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Work in Progress: A Systematic Literature Review of Engineering Education in Middle School Classrooms

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(Work in Progress) A Systematic Literature Review of Engineering Education in Middle School Grades

Introduction

This work-in-progress paper is a systematic literature review of engineering learning and teaching in middle school classrooms. Following the release of the Next Generation of Science Standards (NGSS) in 2013, most state science standards now include engineering in some capacity [1] [2]. This has resulted in a dramatic increase in research on pre-college engineering education in recent years [3]. However, the learning goals for pre-college engineering are still being contested. One argument, which is promoted in science standards, is that engineering design provides an authentic context to apply science concepts [4] [5] [6]. However, others argue that this represents too narrow a view of engineering and promotes misconceptions [7] [8]. In response to these concerns, the American Society for Engineering Education (ASEE) and Advancing Excellence in P12 Engineering Education introduced a *Framework for P-12 Engineering Learning* [9]. This framework outlines learning goals for engineering literacy that move beyond a narrow focus on practices, including engineering habits of mind and knowledge. In addition, the authors call for further research to scaffold learning goals for lower grades. To contribute to this ongoing effort, this study assesses the trends in researching and teaching engineering at a middle school level, particularly within formal classroom instruction. For this work-in-progress paper, we present preliminary results of studies addressing the following questions:

- RQ1: What are the trends in research related to engineering in middle school classrooms?
- RQ2: How is engineering integrated into middle school classrooms?
- RQ3: How has the NGSS, released in 2013, impacted the learning goals of engineering in middle school classrooms?

Method

The systematic literature review follows the procedure developed by Borrego et al. [10], including conducting an initial review to refine the research question, defining inclusion criteria, finding and organizing articles based on inclusion and exclusion criteria, appraising articles, and synthesizing. The search strategy, outlined in Appendix A, focused on studies covering an engineering intervention in middle school classroom settings. The following eligibility criteria guided the screening process:

1. The article was published between 2012 - 2022. This review will pick up from a 2012 literature synthesis [11] and include the impact of NGSS released in 2013.
2. The article was in English and took place in the United States. The goal is to understand the impact of the NGSS developed for American K-12 schools.

3. The article was peer-reviewed, including dissertations, practitioner papers, and conference proceedings. The aim is to ensure that articles meet quality standards as determined by others in the engineering and education communities.
4. The article was focused on instruction in a formal classroom setting for grades 6 - 8.
5. The article has an explicit connection to engineering teaching or learning.

A search was conducted on February 15, 2022. All resulting citations were exported to Covidence, a web-based software for systematic reviews [12]. Covidence removed any duplicates. Articles were reviewed for relevance, and eligibility criteria were applied. Two authors screened the same subset of articles (n=32) for a Kappa coefficient of 0.904 [13]. The screening process, shown in Appendix B, resulted in 234 included studies. This work-in-progress paper presents preliminary results from 48 papers published after 2020.

Before data extraction, the authors developed a coding guide to address each research question. The guide was tested and revised through several rounds of application to the literature. The researchers addressed RQ1 by coding research articles for the design type and goals of the study. This will allow for comparing research trends to the review by Diaz and Cox [11] spanning 2000 - 2012. For RQ2, the focus is on understanding the integration of engineering based on the ASEE Framework [9]. For RQ3, the intention is to identify the influence of the NGSS, including the presence of NGSS science and engineering practices, engineering performance expectations, and core ideas. The final guide is found in Appendix C.

Results

RQ1: What are the trends in research?

Of the included studies, 70% were research articles. The predominant methodology was qualitative (43%), followed by quantitative (14%) and mixed-methods (10%). These studies were categorized by research method (Table 1). Most of the research focused on understanding student behaviors and thinking during engineering instruction (38%) primarily through a qualitative approach. For example, researchers observed or interviewed students engaging in design activities to describe design decisions [16] [17], behaviors during team activities [18], and views related to design thinking [19] [20]. Research around understanding teacher behaviors focused on questioning techniques [21], instructional frameworks for integration [22], the impact of disciplinary background [23], and professional development [24].

A smaller portion of studies measured the impact of the intervention on changing behaviors (9%) or increasing knowledge (15%). This included measuring the performance of the final prototype meeting design criteria [25] [26]. Others focused on measuring increased spatial thinking [27] [28], changes in science and engineering practices [43], and increased understanding of science concepts [29] [26] [30]. Only [31] evaluated engineering concepts.

Table 1. Identifying Trends in Research Aims for Middle School Engineering Education

Categories	*N*
Understand student behaviors and thinking during engineering activities and instruction	13
Understand teacher behaviors implementing engineering activities	7
Measure the impact of the intervention on student's learning (i.e., science concepts)	5
Measure the impact of the intervention on the teacher's learning, behaviors, and attitude (i.e., change in confidence)	4
Measure the impact of the intervention on student's attitudes (i.e., confidence, interest)	4
Measure the impact of the intervention on student's behaviors (i.e., skills like communication)	3

RQ2: How is engineering integrated into middle school classrooms?

The majority of the studies (68%) involved interventions centered around the engineering design process, including the designing and building of a physical prototype such as a prosthetic arm [32], soda can crusher [33], insulating cooler [16], rollercoaster [21], water filter [29], and luggage ramp [22]. The goal of each was to build a prototype that met specified design criteria. Using the ASEE performance expectations [9], Table 2 presents the engineering design practices promoted in the literature. Most instruction included problem framing, information gathering, ideation, prototyping, decision-making, and design communication. Less than half (49%) described the use of engineering graphics, and only 2 studies included project management as part of the intervention.

Table 2. Engineering Design Practices Promoted in the Literature

Categories as defined by the ASEE Framework for P12 Engineering Learning	*N*
Problem Framing	30
Project Management	2
Information Gathering	30
Ideation	34
Prototyping	34
Decision Making	30
Design Methods	19
Engineering Graphics	24
Design Communication	30

RQ3: How has the NGSS impacted learning goals?

A majority of the literature explicitly mentioned the NGSS (59%). This included a heavy emphasis on science and engineering practices, especially connected to defining problems and designing solutions. Additionally, more than half of the studies (56%) integrated science learning into the engineering unit. This was primarily through the use of science concepts to justify design decisions [25] [34] [35] [23] [16] [22] [36] [38] [20] [18] [19] [24] [38]. Table 3 highlights which NGSS core ideas were emphasized during the engineering lesson. Physical science concepts were dominant, including ideas like energy transfer [38] and forces and motion [16] [21] [22] [36] [44]. For example, students designed a solar oven using ideas of heat transfer [38].

Engineering lessons presented in the literature were coded for alignment to specific NGSS engineering design performance expectations for grades 3-5 and 6-8. While a large majority (69%) aligned with elementary-level expectations, only 46% met a middle school performance expectation despite being used in a middle school classroom. The focus was on 3-5 ETS1-1 and MS ETS1-1, which involves defining a design problem based on criteria and is generally connected to the design and testing of a prototype. However, a few interventions focused on developing an idea based on the parameters provided. For example, students designed a fitness game that met specific criteria [39] or developed a method to communicate a solution [40]. These activities did not evaluate design ideas, carry out testing, or other aspects of the design process.

Less common in the literature was instruction around engineering practices that promote evaluation using a systematic process, comparison of multiple design solutions, and iterative testing. For example, students designed a phone amplifier by creating multiple solutions and refining ideas into a final prototype [41]. In a few studies, students analyzed testing data [26] [36] [38] or used a digital tool for the simulation and testing of designs to support an iterative process [42]. However, the vast majority of the design activities involved more of a trial and error or tinkering approach to building the prototype.

Table 3. NGSS Promoted in Engineering Interventions

Category	*N*
NGSS Physical Science Core Ideas	24
NGSS Life Science Core Ideas	10
NGSS Earth & Space Science Core Ideas	8
NGSS Engineering Design Performance Expectations*	
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.	33
3-5 ETS1-2: Generate and compare multiple possible solutions to a problem based on	13

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	22
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 taking into account potential impacts on people and the natural environment that may limit possible solutions.	22
MS ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.	5
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.	6
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.	7

*Note: ETS refers to the "Engineering, Technology, and the Application of Science" disciplinary strand of the NGSS. 3-5 refers to grades 3-5, and MS refers to grades 6 - 8.

Discussion & Future Work

A previous review on pre-college engineering included 55 articles published between 2001 to 2011 that included engineering at any grade level in any setting [11]. Our search strategy specifically focused on engineering at middle school grades and only in formal classroom settings, and the resulting 48 articles from 2020 - 2022 reflect a dramatic increase in research efforts. Additionally, earlier interventions were generally confined to outreach programming, and only 22% of the literature mentioned state standards [11] compared to 59% of our included studies. Despite this shift to classroom instruction, our results indicate that engineering integrations continue a focus on design practices and working prototypes [11] [45].

Additionally, an influence of the NGSS was found through 56% of articles integrating science concepts into the engineering design lesson, and several measured the impact of engineering instruction to promote changes in science learning [29] [26] [30]. Despite this alignment with the NGSS, only 46% of the engineering interventions appeared to meet middle school standards. Within these, the focus was predominantly on defining criteria and constraints and did not mention instruction around design evaluation, iterative testing, or optimization of design solutions. This was reflected in mapping literature to the ASEE Framework, which found that interventions did not generally emphasize design methods. Some studies appeared to conflate a general problem with an engineering problem, as shown in the activity to create a fitness game that met specific criteria [39].

Future work will involve applying the coding guide to the remaining studies from 2012 - 2020. This will provide a more comprehensive review of middle school engineering learning and insights into how integrations may have shifted over time.

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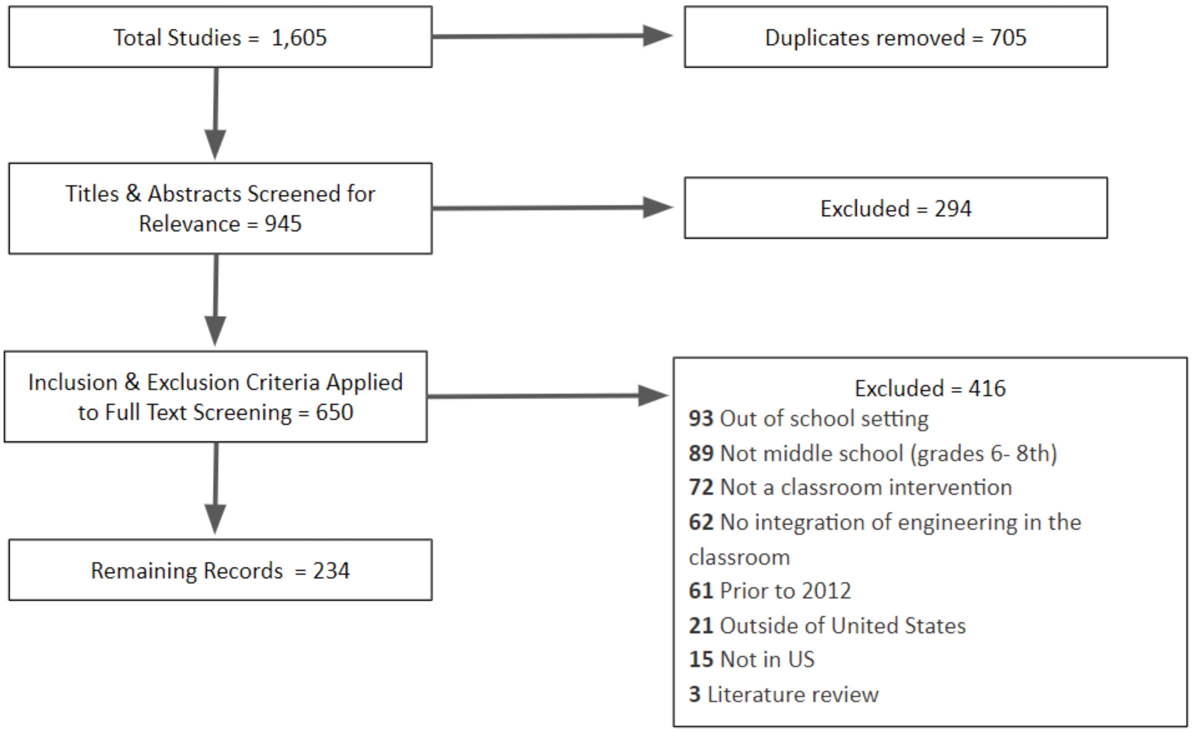
Appendix A: Search Strategy

Search Terms Limited to 2012 - 2022	**Database**	**# of Studies** Accessed 2/15/2022
((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
allintitle: engineering OR design "middle school" OR junior -outreach -OR -informal -OR -summer -OR -camp	Google Scholar	941

Appendix B: Screening Process



Appendix C: Data Extraction Coding Guide

Coding Scheme

General Characteristics

1. Study ID
2. Study Title
3. Journal Title
4. Citation
5. Lead author affiliation

RQ1: What are the trends in research in middle school engineering classrooms?

1. Article Type
    a. Practitioner
    b. Qualitative
    c. Quantitative
    d. Mixed-Methods
2. What are the research goals?
3. What are the areas evaluated and reported on in the study?

RQ2: How is engineering integrated into middle school classrooms?

1. Name of the curriculum, if any.
2. Describe the intervention.
3. Based on the ASEE Framework for P12 Engineering Learning, which of the following engineering practices are explicitly incorporated into the intervention?
    a. Engineering Design
    b. Material Processing
    c. Quantitative Analysis
    d. Professionalism
4. Which of the following engineering design practices are incorporated into the intervention?
    a. Problem framing
    b. Project Management
    c. Information Gathering
    d. Ideation
    e. Prototyping
    f. Decision-Making
    g. Design Methods

   h. Engineering Graphics
   i. Design Communication

5. Which of the following engineering habits of mind are explicitly described as part of the intervention?
   a. Optimism
   b. Persistence
   c. Collaboration
   d. Creativity
   e. Conscientiousness
   f. Systems Thinking

6. Which of the following engineering knowledge domains were explicitly described as part of the intervention?
   a. Engineering Sciences, including statics, mechanics of materials, dynamics, thermodynamics, fluid mechanics, heat transfer, mass transfer & separation, chemical reactions & catalysis, and circuit theory.
   b. Engineering Mathematics, including algebra, geometry, statistics, and calculus, to support solving engineering problems.
   c. 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.

7. If included, describe what engineering knowledge was part of the intervention.

RQ3: How has the NGSS impacted the learning goals of engineering in middle school classrooms?

1. List any standards referenced in the article.

2. Which NGSS Science & Engineering Practices are addressed in the intervention?

   a. Asking Questions and Defining Problems
   b. Developing and Using Models
   c. Planning and Carrying Out Investigations
   d. Analyzing and Interpreting Data
   e. Using Mathematics and Computational Thinking
   f. Constructing Explanations and Designing Solutions
   g. Engaging in Argument from Evidence
   h. Obtaining, Evaluating, and Communicating Information
   i. Unclear
   j. None

3. If present, how is science integrated into the engineering lesson?

4. Which NGSS engineering performance expectations are addressed in the intervention?

a. (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.
b. (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
c. taking into account potential impacts on people and the natural environment that may limit possible solutions.
d. (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.
e. (MS-ETS1-2) Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
f. (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
g. (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.
h. (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.
i. None
j. Unclear

5. If science concepts are a learning goal, which NGSS core ideas are most aligned with the intervention?
    a. PS1: Matter and Its Interactions
    b. PS2: Motion and Stability: Forces and Interactions
    c. PS3: Energy
    d. PS4: Waves and Their Applications in Technologies for Information Transfer
    e. LS1: From Molecules to Organisms: Structures and Processes
    f. LS2: Ecosystems: Interactions, Energy, and Dynamics
    g. LS3: Heredity: Inheritance and Variation of Traits
    h. LS4: Biological Evolution: Unity and Diversity
    i. ESS1: Earth's Place in the Universe
    j. ESS2: Earth's Systems
    k. ESS3: Earth and Human Activity