetically Modified Organisms	Crotty (2017)
2.	Engineering talk	The topic is not explained	Johnston (2019)
3.	Explore cells, consider the relationship of the structure and function of DNA, basic heredity patterns found in nature, study sexual and asexual reproduction.	Genetically modified organisms	Lie (2019)

**Table 11.** The projects and discussed topics in Chemistry

No	Project	Topic	E.g., (only first author cited)
1.	Airbag, chemical reactions project	Force, motion, position and velocity, climate change, energy use, and greenhouse gases.	Chiu (2011)
2.	Cold-pack design, keeping apples from turning brown, devising homemade indicators and pH strips, instruments for measuring the CO <sub>2</sub> level in an aquarium, and building voltaic cells.	Chemical reactions and energy, Rate of chemical reaction, acids and bases, electrochemistry, Aqueous solution, and chemical equilibrium,	Aydin-Gunbatar (2018)
3.	Airplane, popcorn challenge, rocket body to attach to their film canisters	Chemicals	Hammack (2015)

science. It can be concluded that the choice of projects varied on the discussed topic.

#### *The projects and topics in Physics*

The data of the projects and discussed topics in Physics can be seen in [Table 9](#).

[Table 9](#) shows that there were 17 projects related to the implementation of the engineering design process in Physics. It can be concluded that the choice of projects varied depending on the discussed topic.

#### *The projects and topics in Biology*

The data of the projects and discussed topics in Biology can be seen in [Table 10](#).

[Table 10](#) shows that there were three projects related to the implementation of the engineering design process in Biology. It can be concluded that the choice of projects varied depending on the discussed topic.

#### *The projects and topics in Chemistry*

The data of the projects and discussed topics in Chemistry can be seen in [Table 11](#).

**Table 12.** The projects and discussed topics in science integrated with other subjects

No	Project	Topic	E.g., (only first author cited)	Science Content
1.	Wind Turbine	Energy	Berland (2013)	Science and math
2.	A Pinhole camera, a system to take aerial images, wind turbines, robotic vehicles, and construction helmets.	Power equations and energy transformation (Science) Converting between different units of measurement (Math)	Berland (2014); Berland (2016)	Science and math
3.	A model ear, sound detection, and applied them to the operation of the vocal tract.	Sound wave	Ward (2016)	Physics, Biology
4.	The earthquake design task	Genetics (Biology), projectile motion (Physics), chemical energy (Chemistry)	Apedoe (2013)	Physics, Biology Chemistry
5.	Spatula design Wheelchair design	The topic is not explained	Hynes (2012)	Science, Mathematics, Science and Mathematics, General, computer
6.	Making of a clay boat	Concept of volume	Park (2016)	Science and Mathematics

**Table 13.** The distribution of research based on the cognitive benefits

No	Benefits	E.g., (only first author cited)	f
1	Improving students' content knowledge/student's achievement	Chao (2017); Marulcu (2013); Park (2016); Dankenbring (2016); Aydin-Gunbatar (2018); Guzey (2017)	6
2	Improving science teachers' understanding	Mesutoglu (2020)	1
3	Effective for conceptual change	Schnittka (2011)	1
4	Introducing engineering at the beginning of the lesson resulted in higher students' achievements compared to introducing engineering only at the end of the lesson	Crotty (2017)	1
Total			9

Table 11 shows that there were 3 projects related to the implementation of the engineering design process in Chemistry. It can be concluded that the choice of projects varied depending on the discussed topic.

#### *The projects and topics in science integrated with other subjects*

The data of the projects and discussed topics in science integrated with other subjects can be seen in Table 12.

Table 12 shows that there were 6 projects related to the implementation of the engineering design process in science integrated with other subjects. It can be concluded that the choice of projects varied depending on the discussed topic.

#### **Research Question 3: What are the Benefits of the Engineering Design Process in Science Education?**

This study also examined the benefits of the engineering design process in science education. According to Martín-Páez, Aguilera, Perales-Palacios, and Vilchez-González (2019), the benefits of a learning approach can be classified into cognitive benefits, procedural benefits (skills benefits), and attitudinal benefits. In this study, we classified them into four categories of cognitive benefits, procedural benefits (skills benefits), attitudinal benefits, and the combination of the three aforementioned benefits. There is an addition of one category: the combination of the three

mentioned benefits because this study also incorporated interdisciplinary research related to science.

#### *Cognitive benefits*

Cognitive benefits are those that are based on empirical factual knowledge. The complete data of the cognitive benefits of the engineering design process can be found in Table 13.

Table 13 shows that the cognitive benefits of the engineering design process were found in 9 articles. Most articles claimed that the engineering design process improved students' content knowledge. It can be concluded that the implementation of the engineering design process in science education may improve students' content knowledge, science teachers' understanding, and is effective for conceptual change.

#### *Procedural Benefits (Skills Benefits)*

Procedural/skills benefits are proficiency in a specific field. The complete data of the procedural benefits of the engineering design process can be found in Table 14.

Table 14 shows that the procedural benefits (skills benefits) of the engineering design process were found in 21 articles. Most articles claimed that the engineering design process could integrate engineering with science learning. It can be concluded that the implementation of the engineering design process in science education may improve students' content knowledge, science teachers'

**Table 14.** The distribution of research based on the procedural benefits (skills benefits)

No	Benefits	E.g., (only first author cited)	f
1	Encourage mindful planning and students' modeling practices.	Bamberger (2013)	1
2	A better understanding of engineering design aspects was achieved when using qualitative method compared to quantitative	Berland (2014)	1
3	Improved students' thinking	Capobianco (2018)	1
4	Improved students' attention to learning and transfer situation	Chase (2019)	1
5	Better ability in integrating engineering and science learning	Chiu (2011); Berland (2013); Valtorta (2015); Berland (2016)	4
6	Effective monitoring factor for the generation of ideas and students' reasoning	English (2012)	1
7	Improved students' problem-solving skills	English (2013); Syukri (2018)	2
8	Improved students' ability in handling the complexity of a task	English (2016)	1
9	Supported STEM integration	Johnston (2019)	1
10	Useful for structuring stages of design, construction, and redesign	King (2016)	1
11	Improved students' level of ability in various subjects	Schnittka (2012)	1
12	Improved materials selection tasks, completion of their workbooks, and the workbook's reflective record-keeping tasks	Wendel (2010)	1
13	Improvement in sophisticated discourse	Wendell (2017); McFadden (2018)	2
14	Improved the ability in designing projects	Xie (2018); Lie (2019); Apedoe (2013)	3
	Total		21

**Table 15.** The distribution of research based on the attitudinal benefits

No	Benefits	E.g., (only first author cited)	f
1	Improved participation, student interest and self-concept in engineering and science	Capobianco (2014)	1
2	Stimulating students' situational interest	Dohn (2013)	1
3	Impacted positively on students' perceptions of engineering and technology	Hammack (2015)	1
4	Attitudes towards engineering	Lie (2019)	1
5	Supported efficacy	Maeng (2017)	1
6	Improved teachers' views on the implementation of the engineering design process in their teachings	Pleasants (2020)	1
7	Improved interest in STEM subjects and career	Shahali (2016)	1
	Total		7

understanding, and is effective for improving various students' skills.

### *Attitudinal benefits*

Attitudinal benefits are benefits related to behavior or actions based on one's stance. The complete data of the attitudinal benefits of the engineering design process can be found in [Table 15](#).

[Table 15](#) shows that the attitudinal benefits of the engineering design process were found in 7 articles. It can be concluded that the implementation of the engineering design process in science education may result in various attitudinal benefits.

### *Combination of cognitive, procedural/skills, and attitudinal benefits*

The combination of cognitive, procedural/skills, and attitudinal benefits is the benefit obtained by more than one cognitive, procedural/skills, and/or attitudinal benefits. Thus, this section measures more than one variable from the three categories. The complete data of the combination of cognitive, procedural/skills, and attitudinal benefits of the engineering design process can be found in [Table 16](#).

[Table 16](#) shows that the combination of cognitive, procedural/skills, and attitudinal benefits of the engineering design process were found in 11 articles. Most articles claimed that the engineering design process improved scientific knowledge and reasoning. Based on the data, it can be concluded that the implementation of the engineering design process in science education may result in different combinations of cognitive, procedural/skills, and attitudinal benefits.

## DISCUSSION

This study aims to review 48 articles from international highly-regarded journals related to the engineering design process in science education. The focus of this study is to investigate the distribution of research based on the characteristics of the content, projects, and discussed topics, and benefits of the engineering design process in science education. A literature review study that examines the distribution of research based on the characteristics of the content is in line with several previous studies (Deveci & Çepni, 2017). Martín-Páez, Aguilera, Perales-Palacios, and Vílchez-González (2019) which state that the analysis of the distribution of research based on the general

**Table 16.** The distribution of research based on the attitudinal benefits

No	Benefits	E.g., (only first author cited)	f	Benefits
1.	Impacted positively on conceptual knowledge, higher-order thinking skills, and design project activity	Fan (2015)	1	Cognitive & Procedural/skills
2.	Improved subject matter and pedagogical content knowledge	Hynes (2012)	1	Cognitive & Procedural/skills
3.	Improved achievement and creative attitude	Korur (2015)	1	Cognitive & Procedural/skills
5.	Improved scientific knowledge and reasoning	Yu (2019); Wendell (2019)	2	Cognitive & Procedural/skills
6.	Improved students' understanding and self-efficacy	Zhou (2017)	1	Cognitive & Attitude
7.	Improved knowledge building and students' interest	Egbue (2015)	1	Cognitive & Attitude
8.	Motivated students to write and communicate	Hertel (2017)	1	Attitude & Procedural/skills
9.	Improved curiosity and scientific disciplines	Ward (2016)	1	Attitude & Procedural/skills
10.	Improved attitudes and science content knowledge	Wendell (2013)	1	Attitude & Procedural/skills
11.	Improved students' knowledge, attitudes, and practices	Siew (2016)	1	Attitude, Procedural/skills, and attitude
Total			11	

characteristics of the content are one of the important parts in writing a literature review study.

The articles reviewed in this study were published from 2010 to 2020. The span of 10 years was specifically chosen so that the results of this study are not out of date (still conforming to the current situation) and are suitable for use as a reference by stakeholders in the field of science education. The highest number of reviewed articles were published in 2016, and the lowest number was published in 2020. All chosen articles are of good quality because they are indexed by Scopus and WoS. The countries that implement the engineering design process in science education are still very few in number. The research approaches used are quantitative, qualitative, and mixed methods. The most used research approach was qualitative, and the least used approach was mixed methods. Most studies used a qualitative research approach because data collection from some of these studies usually employed one observation or interviews through video recordings. Based on the method of collecting the data, the researcher chose a research approach that was deemed more suitable, which was qualitative, compared to other research approaches. The results of this statement are in line with research in the engineering design process in science education, which mostly used a qualitative research approach (Johnston, Akarsu, Moore, & Guzey, 2019; King & English, 2016). Meanwhile, studies that use a mixed-method research approach mostly employed data collection in more than one manner, such as classroom observations, science tests, and surveys (Guzey, Ring-Whalen, Harwell, & Peralta, 2017). In addition, Gunbatar (2018) also used a mixed-method in his research. In the study, data collection methods used two methods: the Chemistry achievement test and interviews. Furthermore, the engineering design process is implemented in science education of various educational stages (levels). The results of the analysis show that the implementation in the undergraduate/graduate level is still rather scarce compared to the elementary, middle school, and high

school levels. Therefore, there are still many opportunities to seek research novelty from the implementation of the engineering design process at the university level.

This study analyzed the characteristics of the content based on the year of publication, type of publication, countries that implement the engineering design process, research approach, educational stage, and science content. The choice of content analysis was supported by several previous studies that examine the year of publication (Jayarajah, Saat, Rauf, & Amnah, 2014; Martín-Páez, Aguilera, Perales-Palacios, & Vélchez-González, 2019), the type of publication (Belland, Walker, Kim, & Lefler, 2017; Çetin & Demircan, 2018; Henderson, Beach & Finkelstein, 2011; Jeong, Hmelo-Silver, & Jo, 2019; Martín-Páez, Aguilera, Perales-Palacios, & Vélchez-González, 2019), and the countries that implement it (Martín-Páez, Aguilera, Perales-Palacios, & Vélchez-González, 2019; Reinhold, Holzberger, & Seidel, 2018; Uzunboylu & Özcan, 2019). Jayarajah, Saat, Rauf, and Amnah (2014) also claims that examining the research approach is important in the analysis of the general characteristics of the content. In addition, some previous studies also investigate the content based on the educational stage (Deveci & Çepni, 2017; Martín-Páez, Aguilera, Perales-Palacios, & Vélchez-González, 2019) and the science content (Arık & Topçu, 2020). If a study analyzes content based on the year of publication, type of publication, countries that implement the engineering design process, research approach, educational stage, and science content, the results of the study can provide an overview for readers. Readers can judge whether the journals being analyzed are of high quality, up-to-date, and assess other important aspects.

This study also analyzed the distribution of research based on design projects and discussed topics when implementing the engineering design process in science education. The results show that the design projects varied based on the discussed topics. The distribution of research based on design projects and discussed topics

discovered that the implementation of the engineering design process was found in Science, Physics, Biology, Chemistry, and the integration of science with other subjects. Some examples of research in the engineering design process in Science use bridge construction project to teach the topic of measurements to 58 middle school students (English, Hudson, & Dawes, 2012), submarine building to teach the topic of fluid to 89 middle school students (Siew, Goh, & Sulaiman, 2016), and musical instrument, door alarm, compost column, solar panel tracker were also used to teach the topic of energy and matter to 32 elementary school teachers (Capobianco, DeLisi, & Radloff, 2018).

Some examples of research in the engineering design process in Physics design a wind turbine to teach the topic of energy (Bamberger & Cahill, 2013), an optical instrument to teach the topic of mirror and lens (King & English, 2016), and used free electrical energy to teach the topic of electricity and magnetism (Syukri, Halim, Mohtar, & Soewarno, 2018). In addition, some studies related to the engineering process in Biology designed a simple hydroponic system to teach the topic of Plants (Crotty et al., 2017); explore cells, consider the relationship of the structure and function of DNA were also discussed to teach the topic of genetically modified organisms (GMOs) (Lie, Guzey, & Moore, 2019). In Chemistry, the topic of climate change, energy use, and greenhouse gases utilized the project of airbag design and chemical reactions project (Chiu & Linn, 2011). Furthermore, Hammack, Ivey, Utley, and High (2015) taught the topic of chemicals using an airplane design project, a popcorn challenge, and a rocket body attached to their film canisters. In addition to Science, Physics, Biology, and Chemistry, the engineering design process is also implemented in science that is integrated with other subjects. That said, projects at hand may utilize several subjects at once. The engineering design process for the integration of science with other subjects was designing a pinhole camera, a system to take aerial images, a wind turbine, robotic vehicles, and construction helmets. The aforementioned projects were used to teach the topic of power equations and energy transformation (Science) and converting between different units of measurement (Mathematics) (Berland & Steingut, 2016). Moreover, Apedoe and Schunn (2013) taught the topic of Genetics (Biology), projectile motion (Physics), chemical energy (Chemistry) through the project of designing the earthquake task.

The result of this study also shows that the implementation of the engineering design process has its benefits in science education. The said benefits were classified into cognitive benefits, procedural benefits (skills benefits), attitudinal benefits, the combination of the three benefits. This result is in line with the previous study that found STEM approach in science education to have resulted in cognitive benefits, procedural benefits (skills benefits), and attitudinal benefits (Martín-Páez,

Aguilera, Perales-Palacios, & Vélchez-González, 2019). The difference of this study from the aforementioned previous study lies in the classification of the benefits. The previous study divided the benefits into three, whereas this study divided the benefits into four aspects, adding the combination of cognitive, procedural (skills), and attitudinal benefits.

Several previous studies investigated that the cognitive benefits of the implementation of the engineering design process were that it improved students' content knowledge/students' achievement (Aydin-Gunbatar, Tarkin-Celikkiran, Kutucu, & Ekiz-Kiran, 2018; Chao et al., 2017; Dankenbring & Capobianco, 2016; Guzey, Ring-Whalen, Harwell, & Peralta, 2017; Marulcu & Barnett, 2013; Park, Park, & Bates, 2016). Mesutoglu and Baran (2020) also claimed that the engineering design process improved science teachers' understanding. When it comes to procedural benefits (skills benefits), some researches stated that the engineering design process improved students' problem-solving skills (English, Hudson, & Dawes, 2013; Syukri, Halim, Mohtar, & Soewarno, 2018), students' ability in designing a project (Xie, 2018) as well as sophisticated discourse (McFadden & Roehrig, 2018; Wendell, Wright, & Paugh, 2017). Furthermore, attitudinal benefits were also found in the implementation of the engineering design process. The stated benefits include improving students' interest in STEM subjects and career (Shahali, Halim, Rasul, Osman, & Zulkifeli, 2016), attitudes towards engineering (Lie, Guzey, & Moore, 2019), and it impacted positively on students' perceptions of engineering and technology (Hammack, Ivey, Utley, & High, 2015). To add, the engineering design process in science education may result in the combination of cognitive, procedural/skills, and attitudinal benefits. Fan and Yu (2015) claimed that the engineering design process improved students' achievement (cognitive benefits) and creative attitude (procedural/skills benefits). This finding is supported by another study asserting that the engineering design process improved scientific knowledge (cognitive benefits) and reasoning (procedural/skills benefits) (Yu, Wu, & Fan, 2019; Wendell, Swenson, & Dalvi, 2019). One research even found the combination of all three benefits: improved students' knowledge (cognitive benefits), attitude (attitudinal benefits), and practices (procedural/skills benefits) (Siew, Goh, & Sulaiman, 2016). So, the benefits of the implementation of the engineering design process in science education include cognitive benefits, procedural (skills) benefits, attitudinal benefits, and a combination of the three benefits.

This research also has its strengths and weaknesses. The strength of this research is that the chosen journals are of high quality and up to date. This statement is supported by the fact that the selected articles were chosen from journals indexed by Scopus (Q1 and Q2)

and the Web of Science (WoS) in the last ten years. The results of this study are very useful because topics and projects commonly used by previous researchers are elaborated. In addition, the results of this research can be useful for teachers, lecturers, or further researchers in order to implement the engineering design processes in science education or other fields. Meanwhile, the weakness of this research is that aspects related to how the stages of the engineering design process in science education have not been explained. However, research related to stages of the engineering design process in science education can be explained in further research.

## CONCLUSIONS

Currently, the reform of science education is to integrate science learning with the engineering design process. However, there are still challenges met in its implementation. The implementation is found to still be rather inconsistent. Most science teachers are still too unfamiliar with the engineering design process to be able to implement it in their science teaching. Therefore, a literature review study is important to be carried out. This study analyzed the characteristics of the content based on the year of publication, type of publication, countries that implement the engineering design process, research approach, educational stage, and science content. The result of the study shows that there were 48 articles chosen for review published from 2010 to 2020. All chosen articles are of good quality because they are indexed by Scopus and WoS. The countries that implement the engineering design process in science education are the United States of America (USA), Australia, Taiwan, Turkey, Malaysia, Denmark, and Indonesia. The most used research approach was qualitative, and the least used approach was mixed methods. Moreover, the engineering design process is implemented in science education of various educational stages (level). However, the implementation in the undergraduate/graduate level is still rather scarce. The engineering design process was found to be implemented in Science, Physics, Biology, Chemistry, and the integration of science with other subjects. This study also analyzed the distribution of research based on design projects and discussed topics when implementing the engineering design process in science education. The results show that the choice of projects used in implementing the engineering design process varied based on the discussed topics. Additionally, the implementation of the engineering design process has its benefits in science education. The benefits include cognitive benefits, procedural benefits (skills benefits), attitudinal benefits, and the combination of cognitive, procedural (skills), and attitudinal. The engineering design process is considered a new trend in the current reform of science education. Thus, the results of this study can be used as a reference for all stakeholders involved in science education, especially teachers,

lecturers, or future researchers. In addition, the engineering design process can be used as an alternative learning approach in science education. The gap for future research is that we have not found any study that implements the engineering design process in the subject of integrated science with preservice science teachers as subjects. Therefore, we recommend the engineering design process to be implemented in science education with projects and topics that have yet to be discussed by previous researchers. Also, research related to stages of the engineering design process in science education can be explained in further research.

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