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Learning Goals in Middle School Engineering: A Systematic Review and Comparison with NGSS and ASEE Frameworks (Fundamental)

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Abstract

This research paper is a systematic literature review of pre-college engineering education that includes practitioner and research articles at the middle school level from 2012 - 2022. The inclusion of engineering in the *Next Generation of Science Standards* (NGSS, 2013) and the release of the *Framework for P-12 Engineering Learning* (FPEL) developed in partnership with the *American Society for Engineering Education* (ASEE & AE3, 2020) provide different approaches to the inclusion of engineering in K-12 settings. In order to provide more clarity on the learning goals for engineering education, this paper uses a directed content analysis design to identify the alignment of research and practitioner articles to the learning goals promoted in the NGSS (2013) and FPEL (2020). With a focus on formal middle school classrooms in the United States, this study addresses the following research questions: *1*) What are the trends in articles being published?; *2*) How are the FPEL learning goals reflected in the literature?; *3*) How are the NGSS learning goals reflected in the literature? The search strategy resulted in 102 studies. The findings highlight the significant influence of the NGSS, which focuses on engineering practices as a context for science learning. However, interventions were not well aligned with middle school expectations. For example, NGSS expects students to use a systematic and iterative approach to design (MS-ETS1-2), but only 17% of articles promoted this learning goal despite 75% including a design activity. When considering the learning goals promoted by the FPEL, few studies reflected the view of engineering to be taught as a stand-alone discipline with little emphasis on engineering-related topics outside of design practices. Gaps in the literature and recommendations are discussed.

Introduction

Engineering is increasingly being recognized as an area of interest for K-12 curriculum, and several framework and standards documents have proposed engineering learning goals for K-12 classrooms [1] - [4]. One significant effort was *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [5], which promotes the integration of engineering design practices into science classrooms as an authentic context for learning and applying science concepts [5] - [7]. The result was the *Next Generation Science Standards* (NGSS) [8], integrating engineering across K-12 science standards, and by 2015, most state science standards included engineering in some capacity [9]. However, concerns have been raised that engineering within a science context may lead to misconceptions [3], [4]. In response, the American Society for Engineering Education (ASEE) and Advancing Excellence in P12 Engineering Education (AE3) introduced a *Framework for P-12 Engineering Learning* (FPEL) [10]. The FPEL established a comprehensive definition of engineering literacy for graduating high school students, achieved through authentic and rigorous engineering learning goals. The FPEL calls for more research around pre-college engineering learning, especially in scaffolding these learning goals to lower grades. To support these efforts, this paper presents a systematic literature review on engineering instruction in formal middle school classrooms across the United States. Using both the NGSS and FPEL frameworks, a coding guide was devised to analyze trends in engineering education within the research and practitioner literature between 2012 - 2022.

Next Generation Science Standards.

The NGSS [8] is a three-dimensional approach to science education that includes:

1. Disciplinary core ideas (DCIs): the content students need to know (e.g., physical science concepts)
2. Science and engineering practices (SEPs): how students should learn science and engineering (e.g., asking questions or using models)
3. Crosscutting concepts: The big ideas that cross multiple subject areas (e.g., patterns or scale)

The NGSS then combines these dimensions to create performance expectations for each grade level. Engineering is integrated across these standards, but the authors only include the "practices and ideas about engineering design that are considered necessary for literate citizens" (p. 3, [8]). The result is that several standards across life, physical, and Earth and space science areas ask students to use an engineering practice to demonstrate an understanding of core science ideas. For example, in middle school physical science: "Students will apply Newton's third law to design a solution to a problem involving the motion of two colliding objects" [8].

The NGSS standards also have stand-alone engineering design performance expectations, which do not connect to a science topic. These engineering standards reflect the NRC Framework's three DCIs for engineering [11]:

1. Defining and Delimiting an Engineering Problem
2. Developing Possible Solutions
3. Optimizing the Design Solutions

These design practices are scaffolded across the K-12 standards. By middle school, students are expected to "use systematic methods […] in order to arrive at an optimal design" (p. 4), [11]. While engineering is in both the DCIs and SEPs, Cunningham and Carlsen [12] point out that each engineering DCI is written with a verb (e.g., define the problem), unlike all other science DCIs that use nouns (e.g., forces and motion). This approach implies and likely underscores the belief that engineering, at least for K-12 settings, is an application of science without a separate knowledge base. The goal is for students to use these engineering practices to apply and learn science ideas.

Framework for P12 Engineering Learning

Nature of engineering researchers argue that although the discipline draws on math and science knowledge, engineering has a unique theoretical knowledge base [13] - [17]. Several have raised concerns that the NGSS approach of teaching engineering as a set of practices creates misconceptions [4], [10]. In response, the FPEL was released to provide a holistic view of engineering learning as a distinct discipline outside of science and other subjects [10]. These include engineering practices, habits of mind, and knowledge. The FPEL recommends starting with habits of mind in early grades, adding in engineering practices, and later helping students identify essential knowledge to support those practices. For engineering practices, the FPEL includes design practices like those in the NGSS, along with material processing, quantitative analysis, and professionalism. The third area of engineering knowledge contains concepts related to engineering sciences, mathematics, and technical applications. Authors call for additional work to scaffold these learning goals for graduating high school seniors to support engineering literacy across K-12.

Systematic Reviews on K-12 Engineering Education

As engineering continues to gain popularity in K-12, systematic literature reviews can provide context to the development of engineering learning and teaching over time [18]. Literature reviews are critical in informing better practices, future research efforts, and policy development. However, fewer than 10% of systematic reviews in engineering education have focused on pre-college education [18] despite a growing emphasis on research in this area [19], [20]. One of these was conducted in 2012 by Diaz and Cox, who looked at all pre-college engineering education research from 2000-2011 [21]. The review led to about 50 articles, mostly involving outreach program settings, and found that studies generally focused on integrating math and science content in a hands-on activity using the engineering design process. The review also found that the dominant goals of the interventions were to increase the number of engineers, improve math and science scores, and increase technology literacy. This work was followed by Hynes et al., who investigated research publications between 2000-2015 [19]. The resulting 218 papers represented a substantial increase in articles after 2011. Research shifted to formal classroom settings (75% of studies), especially at the high school level. The paper also explored the nature of the research questions and presented a synthesis of the research aims related to students, teachers, and curriculum. Neither review included practitioner papers.

More recent literature reviews have focused on specific areas of pre-college engineering education. Margot and Kettler [22] investigated teachers' perceptions of STEM education, followed by Mesutoglu and Baran [23], who identified best practices for professional development. Others explored components of engineering instruction, including the conceptualization of argumentation [24] and authenticity [25] in engineering education literature. Lammi and colleagues sought to understand prominent aspects of engineering design and related pedagogical challenges [26]. However, a broad literature review of pre-college engineering education learning goals has not included literature beyond 2015 [19]. This is especially critical with the growing adoption of engineering across state science standards and the issues highlighted by the FPEL [10].

Current Study

Building from the review by Hynes and colleagues [19], this paper focuses on publications from 2012 - 2022 and expands the search to include practitioner papers. This study also investigates intended learning goals to understand how current literature aligns with the NGSS and FPEL viewpoints. Because the field has dramatically expanded since the last broad review [20], this paper will focus on middle school classrooms in the United States, addressing a gap in the FPEL [10]. Through directed content analysis, the following research questions:

- RQ1: What are the trends in articles being published?
- RQ2: How are the FPEL learning goals reflected in the literature?
- RQ3: How are the NGSS learning goals reflected in the literature?

Methods

This systematic literature review followed the framework developed by Borrego et al. [18], including *1)* search strategy, *2)* developing and applying criteria, and *3)* data extraction and synthesis.

Search Strategy

To maximize the number of relevant studies, the search strategy included the education-focused databases ERIC (EBSCO), Education Source (EBSCO), and APA PsychInfo (EBSCO), the multidisciplinary Academic Search Complete (EBSCO), and engineering-specific Compendex (Engineering Village), Inspec (Engineering Village), and IEEE Xplore. Additionally, the first 300 articles from Google Scholar were included in case any relevant studies were missed [27], such as ASEE publications. The search validation process began with broad search terms, leading to the selection of twenty relevant articles. As the search terms were refined, the results were reviewed to confirm the inclusion of these identified relevant studies. The final search terms are shown in Appendix. The period of the search was limited to January 2012 through December 2022. An initial search was conducted on February 2, 2022, and a second search was conducted on March 15, 2023, to capture the remainder of 2022.

Developing and Applying Criteria

To address the research questions, the studies needed to describe an engineering intervention in a classroom setting for middle school students. After reviewing a subset of articles, the following inclusion and exclusion criteria were developed to guide the screening for inclusion in the study.

1. *The article was published between 2012 - 2022.* This review picks up from the work of Diaz and Cox [21] and Hynes [19]. Additionally, the NGSS was released in 2013, so this range will include the impact of these standards on engineering instruction.
2. *The article was in English and took place in the United States.* The NGSS and FPEL are guiding documents for classrooms in the United States [8], [10].
3. *The article was peer-reviewed, including dissertations, practitioner papers, and conference proceedings.* This follows criteria from Wilson-Lopez and colleagues [24].
4. *The article was focused on instruction in a formal classroom setting for grades 6 - 8.* If the article was an empirical study, participants must be middle school teachers or students. Studies that involved professional development for middle school classroom teachers were included. If the article is for practitioners, the target audience must be middle school educators. Articles addressing only informal settings, such as summer camps or outreach presentations, were excluded.
5. *The article is focused on the instruction or learning of engineering.* Articles that explicitly defined the intervention as engineering were included.

6. *Systematic reviews or meta-analyses were excluded.* The goal was to focus on engineering-related instruction at the middle school level. Since all articles included in such studies may not be relevant, they were not included in this systematic review.

After conducting the search, all resulting citations were exported to Covidence, a web-based software for systematic reviews [28]. Covidence was used to detect duplicates in the literature. One researcher then reviewed the titles and abstracts to determine their relevance to the research questions. Next, the above inclusion criteria were applied to the full text. To ensure reliability in screening, a second researcher screened a subset of articles (n=32) for a Kappa coefficient of 0.904 [29]. The first researcher then screened the remaining articles.

Data Extraction and Synthesis

A subset of the literature was reviewed to increase familiarity, and a coding guide was developed to limit the scope of the analysis to the relevant information according to the research questions. A deductive approach was used to look for the absence or presence of codes, as this study aims to determine the extent to which these categories (i.e., NGSS engineering standards) are present in the literature [30]. The coding guide was tested and revised through several rounds of application to the literature. The following describes the coding categories used for each research question.

RQ1: What are the trends in articles being published?

Table 1 provides the coding guide for RQ1. Each article was categorized by type and year published. Those identified as research were further analyzed using categories similar to those of Hynes [19] to identify the focus of the research questions. An open-response question provided a space to add more information on the research area.

Table 1. Coding Guide for RQ1

Coding Guide Questions	**Categories**
Article Type	Practitioner Research: Qualitative Research: Quantitative Research: Mixed-Methods
Year	2012 - 2022
Research Goals *Excludes practitioner articles*	Student Thinking/Conceptions Student Behaviors Student Attitudes Teacher Thinking/Conceptions Teacher Behaviors/Strategies Teacher Attitudes
What are the areas evaluated and reported on in the study?	Open-response

RQ2: How are the FPEL learning goals reflected in the literature?

To investigate the alignment of literature with the FPEL [10], the coding guide included the three dimensions of engineering learning: habits of mind, practices, and knowledge (Table 2). During coding, researchers referenced the definitions and examples provided by the FPEL to determine if they were promoted in the articles.

Table 2**.** Coding Guide for RQ2

Coding Guide Questions	**Categories**
Which of the following FPEL **engineering habits of mind** are explicitly described as part of the intervention?	Optimism; Persistence; Collaboration; Creativity; Conscientiousness; Systems Thinking
Which of the following FPEL **engineering practices** are explicitly incorporated into the intervention?	Engineering Design; Material Processing; Quantitative Analysis; Professionalism
Which of the following FPEL **engineering knowledge domains** were explicitly described as part of the intervention?	**Engineering Sciences**, including statics, mechanics of materials, dynamics, thermodynamics, fluid mechanics, heat transfer, mass transfer and separation, chemical reactions and catalysis, and circuit theory. **Engineering Mathematics**, including algebra, geometry, statistics, and calculus, to support solving engineering problems. **Engineering Technical Applications**, including mechanical design, structural analysis, transportation infrastructure, hydrologic systems, geotechnics, environmental considerations, chemical applications, process design, electrical power, communication technologies, electronics, and computer architecture.
If included, describe what **engineering knowledge** was part of the intervention.	Open-response

RQ3: How are the NGSS learning goals reflected in the literature?

The final research questions investigated the alignment of the literature with the NGSS [8], which includes engineering as an integral part of the science curriculum (Table 3). The first part of the coding guide identifies if the intervention includes a science DCI (physical science, life science, and earth and space science). The second question codes the articles for an ETS performance expectation, which are scaffolded for K-2, 3-5, middle school (MS), and high school (HS) grade bands. For this study, which focused on middle school interventions, authors coded studies for alignment to 3-5 and MS ETS performance expectations. Note that grades 3-5 only have three ETS performance expectations, while the MS grades have four expectations.

Table 3. Coding Guide for RQ3

Coding Guide Questions	Categories
If science concepts are a learning goal, which **NGSS core ideas** are most aligned with the intervention?	Physical Science Earth & Space Sciences Life Science
Which NGSS **engineering performance expectations** are addressed in the intervention?	**3-5 ETS1-1**: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. **3-5 ETS1-2**: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. **3-5 ETS1-3**: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved **MS ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. **MS ETS1-2**: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. **MS ETS1-3**: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. **MS ETS1-4:** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Extraction of Data

The final coding guide was imported into Covidence. In addition to the questions provided in Tables 1-3, the guide asked researchers to describe the engineering intervention. Using Covidence, the coding guide was applied to the full text of each study. A comment section captured any concerns or additional information that required discussion by the team. After coding, all results were exported into Excel. The analysis followed a narrative synthesis method, where descriptive statistics and trends are reported based on predefined categories [31].

Results

The search strategy results are found in Figure 1, which provides a flowchart of the screening process based on the *Preferred Reporting Items for Systematic Review and Meta-Analyses* (PRISMA) guidelines [32]. The database search resulted in 1,263 articles, of which Covidence found 317 duplicates. These were screened for relevance, and then the exclusion criteria were applied to ensure each study described an engineering intervention for a formal middle school classroom in the United States and was published between 2012 - 2022. The result was 102 articles included in this systematic review.

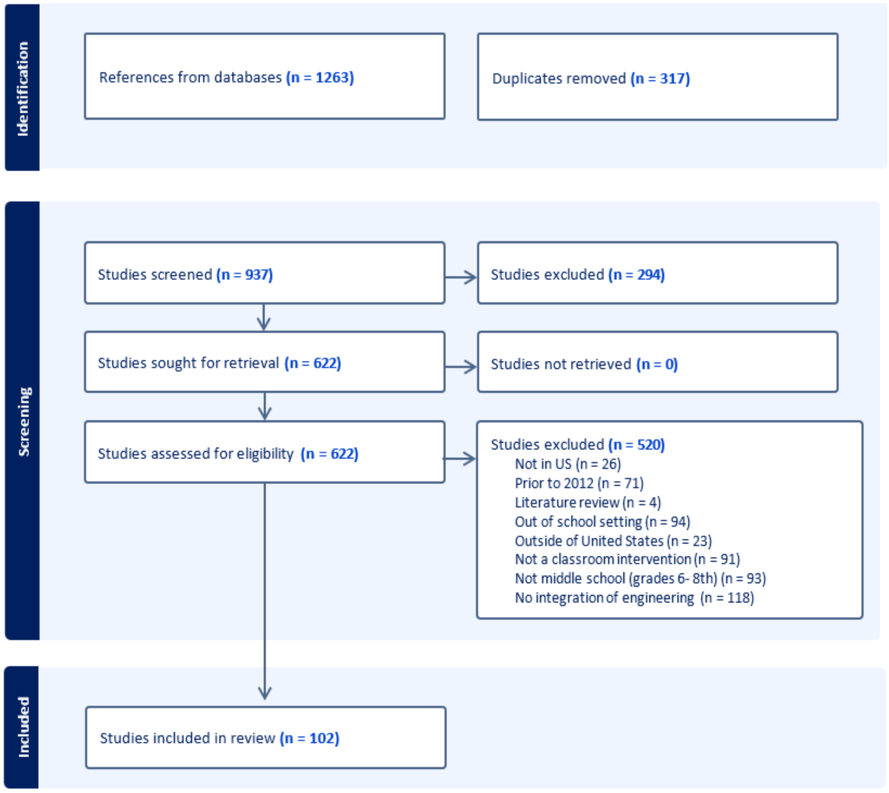

Figure 1. *PRISMA Flowchart of Screening Process*

RQ1: What are the trends in articles being published?

As shown in Figure 2, the number of articles (N= 102) generally increased from 2012 to 2020, with a decrease in 2021 and a more drastic decline in 2022. More than half (n = 55) were published between 2018 - 2021. A majority of articles were research studies (70%, n = 71). The research methods used from this subset were 62% qualitative, 30% quantitative, and 9% mixed-methods. The full text of the research articles was further analyzed to determine the focus of the research questions.

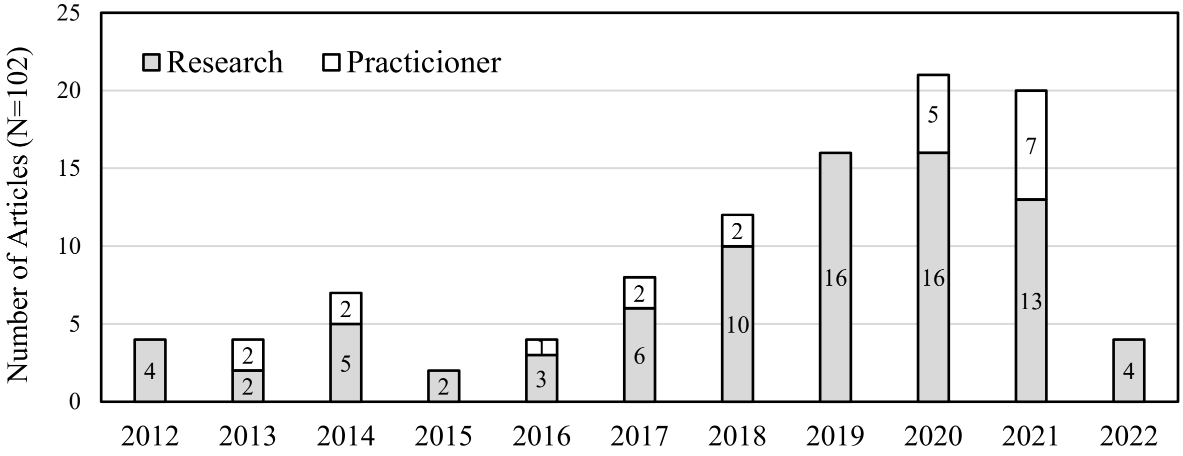

Figure 2. Article type by year of publication (N=102).

Research on Students

Out of the 71 research articles, more than half (66%, n=47) investigated student thinking or conceptions, behaviors, or attitudes with categories of research goals presented in Table 4. Of these, most studies (n=20) focused on student's understanding of or enactment of design practices. For example, Wind et al. [33] investigated student conceptions of the engineering design process, while Goldstein et al. [34] identified rationales for design decisions. Several articles measured the ability of a prototype to meet design criteria by identifying improvement in design practices [35] - [39].

Table 4. Overall Aim of Research Studies on Middle School Engineering Education (n = 47)

Areas Evaluated in Research Articles	**n**	**% out of 47**
Student Understanding or Enactment of Design Practices	20	42
Student Attitudes and/or Interest towards Engineering	9	19
Student Habits of Mind or Thinking Skills (i.e. collaboration)	9	19
Student Understanding of Science	8	17
Student Understanding of Math	4	8

Other studies looked at habits of mind or thinking skills (n=9), such as the ability to work in teams during design activities. For example, Wieselmann et al. [40] found that single-gender groups had less conflict during team design challenges compared to mixed-gender groups. Studies categorized as measuring student attitudes (n=9) investigated the impact of an engineering intervention on interest in science or engineering subjects, the development of an engineering identity, and self-efficacy.

Less prevalent was evaluating students' understanding of science (n=8) or math (n=4). For example, Knezek and Christensen [41] measured gains in energy and environmental science concepts after an engineering design challenge. After an engineering-focused activity, Bowen and Peterson [42] measured an understanding of slope and y-intercept. In a chemistry unit, Cole et al. [43] explored whether an engineering design project that involved spatial abilities related to students' understanding of the conservation of matter.

Research on Teachers

In studies focused on teachers (43%, n=31), most researchers investigated teacher behaviors or strategies (n=19). For example, researchers explored questioning techniques [44], strategies of engineering integration into a unit [45] - [48], positioning of failure [49], and adoption of culturally relevant instruction [50]. One study measured differences in teaching behaviors based on teacher characteristics, such as subject matter background [51], while others measured the impact of professional development on instruction [52], [53].

Others examined teacher learning (n=11) or attitudes (n=11) related to an engineering intervention. For example, studies investigated attitudes regarding community assets [54], integration of engineering with math and science [55], and teaching efficacy [56], [57]. Others explored teachers' understanding of the engineering design process [23], [58], [59]. One study focused on understanding goal conflicts that arise when integrating engineering practices in the science classroom [60].

RQ2: How are the FPEL learning goals reflected in the literature?

The remaining results (RQ2 and 3) focus on the learning goals identified in practitioner and research studies (N=102). In comparing articles to the FPEL [10], the learning goals primarily reflected habits of mind (found in 89% of included studies) and engineering practices (75% of studies) with less alignment to topics within engineering knowledge (15% of studies).

Engineering Habits of Mind. The term "habits of mind" was rarely used in the literature except for Jimenez et al. [61], who explored the engineering habits of mind of students with intellectual disabilities. However, most articles described at least one FPEL habit of mind, which includes optimism, persistence, collaboration, creativity, conscientiousness, and systems thinking [10]. For example, several articles emphasized collaboration during design challenges [40], [62], [63], [64], [65]. Others focused on creativity in the design process [34], [53], [66]. Systems thinking was the primary focus of the study by Gomoll et al. [49], where students explored the interconnectedness of social and technical problems during a robotics design challenge.

Engineering Practices. While engineering practices were part of 75% of studies, these predominantly focused on design practices (95%, n=87). Studies generally promoted this through the design, building, and testing of physical objects, such as a solar oven [67], liquid soap [68], prosthetic arm [69], soda can crusher [70], insulating cooler [71], rollercoaster [72], water filter [73], money sorter [74], and luggage ramp [75]. Each activity aimed to build an object that met specific design criteria. As shown in Figure 3, a smaller emphasis was placed FPEL practices related to material processing, quantitative analysis, and professionalism.

Engineering Knowledge. A smaller portion of articles (n=15) explicitly linked the intervention to a learning goal of engineering knowledge, such as fluid mechanics [76] and truss analysis [35]. Engineering science topics included fluid mechanics [76], energy transfer [23], [43], [77], and circuit theory [78]. Examples of engineering mathematics were algebraic thinking [56] and probability [79]. Additionally, several articles involved a truss design challenge [35], [50], [80], [81], which promoted all three components of engineering knowledge from science (truss analysis), math (geometry calculations in bridge design), and technical applications (structural analysis including material failure).

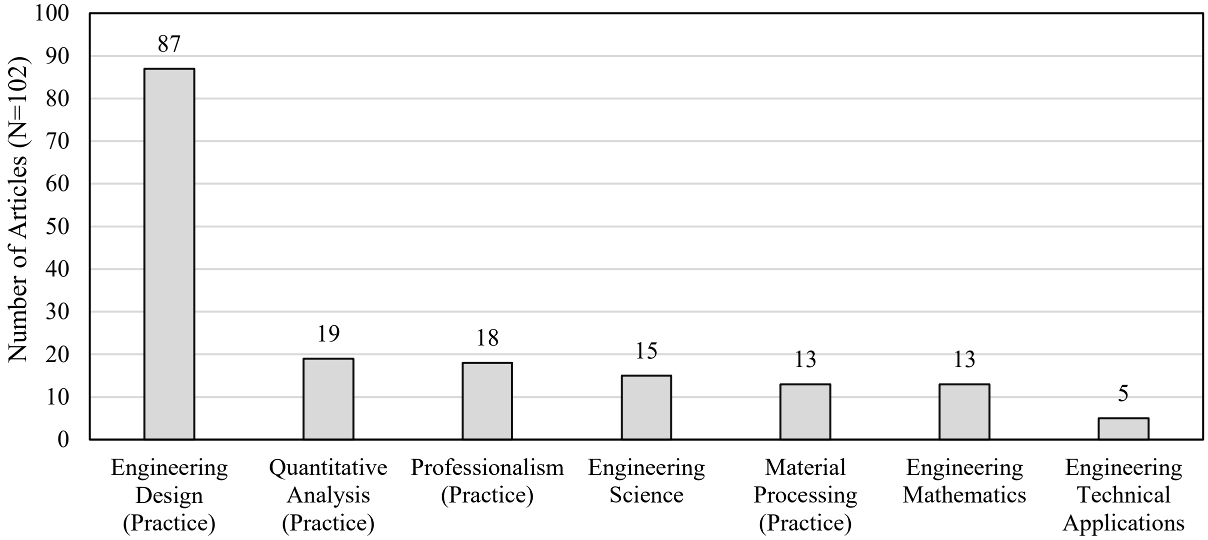

Figure 3. FPEL Engineering Practices and Knowledge Topics in Literature (N=102)

RQ3: How are the NGSS learning goals reflected in the literature?

More than half of the literature explicitly mentioned the NGSS (*n*=58), such as aligning the intervention with an NGSS performance expectation or citing the NGSS in the rationale or introduction of the article. Figure 4 shows how this trend changed over time compared to the total number of published articles.

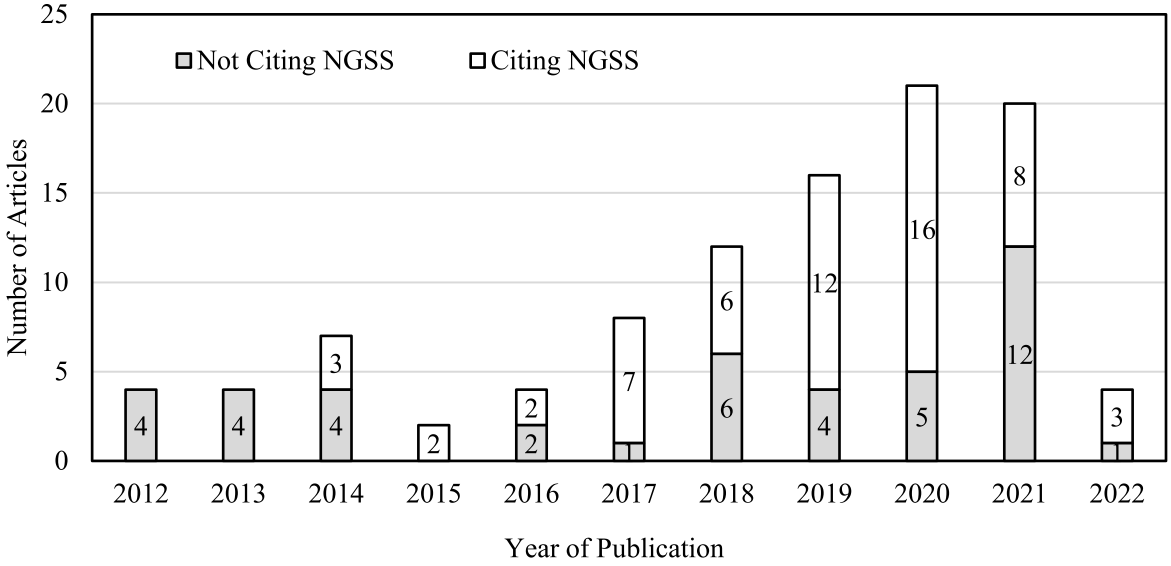

Figure 4. Number of Articles Citing the NGSS Compared to Total Articles (N=102)

NGSS Disciplinary Core Ideas. Most articles (58% of all studies) addressed an NGSS science DCI in the engineering intervention. Physical science concepts (*n*=31) were dominant, especially topics related to forces and motion [44], [82], [83], [84]. Life sciences (*n*=9) and earth and life sciences (*n*=9) were not as commonly integrated into the lesson. Science concepts were generally integrated into the engineering intervention as a basis for justification of design decisions [36], [40], [51], [52], [55], [68], [80], [82], [83], [85], [86], [87]. For example, students designed a solar oven to cook fish and applied ideas of heat transfer in the design [86].

NGSS Engineering Expectations. For NGSS performance expectations, this study focused on ETS performance expectations for grades 3-5 and MS. These expectations can be categorized into the following components of design practices, with their frequency across the literature shown in Figure 5.

- Defining an engineering problem 3-5 ETS1-1, MS ETS1-1
- Developing solutions 3-5 ETS1-2, MS ETS1-2
- Testing solutions 3-5 ETS1-3, MS ETS1-3
- Optimizing design: MS ETS1-4

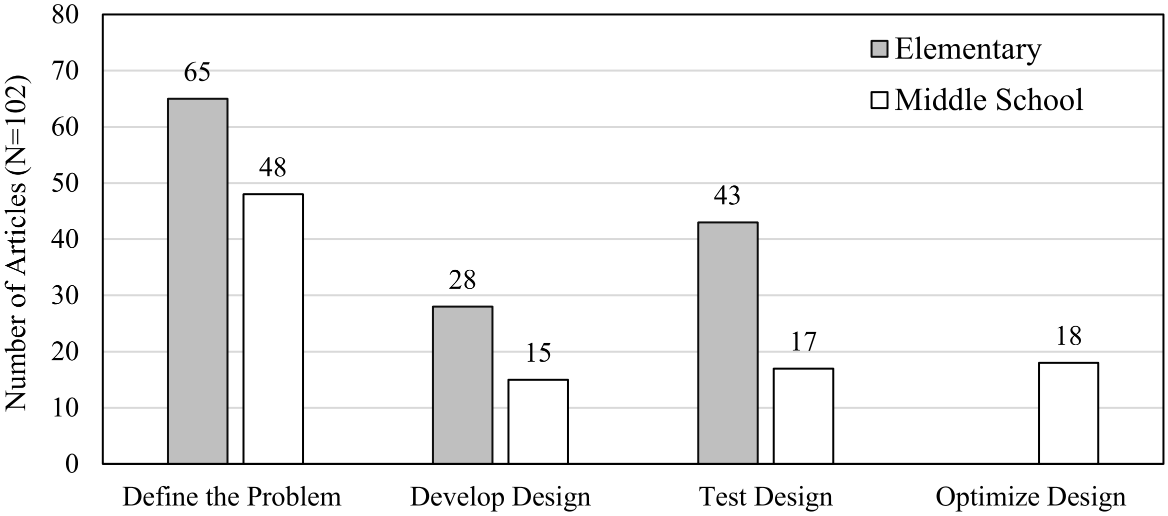

Figure 5. NGSS ETS Expectations Promoted in Middle School Literature (N=102)

While 69% of all literature aligned with at least one of the elementary-level expectations, only 54% met any of the middle school performance expectations despite being used in a middle school classroom.

NGSS: Defining the Problem (ETS1-1). NGSS ETS1-1 involves defining an engineering problem. Elementary students are expected to frame a problem using criteria and constraints (3-5 ETS1-1; 64% of studies). For example, in one study, designing a tower out of notecards to hold the most weight was described as meeting this expectation [37]. Several interventions featured generic problems with constraints to meet this expectation, such as designing a fitness game [88] or developing a method to communicate a solution [89]. The middle school version takes problem framing further and requires students to consider relevant scientific principles and environmental impact (MS ETS1-1; 47% of studies). For example, students were tasked with designing a learning space that meets certain decibel levels, budget, and space requirements while applying scientific principles of sound and impact on inhabitants [55].

NGSS: Developing Solutions (ETS1-2). The second performance expectation, ETS1-2, involves comparing multiple design solutions. The elementary version has students compare solutions to the criteria and constraints of the problem (3-5 ETS1-2; 27% of studies). For example, students designed a phone amplifier by creating multiple solutions and refining ideas into a final prototype [90]. In middle school, students are expected to implement a systematic approach to evaluating multiple ideas (MS ETS1-2; 15% of studies). One example is an upgraded version of the tower challenge, where students used a score equation to consider trade-offs of material usage, height, and weight supported [37]. Using a design matrix method, students systematically compared multiple tower design ideas.

NGSS: Testing Prototypes (ETS1-3). The third performance expectation, ETS1-3, involves testing prototypes. Elementary students need to control variables and consider failure points in the design for improvement (3-5 ETS1-3; 42% of studies). For example, students were tasked with designing and building a small cooking device using solar energy, and testing involved ensuring the container met design criteria and the device reached the desired temperature for cooking [86]. If testing revealed that the device did not meet the requirements, students worked to make improvements, such as altering the materials. In middle school, testing needs to involve multiple design solutions where students identify the best features of each design and combine them into a better design (MS ETS1-2; 17% of studies). For example, students optimized a truss structure design by creating multiple solutions and recording results for each. Using a spreadsheet, students calculated cost and mass and predicted deflection to provide a score for comparing solutions [81].

NGSS: Optimize Design (ETS1-4). The fourth performance expectation, ETS1-4, involves developing a model to generate data for iterative testing and optimization. This expectation is first introduced in the middle school grades (MS ETS1-4; 18% of studies); thus, it does not have an elementary-level expectation. The term "model" or "modeling" took on various definitions across the articles, reflecting the multiple uses of the term in the NGSS. The expectation in NGSS appears to focus on students collecting data and using that data to inform changes through an iterative process, and the use of the term "model" in this expectation is unclear. Some papers defined a model as the drawing of an engineering design solution, such as a coin sorter [74]. Others defined modeling as a physical model allowing testing and data collection, such as a robot [56], [77] or a drag device made of recycled materials [66]. These examples required students to use an iterative approach that included designing, testing, and reflecting to create a better design. While physical prototypes were limited to a few design cycles, some articles described the ability to quickly complete multiple iterations of design through a virtual design challenge [35], [38], [83], [91], including mathematical modeling to predict behavior based on material properties [81]. The studies were coded when the term "model" or "modeling" was used in the context of data-driven changes. Still, substantial overlap may exist with ETS1-3 given the multiple uses of the term "model."

Discussion and Implications

The literature on engineering education in K-12 settings has substantially increased in recent decades. A review by Diaz and Cox [21] from 2000 to 2011 included 50 studies, which expanded to 218 articles by 2015 [19]. While recent reviews have explored components of engineering education, such as teacher perceptions [22] or teaching strategies for engineering design [26], a more comprehensive review of engineering education across the literature since 2015 is missing. This is especially pertinent given the ongoing debate surrounding the NGSS [8] and the FPEL [10] concerns about the potential misrepresentation of the engineering discipline within a science-centric context. The current study addresses this gap by investigating the trends in the literature from 2012 – 2022, focusing on exploring how current engineering education efforts reflected in the literature align with the NGSS and FPEL viewpoints of engineering learning. Because the literature has drastically expanded since the last broad review [20], this study focused on middle school classrooms in the United States, a gap in the FPEL [10]. A search of practitioner and research studies found 102 articles between 2012 - 2022. Most (n=71) were research studies, representing an increase from 50 research studies of middle school settings worldwide from 2000 - 2015 [19].

Engineering as a Vehicle for Science Learning

The release of the NGSS in 2013 sparked the wide-scale incorporation of engineering into K-12 science classrooms as a context to apply science knowledge [8]. According to Lopez and Goodridge [93], 70% of state science standards were directly influenced by the NGSS, and 80% now include engineering. This growing emphasis on engineering is reflected in the current study, with 57% of articles explicitly citing the NGSS and the number of articles increasing each year after 2017. An exception occurred in 2022, likely due to the impacts of the COVID-19 pandemic and a shift to distance learning [94].

A closer look at the alignment of NGSS in the middle school engineering education literature found that 58% of interventions intended to promote the learning of science concepts by applying scientific principles to design decisions, reflecting a view that engineering design activities provide a context for students to learn and apply scientific ideas [92], [95], [96]. However, of the articles that investigated design-based science lessons, only 17% evaluated the learning of science. Instead, research articles predominantly measured the impact of developing design practices (42%), followed by attitudes towards engineering (19%) and habits of mind (19%). If the goal of design activities is science learning, research is needed to understand the extent to which engineering education can meet this goal, as well as effective integration strategies. In addition, increased efforts are needed to overcome teachers' limited pedagogical and content knowledge of engineering-based science teaching [45], [97], [98], [99].

Challenges in Promoting Authentic Design Practices

To promote engineering literacy, the NGSS and FPEL identify design practices as a key component of K-12 engineering instruction, reflected in 75% of the middle school literature [8], [10]. However, only 54% aligned with an NGSS middle school performance expectation despite being used in a middle school classroom. Interventions often encouraged a trial-and-error approach to design solutions [35], [44], [53], [100], which is counter to the view of the FPEL where "engineering design—is an iterative process. It is not about trial and error [but] a systematic, intelligent process" (p. 25-26) [10]. The NGSS supports this view of informed design, but only 15% of the articles examined in this study asked students to "evaluate competing design solutions using a systematic process" (MS-ETS1-2), and only 18% supported the development of a model for iterative testing (MS-ETS1-4). This discrepancy echoes the concerns raised in the FPEL that the current state of engineering may lead to misconceptions about the discipline [10].

One consideration is whether such expectations are developmentally appropriate for middle school learners. For example, Wilkerson et al. found that when engaged in self-directed engineering activities, middle school students often do not explore multiple solutions (MS ETS1-2) and instead use a trial-and-error approach [101]. Even with prompting, Gale et al. found that students rarely iterated on a design or considered tradeoffs, an expectation of MS ETS1-4 [77]. The authors also noted that teachers often viewed optimization as too advanced for students or found the process too time-consuming when faced with the expectations of required science content standards. While several included articles investigated teaching strategies that promote engineering practices (n = 19), more research is needed on factors hindering effective implementation.

Connecting Design to Engineering Knowledge

Another component of engineering practices is utilizing relevant content knowledge to make informed design decisions [102] - [105]. The NGSS identifies design practices that are connected to science content, but this overlooks how engineering knowledge, an essential part of design, has a related but separate theoretical base from science [60], [74]. When the authors of the NGSS connect science concepts to design practices, the goal is to promote learning of the *natural* sciences. In contrast, when engineers develop design solutions, they pull from knowledge of the *engineering* sciences [106]. For example, in MS-PS3-3, students are asked to "apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer." In this case, an understanding of thermal energy transfer supports the design of a solar cooker, a concept that the FPEL identifies as part of engineering sciences [10]. On the other hand, in MS-LS2-5, students are expected to "evaluate competing design solutions for maintaining biodiversity and ecosystem services" [8]. A provided example is the design of a water purification system, which would require students to apply knowledge of filtration methods, flow rates, and material properties, all identified as part of the FPEL engineering sciences. Instead, the NGSS expects connections to the life science topics of ecosystem dynamics and the impact of biodiversity on human resources. Unclear is how the design of a water purification system promotes these ideas.

As raised by Pleasants and Olson, more work is needed to understand the kinds of knowledge that are internal to engineering and how knowledge is used from other disciplines [17]. For example, 58% of included articles promoted an NGSS science core idea compared to 15% of articles connected to the engineering sciences. How does engineering science connect with the traditional natural sciences, and what is relevant to K-12 engineering instruction?

Moving Beyond Design

The FPEL proposes engineering literacy for all students, which moves beyond a focus on design [10]. The three-dimensional approach includes habits of mind, practices, and knowledge, with earlier grades emphasizing habits of mind. This was evident in the 89% of studies coded for FPEL habits of mind (e.g., creativity, collaboration, and persistence), with several studies investigating behaviors like collaboration or conflict management during team activities [40], [63], [64], [65]. However, such habits of mind, including teamwork and persistence, permeate educational experiences (e.g., sports, group projects, science labs) and thus do not distinguish engineering as a discipline. Instead, such "engineering" habits of mind are likely desired outcomes of any high-quality educational experience. According to the FPEL, engineers collaborate to achieve an optimal design that appeals to customers and other stakeholders [10]. The context of the engineering problem is essential. Thus, understanding how habits of mind are promoted within high-quality engineering education experiences needs investigation rather than viewing habits of mind as isolated outcomes [107].

Along with habits of mind, the FPEL identifies engineering practices as a primary focus in middle school grades, with the development of engineering knowledge limited to an initial introduction [10]. However, this raises the issue of the extent to which authentic design practices and habits of mind can be taught without a connection to engineering knowledge. For example, in a paper tower challenge, without understanding topics like statics and material properties, students use a trial-and-error approach to determine a design that will hold a certain weight [89]. Such an approach lacks a connection to authentic professional engineering work that relies on extensive content knowledge to solve engineering problems [108]. Compare this approach to what is used by the *Accreditation Board for Engineering and Technology* (ABET) [109], which accredits undergraduate engineering programs. ABET requires engineering students to complete minimum credit hours in science, math, and engineering before a culminating design experience based on knowledge developed in earlier classes. In contrast, the current literature review found that middle school engineering instruction is heavily focused on design practices (85%) with limited connections to engineering knowledge, including sciences (25%), mathematics (13%), and technical applications (5%). If authentic engineering practices are a goal for K-12 engineering learning, more understanding is needed on how these incorpoate relevate knowledge domains at an appropriate level.

Limitations

This systematic review and analysis is limited to what is reported in the literature and is not comprehensive of the state of engineering across all middle school classrooms. Reported research is based on what researchers select to study, often following trends promoted by education journals or funders [110]. Additionally, peer-reviewed journals and other publication sources generally favor strong positive results [111]. Second, the coding of literature was limited to the available information on the engineering intervention. In some cases, especially in practitioner articles, the lesson sequence, teacher behaviors, and student activities were well documented. Others only provided a few sentences on the engineering intervention. Therefore, a lack of coding could reflect a lack of information and not the exclusion of that component from the actual intervention. Also, this review intended to capture the learning goals as identified by the authors and not whether the intervention was effective in promoting these. While 56% of the literature cited the NGSS, none mentioned the FPEL. In both cases, the researchers relied on available information on the intervention to determine alignment with the learning goal.

Conclusion

The findings of the systematic literature review provide insight into how engineering is being promoted across middle school classrooms. The influence of the NGSS was found in the emphasis on engineering practices, often with the goal to promote the learning of science concepts. However, more research is needed to ensure these integrations support authentic engineering practices [55], [112], [113]. Less common in the literature was the FPEL vision of engineering literacy as a separate discipline with a distinct knowledge base [10]. Promoting authentic learning experiences requires more work to understand the nature of engineering, how it connects to other fields of study, and what is most relevant for K-12 students [17], [112], [113], [114]. A critical component is the teacher in scaffolding and supporting engineering learning [115] - [117]. However, educators often lack preparation in engineering and need professional development to navigate and facilitate effective engineering instruction [97]. These issues must be considered to develop attainable engineering learning goals for K-12 settings.

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Appendix. Search Strategy

Search Terms Limited to 2012 - 2022	**Database**	**No. of Studies** 2/15/2023
((DE "Engineering" OR DE "Engineering Education" OR DE "Engineering Technology") OR TI engineer*) AND ((DE "Middle Schools" OR DE "Grade 6" OR DE "Grade 7" OR DE "Grade 8" OR DE "Intermediate Grades" OR DE "Junior High Schools" OR DE "Middle School Students" OR DE "Middle School Teachers") OR TI (middle school OR junior high OR 6th OR 7th OR 8th OR "grade 6" OR "grade 7" OR "grade 8") OR AB (middle school OR junior high OR 6th OR 7th OR 8th OR "grade 6" OR "grade 7" OR "grade 8")) AND (DE "Classroom Research" OR TI Class* OR AB Class*) NOT (DE "Foreign Countries")	ERIC via EBSCO	174
	Academic Search Ultimate via EBSCO	96
	Education Source via EBSCO	75
	PsychINFO via EBSCO	35
("Document Title": "engineer*") AND ("Abstract": "middle school" OR "junior high" OR "Grade 6" OR "Grade 7" OR "Grade 8")	IEEE via IEEE Xplore	37
(((Engineering Education) WN CV)) AND (("middle school" OR "junior high" OR "Grade 7" OR "Grade 8" OR "Grade 6") WN AB)) AND ((class*) WN KY)))	Compendex via Engineering Village	254
	Inspec via Engineering Village	38
engineering OR design "middle school" OR junior -outreach -OR -informal -OR -summer -OR -camp	Google Scholar	941