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Systematic Review of Research in P-12 Engineering Education from 2000–2015*

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Nations throughout the world have recognized the importance of having a Science, Technology, Engineering, and Mathematics (STEM) competent workforce in today's highly competitive and technical economy. As such, the past fifteen years have seen a sharp rise in introducing pre-college (P-12) students to engineering and engaging them in learning engineering principles. Policy decisions to include engineering in national curriculum and standards have not been informed by as rich a body of research as subjects such as mathematics and science; however, research on P-12 engineering education is on the rise. This paper presents a systematic review of the engineering education research in P-12 published in journals from 2000–2015. A systematic review follows a set of replicable, detailed procedures that describe how the articles were selected, reviewed, and analysed. The results of this review included 218 peer-reviewed journal articles. The paper details the kinds of research and research questions these papers focused on, and synthesizes and discusses findings of across different topics, and proposes research topics ripe for further work.

Keywords: systematic review; pre-college; literature synthesis

1. Introduction

Introducing P-12 students to engineering has been on a sharp rise over the last twenty years [1–6]. As nations recognize the need for Science, Technology, Engineering, and Mathematics (STEM) professionals to support a vibrant economy and to advance solutions to humanity's grand challenges (http://www.engineeringchallenges.org/), they have invested many resources in promoting engineering from an early age. Recently, in the United States context the Next Generation Science Standards [7], which are shaping many states' science curriculum, include engineering as a core part of the curriculum. Likewise, many other developed nations have as a matter of policy placed emphasis on engineering and design in national curriculum and standards [2–4]. These policy decisions have not been informed by the same amount of research-based evidence as reforms in mathematics, literacy, or the traditional science disciplines as the body of research in engineering education at the precollege level is in its infancy.

Diaz & Cox [8] conducted a systematic literature review on precollege engineering education research published 2000–2011. The review criteria they defined led to just over 50 research papers within US contexts. We believe this review preceded a turning point in P-12 engineering education research that has led to a relative expansion of published research articles. The review also chose not to include non-US research publications. For these two primary reasons coupled with the continued investment in bring engineering education experiences to P-12 students, the authors felt there was a need and opportunity to conduct a broader systematic review of research in precollege engineering education. As Borrego, Foster & Froyd [9] noted such a systematic review can help trace the historical development of a field or research area, describe the state of knowledge or practice, and support the evaluation and development of theory. As the research in the area of P-12 engineering education is still in its infancy, this review can establish a historical marker in relation to the Diaz & Cox review, update the field on the current state of knowledge and research practice, and provide some early foundations for continued work toward theory development and evaluation. Ideally, this review will support researchers in P-12 engineering education in situating their own work, identifying new areas for exploration, and continue knowledge building in this important area.

1.1 P-12 Engineering education landscape

The formal inclusion of engineering in state and national curriculum has a relatively short history. Massachusetts was the first state within the United States to formally recognize engineering as a standard part of the curriculum for pre-college students [10]. However, the United Kingdom's move toward a National Curriculum in 1990 included a revamp of the way they taught technology education. The new National Curriculum called for the teaching of Design and Technology where design as a process was newly prominent asking students to design

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technological artifacts aimed at making people's lives easier [11]. There are many similarities to the engineering education movement in the United States to United Kingdom's focus on the design process. Other nations have identified the need to prepare their students to solve complex problems with creative and innovative solutions using engineering and design. As this review highlights, there are many programs around the world being developed and tested to improve the perceptions, knowledge, and abilities of both P-12 students and teachers.

2. Method

Guided by papers that detail the methodology for conducting a systematic review [9, 12] as well as examples of systematic reviews [8, 13], the authors followed a six step systematic process: (1) identified the scope and research questions for the review; (2) defined a set of inclusion criteria; (3) found and catalogued sources; (4) critiqued and appraised the articles; (5) synthesized the results; and (6) reported the findings along with the potential limitations of the review. Following guidelines from these methodological papers on systematic reviews and systematic review papers, a set of inclusion criteria was created to identify peer-reviewed journal publications on P-12 engineering education research.

2.1 Scope and research questions

The goal of this review was to identify all research papers published in peer-reviewed journal publications on the topic of P-12 engineering education. The field of P-12 engineering education research is relatively new and still growing. The research questions guiding this review concern more general trends and specific details of the research being conducted:

Research Questions

1. How many and what are the nature of research articles being published on P-12 engineering education in peer-reviewed journal publications since 2000?
2. Are there any trends in the types or focus of research articles being published on P-12 engineering education in peer-reviewed journal publications since 2000?
3. What is the nature of the research questions being asked in these research articles?

2.2 Inclusion criteria

Given the above scope and research questions, the following set of criteria were defined. All papers must have met these criteria (see Table 1) to be included in the review. Rationale for each criterion is provided below.

Table 1. Systematic review inclusion criteria

Criteria	Description
Publication type	Peer-reviewed journal publication
Paper type	Research (we did not consider position papers, literature reviews, or practitioner papers)
Publication date	January 2000–February 2015
Research context	P-12 engineering & design teaching and learning (this may include research on P-12 teachers, informal settings involving P-12 students, formal classroom settings)
Language	Paper is written in English

2.2.1 Rationale

Publication type. Choosing peer-reviewed journal articles was a choice that eliminated many conference papers reporting on P-12 engineering education research. This choice was made due to the large number of conference papers and the highly variable quality of these publications. Peer-reviewed journal articles were surmised to be of generally higher quality than conference papers. This certainly is not always the case. Many conference papers are very strong. For this reason, we note this as one limitation of the current review as there are many high quality works submitted to conferences around the world; however, including all such papers was beyond the scope of this review.

Paper type. All papers were expected to be reporting on original research. The field has many position pieces, literature reviews, and practitioner papers; however, in assessing the state of research in the field only research papers were considered.

Publication date. As mentioned previously, papers from January 2000 through February 2015 were considered. This coincides with the timeline Mendoza and Cox [8] used in their review adding the years since their review, and captures most work that started upon the inclusion of engineering in state and national curriculum frameworks.

Research context. Papers conducting research on P-12 engineering and design teaching and learning in any setting were selected. This includes research conducted with teachers and their preparation to teach engineering in both formal and informal P-12 settings. Survey studies were included if the participants were P-12 students, teachers, or administrators. Notable exclusions included studies reporting on educational technologies or curriculum that did not report on use by students or teachers. For example, some studies described the efficacy of P-12 educational technologies, but only reported on results from testing by undergraduate or graduate students.

Language. The authors required all articles be published in English as that is their common language.

2.3 Finding and cataloging sources

The authors consulted a University librarian to select the most appropriate databases to search for the purposes of this review. The databases provided sufficient breadth across journals in engineering and education. The search was conducted across five large periodical databases (PsycInfo, EBSCO Full text/ERIC, Scopus, Professional Development Collection, EBSCO Education Source). Initial searches used a relatively broad set of search criteria so as to avoid eliminating potential articles. Each database has slightly different methods for searching, but the search terms in Fig. 1 were used to search the titles, subjects, and abstracts of articles within each database. Additionally, the search was restricted to peer-reviewed journal publications published from January 1, 2000 through February 28, 2015. The resulting sets of publications from each database were consolidated into the Mendeley citation manager to eliminate duplicates. This initial search resulted in more than 5,000 articles. These articles went through numerous elimination rounds as many false positive results were found. For example, the STEM search term returned results of teaching stem-cell biology to students. First, article titles were scanned to identify such obvious mismatches. Then article abstracts were read to further eliminate articles that did not match the inclusion criteria specified in Table 1. Final elimination or inclusion was determined when the remaining articles were retrieved and the body of the article was scanned to determine if it met the inclusion criteria as well as evaluated along a number of dimensions that will be discussed in the forthcoming Critique and Appraisal section. This process resulted in a total of 218 research articles.

2.4 Critique and appraisal

To provide insights into the variety and quality of the research within this article set the authors developed a rubric to evaluate the research studies. This rubric collected the citation, year of publication, country of study, research method, research setting, participant type(s), number of participants, whether a theoretical framework was cited, research questions, research methods (approach, appropriately cited, and justified). The analysis of this data is included in the following section.

3. Results and synthesis

Following the procedures described above, the systematic review yielded 218 peer-reviewed journal publications on P-12 engineering education research. Fig. 2 shows the distribution of these articles over the years of the review (2000–2015). The significant increase in articles published after 2011 (the dates included in the Diaz & Cox review [8]) further justify the need for this review. This increase follows the increased emphasis on engineering and STEM education throughout the world as countries recognize the importance of being

((Engineer* OR STEM) AND (Educat* OR Learn* OR Teach*) AND ((Secondary AND School) OR (Primary AND School) OR K-12 OR P-12 OR Pre-college OR (Elementary AND School) OR (Middle AND School) OR (High AND School)))

Fig. 1. Boolean search terms used to identify potential articles. Note: * denotes any characters following search term would be included (i.e., educat* includes education, educator, educate, etc.).

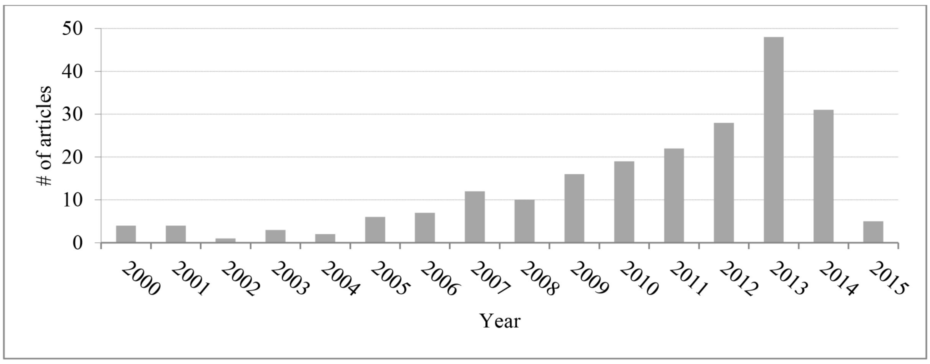

Fig. 2. Articles by publication year.

competitive in a STEM-driven, global economy. The emergence of engineering education Ph.D. programs in colleges of education and engineering are also likely responsible for this increase as many such programs began 2004 or later (e.g., Purdue University, Virginia Tech, Utah State, Tufts University, etc.). Graduates of these programs began careers as researchers contributing to the increased research published in the field. The noticeable dip in publications from 2013 to 2014 might be explained by the lag in journal papers being indexed in the various databases. The research was primarily conducted in the United States (N = 165), yet there was a diverse mix of international studies (N = 52). Leading the list of international studies were Taiwan (N = 9), Israel (N = 12), Australia (N = 7), United Kingdom (N = 5), and Canada (N = 4).

The articles described research studies that varied along a number of dimensions (research method, research subject(s), research context, location of study, etc.). The authors categorized the research methods of the studies as quantitative, qualitative, mixed methods, evaluation, or other. Many of the papers specifically stated the research approach, but did not put it in these specific terms for which cases the authors of this paper categorized the stated methods appropriately. The resulting breakdown of the 218 papers is as follows: 38% quantitative, 37% qualitative, 19% mixed methods, 11% evaluation, and 4% other. Things counted as evaluation approaches were explicitly stated as such, and those categorized as other were not distinct or described well enough to be categorized.

The research setting roughly broke down as 75% in formal P-12 classroom or teacher professional development settings and 25% informal or out-of-school settings. The research subjects were primarily P-12 students where approximately 67% of the studies focused on students and 33% focused on adults (i.e., in-service and pre-service teachers, administrators, or parents). A number of studies considered data from both teachers and students. The breakdown of the age of students shows a skew toward older students. Fig. 3 shows the numbers of studies focusing on the varying grade levels. Clearly younger students in primary or elementary grades have been the focus of far fewer studies than those in early secondary (or middle school) and secondary (or high school). The number of research participants varies somewhat evenly from smaller-scale studies of less than 50 participants to those into the thousands of participants. Fig. 4 shows this breakdown.

3.1 Frequent terms used in publications' research questions

The third research question driving this systematic literature review had to with the nature of the

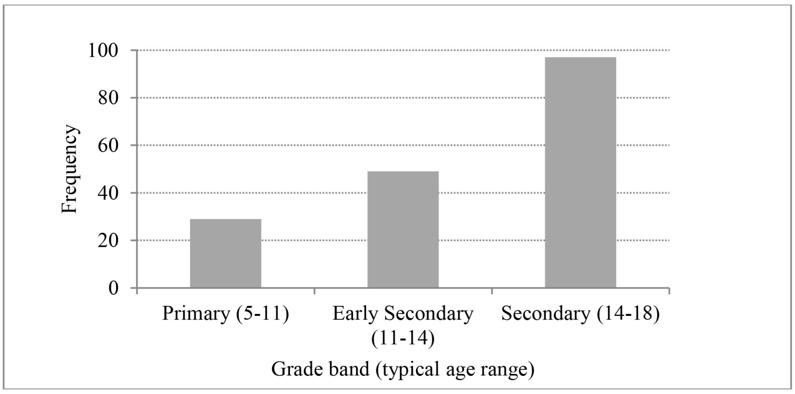

Fig. 3. Breakdown of age/grade range of research subjects for student-focused studies.

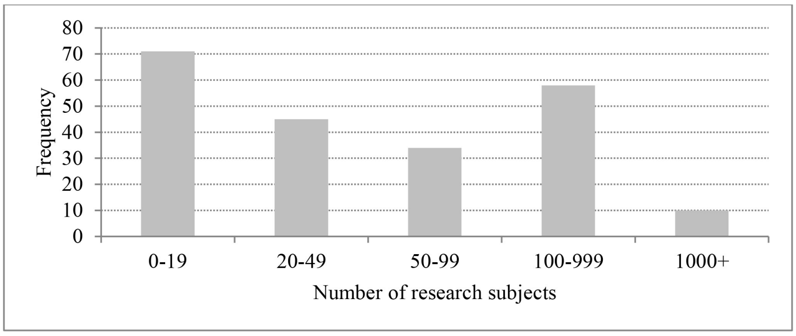

Fig. 4. Breakdown of number of study participants across articles.

research questions being asked by the studies. Each article was opened and the research questions, study purpose, or study aims were copied and pasted into our database. The text of the research questions was then analyzed to identify trends and themes. A simple frequency analysis of the over 9500 words provides some insights into what is being studied. The analysis was conducted after removing common words (e.g., a, and, the, etc.), generic research terms (e.g., study, research, and purpose), and common educational terms (e.g., teach, learn, school, students, teachers, etc.). The first subset of terms related to the disciplines other than engineering that were mentioned. To be expected the other STEM disciplines were most frequently mentioned in the following order technology (N = 60), science (N = 53), and mathematics (N = 35). Table 2 highlights the other most frequently observed terms. The use of these terms highlights the great focus on research subjects' affective orientations to engineering. The focus on affective versus learning outcomes was pretty evenly split. A number of studies report research aiming to measure change in students' perceptions, attitudes, and beliefs regarding engineering to motivate the engagement and pursuit of engineering. In the learning outcome space studies used terms such as knowledge, understanding, ability, cognitive, and learning.

This textual analysis of the research questions along with the analysis of the research papers (e.g., research method, research subjects, etc.) helped the authors develop a set of themes to explore in more depth. For each theme a subset of 5–10 exemplar papers were identified and then analyzed for more detail. The selection process identified higher quality papers. The process used to identify these papers was twofold. Each paper's research quality was assessed by noting if the paper cited a theoretical framework upon which the study was formed, connected the studies research questions to the theoretical framework, cited a methodology or methods used, justified the use of the method/ology, and included some sort of study validity, reliability, or trustworthiness of the data collection/analysis. Papers received a point for the presence of each of these. Papers scoring in the top half of the entire paper set were considered. From there, papers matching the themes were identified and further narrowed down to papers that were either highly cited in the field or from more highly regarded engineering education journals (i.e., *Journal of Engineering Education*, *International Journal of Engineering Education*, *Journal of Science Education and Technology*, and *International Journal of Technology and Design Education*).

Table 2. Research question frequent terms

Term	Count
Perception/perceive(d)	54
Knowledge	31
Attitudes	28
Process	25
Understanding	21
Ability	16
Cognitive	15
Skills	15
Learning*	15
Self-efficacy	14
Beliefs	12
Motiv-ate/ation	10

The themes centered on three key aspects of education (students, teachers, and curriculum). A very common theme in investigating students was to understand their perceptions, attitudes, beliefs, and motivations toward engineering. Issues related to knowledge and learning among students was also quite common and is somewhat captured in the final theme looking at curriculum and programs. The second theme had to do with the preparation of teachers and developing their knowledge and beliefs to teach engineering. Unlike most disciplines, teachers are not likely required to have an engineering degree or significant engineering coursework to teach engineering. Often, mathematics, science, or technology teachers are asked to teach engineering. Thus, there is significant work done to prepare these teachers. The final theme relates to engineering curriculum and programs where researchers investigated a variety of things related to their effectiveness. The emergence of P-12 engineering education has require new curriculum development that continues to evolve.

3.2 Students' perceptions, attitudes, beliefs, and motivations

Papers in this theme focus on student perceptions, attitudes, beliefs, and motivations with respect to engineering. Exemplar articles were chosen based on the aforementioned criteria and research questions that explicitly used the terms "attitude(s)", "perception(s)", and "motivation(s)" and "engineering" or "design". Articles were excluded from this theme if they focused on student attitudes, perception, and/or motivation toward specific instructional methods or technology rather than engineering, even if the methods or technology were engineering-based or -focused. Articles that asked whether a specific instructional method or technology had an impact on student attitudes, perception, and/or motivation related to engineering were included.

A total of ten papers were identified. Eight of the ten were collaborative research projects including multiple authors while single authors wrote two. A wide variety of journals are represented in this sample. Ten exemplar articles were published in eight journals including the *Journal of Engineering Education*, the *European Journal of Engineering Education*, *Advances in Engineering Education*, *International Journal of Engineering Education*, *Journal of Science Education and Technology*, *International Journal of Science Education*, and the *Bulletin of Science, Technology, and Society*. The wide range of journals reflects the lack of a "home" for engineering education in P-12 settings. Engineering has traditionally been taught in technology education classes, and more recently has been found in science classrooms. Engineering education as a field has also paid more attention to P-12 engineering education in recent years as this article has shown. Articles in science education, technology education, and engineering education journals reflect this fragmented history.

Eight of the articles were published in 2010 or later, again aligning with the growing interest in and body of research for P-12 engineering education. Seven of the ten studied formal P-12 classrooms, with one taking place in a design competition, one as a survey, and one within an after-school program. Eight studies took place in the United States, with one article taking place in Denmark and the final taking place in Israel. The studies varied in size, with three large-scale studies (N = 296, 442, and 565) and the other seven having fifty participants or fewer (N = 50, 46, 28, 20, 20, 20, 8). Three of the studies focused primarily on elementary school students, two on middle school students, four on high school students, and one study had elementary, middle, and high school participants. Nine studies used written instruments including surveys and tests like the Draw an Engineer Test, three used observations, and four used interviews as a data source. Six of these used purely quantitative research methods, two used qualitative methods, and three were mixed- or multiple-methods studies.

Four of these papers have a gender component in their results [14–16], one of which specifically focused their study on African-American males [17]. No studies compared results by ethnicity, and one compared urban and suburban students, finding that there was a difference in conceptions of an engineer between these two groups; urban students conceived of engineers more commonly as laborers while suburban students more often conceived of engineers as technicians [14]. Key findings include almost no males drawing female engineers in a study that incorporated the Draw an Engineer Test [14, 16].

It is a common idea that papers that do not have significant results do not get published in journals. In the studies that provided an intervention, five showed positive effects [15, 18–21] while three showed no significant effect [17, 22, 23]. Hands-on projects were involved in every intervention that showed a positive impact on engineering perceptions. In one study [15], the sample spanned elementary through high school students and found that the elementary students had greater changes in engineering perceptions compared to the older students.

The study of students' perceptions, attitudes, beliefs, and motivations with regard to engineering spans a broad base of educational and psychological constructs leaving much room for further study within the constructs identified in these papers and ones that have yet to be studied in an P-12 engineering context. The exemplars used in this study provide some foundation upon which to build future studies. The majority of these papers detail small-scale, exploratory studies providing opportunities for large-scale studies allowing for more reliable generalization across new and populations. Exact replication would be difficult for many of these papers due to their use of very specific and ever-changing interventions. Rigorous fidelity of implementation would be required for full replication, something that would be difficult to do in educational settings. Reproducing these studies in new populations and contexts, especially in scale-up efforts, would allow researchers to track common student perceptions, development, and reactions to the published interventions. One study has found that elementary students had a higher change in engineering attitudes and perceptions and few focused on gender, race/ethnicity, or other minority status [15]. Understanding the intersection of these factors and developmental changes is needed to implement timely, well-designed engineering interventions.

3.3 Teachers' beliefs and knowledge

Another theme identified among the papers was research pertaining to teachers (approximately 50 papers in total). Of the papers that were identified, over half were published between the years 2011 and 2015. Interestingly, the research that focused on teachers uses diverse methodologies; however, the research favors those using qualitative methodologies (67%), over quantitative (23%), and mixed methods approaches were employed even less often (10%). Over half (57%) of these studies contained a small number of participants (n = 0–19) while the remaining articles examined a large sampling of teachers (n = 20–49, n = 50–99, and n > 100), which were relatively evenly distributed among each category, 13%, 17%, and 13% respectively. While there has been an increase in the number of papers focusing on teachers, nearly all attend to in-service teachers. The relatively scarce number of research dedicated to pre-service teacher points to a potential population warranting further study.

Although the research investigated several different aspects related to teachers, the most common themes involved the exploration of teachers' beliefs, perceptions, and knowledge of engineering and engineering design. Six research papers were identified using the aforementioned quality metrics as well as identifying papers focused on teachers. The papers represent the variety of work that has been done in this area.

Teachers' beliefs and perceptions of engineering education have been studies using a variety of methodologies and samples sizes. In addition, it has been explored at elementary level [24], middle school level [25], and high school level [26]. Both Purzer et al. [24] and Nathan et al. [26] use survey instruments to gather information from a large population of teachers. Nathan et al. [26] research highlighted factors that teachers identify as influencing instructional choices when preparing students for engineering at the college level. Teachers consistently noted several factors as influential such as students' interests, background and academic achievement. Teachers indicated that socioeconomic status of their students was not a primary factor in their decision-making process, but did play a role under certain conditions. Purzer et al. [24] focused on how teachers' viewed the importance and familiarity of Design Engineering Technology (DET), in addition to how they perceived engineers when considering the different backgrounds of teachers. In general, teachers reported DET as being important; however, they were not familiar with it. The ethnic background of the teachers and teaching experience did result in motivational differences in teaching DET as well as difference in how teachers perceived engineers. Wang, Moore, Roehrig, and Park [25] used a qualitative approach to examine teachers' beliefs and perceptions about integrated STEM. Similar to the other two studies, they found that teacher perceptions of STEM integration influence their classroom practices and that it may also be discipline dependent. However, further research may be done to replicate these findings since the sample size was small. The findings from these three studies suggest that beliefs, perceptions, and expectation about engineering education tend to vary for teachers in different disciplines.

Another facet of research is exploring P-12 teachers' knowledge of engineering content as well as engineering education. Currently, researchers are using exploratory qualitative methods to gain insight into the teachers understating of the Engineering Design Process. Many of these investigations are occurring with in-service teachers [27]; however, research is emerging that focuses on pre-service teachers [28]. Hynes [27] found that teachers generally have a sufficient understanding of the engineering process as a holistic approach, but have a variable understanding of the different practices or stages of the engineering design process. Similarly, Wendell [28] found that pre-service teachers were able to create a stable framing for their design task and act agentively in the pursuit, but emphasized some design practices (i.e., solution generation and feasibility analysis) at the expense of others (i.e., information gathering, solution modeling, and evaluation).

3.4 Curriculum and programs

Research studies in the curriculum and programs theme had research questions centered on a specific lesson, unit, curriculum, program, or technology. Those who developed the intervention, in most cases, also conducted the studies except for a few cases involving widely adopted commercial curricula. Often data from both the students and teachers were used to evaluate the intervention. The researchers rarely used control groups opting to use pre/post tests in most cases. Beyond the popularity of survey studies, there were a few taking a qualitative approach. These studies can be categorized based on duration: single lesson/workshop (1–3 hours), unit or camp (1–4 weeks), course (2–4 months), or project (years).

Shields [29] conducted a survey study with 60 secondary school principals in the state on Indiana to evaluate administrators' view of Project Lead the Way (PLTW) curriculum at schools where PLTW is not implemented. The principals viewed PLTW as a valid part of the technology education though the cost of implementing PLTW, including equipment and teacher training, was a barrier to implementation. Sabo [30] evaluates a specific lesson on pre-calculus through earthquake engineering. The evaluation presents data on student perceptions using a scale and student reflections. Dave et al. [31] describes a camp around designing bags from used jeans. Using pre/post test focused on student attitudes towards science and mathematical and specific aspects of the camp experience. In another project, Hotaling et al. [32] developed and evaluated educational modules that teach students to design sensors used to monitor water quality. Thirty teachers across New York State implemented the modules in their classrooms reaching over 1,700 middle and high school students. Their study showed the curriculum was well received by teachers and of interest to wide range of students, and flexible for integration into different subject areas and types of courses. Schnittka et al. [21] evaluated a design studio model's impact on students' motivation, beliefs, and identification with engineering, science, and computer science. They associate students' sense of empowerment to the approach, effort, and interest in taking courses in STEM subjects. They also highlighted the content supported students identification with engineering, science, and computer science.

A two-year project added enrichment activities to regular school curricula by introducing real-world, engineering applications of science and mathematics concepts with aim of supporting creativity and problem-solving [33]. The program also included an after-school programming (for girls only) that was led by engineering students from the local university. The article reports that the program had significant impact on students' confidence in science and mathematics, awareness of engineering and interest in engineering as a potential career.

3.5 Opportunities for research

As a burgeoning field, P-12 engineering education is ripe with opportunities for future research. Much of the work highlighted in this article is exploratory in nature providing rich descriptions of areas ready for further research. Many of the programs have the potential to be scaled up, researched using different theoretical constructs, or inform the development of new educational theories. The research appropriately addresses issues with both the learning and teaching of engineering as well as the public's perceptions of engineering. This work needs to continue with more high quality studies. One area of research that was starkly limited was research on diversity and inclusion with respect to engineering. Many nations are spearheading efforts to diversify who becomes an engineer. In the United States, initiatives to increase women and underrepresented ethnic groups (e.g., African American, Hispanic, and Native Americans) are widespread. South Korea and India have focused efforts on increasing women in engineering generally, or in specific disciplines (i.e., mechanical and civil engineering) [34, 35]. This has been cited as both an issue regarding improving engineered solutions by having diverse perspectives throughout the design process as well as a social justice issue in providing equal access to engineering for all people. There are rich opportunities to develop more research focusing on race and gender issues related to P-12 engineering education.

An analysis of the 218 articles' research questions results in just two papers (less than 1%) that include questions related to race or ethnicity as a focal part of the research [17, 36]. With the current attention and resources being committed to diversity issues, it appears as though there is a rich opportunity to initiate research related to racial and ethnic diversity in engineering at the P-12 level. P-12 students often make choices that impact their ability to pursue an engineering degree. They may choose not to pursue advanced science or mathematics courses that are the gateway into many undergraduate engineering programs. It will be important to have research-based recommendations for how to engage diverse groups of students, and ensure they do not rule out engineering to early on. Research related to diversity in undergraduate engineering education and in the profession could be a starting point for research in the P-12 domain.

Research related to gender (i.e., appealing to girls) is not quite so bleak. Nineteen of the 218 articles investigated issues of engineering and gender. These papers often looked at appealing equally to boys and girls using various attitudes and beliefs surveys. Further work needs to be done to specify the more generalizable characteristics of engineering activities and curricula that meaningfully engage girls in engineering.

4. Limitations of the Review

Systematic literature reviews can provide valuable insights into disciplines of research [9]; however, the process is not perfect and there are limitations to each review. First and foremost, the selection process outlined in this paper omitted any conference proceedings reporting on P-12 engineering education research. The American Society of Engineering Education's Pre-College Engineering Education division has been eliciting hundreds of P-12 engineering education research papers over the past 15 years. There are a number of highly cited works that have spurned new curriculum, pedagogies, and research [37–40] that were not included in this review. Additionally, the selection process and databases used may have missed articles that should have been included. It is likely that the total of such articles is a bit higher than the 218 reported here. The review did not dive as deeply into the individual articles leaving open the possibility of a more comprehensive review revealing more themes and insights to guide future research. The full list of the 218 citations is available for download via http://dx.doi.org/10.4231/R7WD3XJB for researchers who would like to conduct further analysis or use for their own reference library.

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References

1. S. Brophy, S. Klein, M. Portsmore and C. Rogers, Advancing engineering education in P-12 classrooms, *Journal of Engineering Education*, **97**(3), 2008, pp. 369–387.

2. M. Harris and V. Wilson, Designs on the Curriculum? A Review of the Literature on the Impact of Design and Technology in Schools in England, *Journal of Design & Technology Education*, **8**(3), 2003.
3. A. Jones, The development of a national curriculum in technology for New Zealand, *International Journal of Technology and Design Education*, **13**, 2003, pp. 83–99.
4. H. E. Middleton, *Technology education and research in Australia: A coming of age in the 21st century*, 2009.
5. National Research Council (NRC), *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, The National Academies Press, Washington DC, 2009.
6. C. P. Lachapelle and C. M. Cunningham, Engineering in elementary schools in J. Strobel, S. Purzer, M. Cardella (eds), *Engineering in pre-college settings: Synthesizing research, policy, and practices*, Lafayette, IN: Purdue Univ, 2014.
7. NGSS Lead States, *Next Generation Science Standards: For states, by states*, Washington, DC, 2013.
8. N. Diaz and M. F. Cox, An overview of the literature: Research in P-12 engineering education, *Advances in Engineering Education*, **3**(2), 2012, pp. 1–37.
9. M. Borrego, M. J. Foster and J. E. Froyd, Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields, *Journal of Engineering Education*, **103**(1), 2014, pp. 45–76.
10. I. Miaoulis, K-12 Engineering: The missing core discipline in J. Strobel, S. Purzer, M. Cardella (eds), *Engineering in pre-college settings: Synthesizing research, policy, and practices*, Lafayette, IN: Purdue Univ, 2014.
11. S. Atkinson, Design and technology in the United Kingdom, *Journal of Technology Education*, **2**(1), 1990.
12. K. S. Khan, R. Kunz, J. Kleijnen and G. Antes, Five steps to conducting a systematic review, *Journal of the Royal Society of Medicine*, **96**(3), 2003, pp. 118–121.
13. J. S. Brotman and F. M. Moore, Girls and science: A review of four themes in the science education literature, *Journal of research in science teaching*, **45**(9), 2008, pp. 971–1002.
14. B. M. Capobianco, H. A. Diefes-Dux, I. Mena and J. Weller, What is an engineer? Implications of elementary school student conceptions for engineering education, *Journal of Engineering Education*, **100**(2), 2011, pp. 304–328.
15. A. M. Johnson, G. Ozogul, M. D. DiDonato and M. Reisslein, Engineering Perceptions of Female and Male K-12 Students: Effects of a Multimedia Overview on Elementary, Middle-, and High-School Students, *European Journal of Engineering Education*, **38**(5), 2013 pp. 519–531.
16. F. O. Karatas, A. Micklos and G. M. Bodner, Sixth-Grade Students' Views of the Nature of Engineering and Images of Engineers, *Journal of Science Education and Technology*, **20**(2), 2011, pp. 123–135.
17. C. D. Denson and R. B. Hill, Impact of an Engineering Mentorship Program on African-American Male High School Students' Perceptions and Self-Efficacy, *Journal of Industrial Teacher Education*, **47**, 2010, pp. 99–127.
18. N. B. Dohn, Situational interest in engineering design activities, *International Journal of Science Education*, **35**(12), 2013, pp. 2057–2078.
19. A. Gero, Interdisciplinary program on aviation weapon systems as a means of improving high school students' attitudes towards physics and engineering, *International Journal of Engineering Education*, **29**(4), 2013, pp. 1047–1054.
20. M. Robinson and B. Kenny, Engineering Literacy in High School Students, *Bulletin of Science, Technology and Society*, **23**(2), 2003, pp. 95–101.
21. C. G. Schnittka *et al.*, Informal engineering education after school: Employing the studio model for motivation and identification in STEM domains. *Advances in Engineering Education* **3**(2), 2012, pp. 1–32.
22. N. Mentzer and K. Becker, Motivation while Designing in Engineering and Technology Education Impacted by Academic Preparation, *Journal of Industrial Teacher Education*, **46**, 2009 pp. 90–112.
23. K. B. Wendell and C. Rogers, Engineering Design-Based Science, Science Content Performance, and Science Attitudes in Elementary School, *Journal of Engineering Education*, **102**(4), 2013, pp. 513–540.
24. S. Purzer, M. E. Cardella and M.-C. Hsu, Elementary teachers' views about teaching design, engineering, and technology, *Journal of Pre-College Engineering Education* **1**(2), 2011, pp. 31–39.
25. H.-H. Wang, T. J. Moore, G. H. Roehrig and M. S. Park, STEM integration: Teacher perceptions and practice, *Journal of Pre-College Engineering Education*, **1**(2), 2011, pp. 1–13.
26. M. J. Nathan, N. A. Tran, A. K. Atwood, A. Prevost and L. A. Phelps, Beliefs and expectations about engineering preparation exhibited by high school STEM teachers, *Journal of Engineering Education*, **99**(4), 2010, pp. 409–426.
27. M. M. Hynes, Middle-school Teachers' Understanding and Teaching of the Engineering Design Process: A Look at Subject Matter and Pedagogical Content Knowledge, *International Journal of Technology and Design Education*, **22**(3), 2012, pp. 345–360.
28. K. B. Wendell, Design practices of preservice elementary teachers in an integrated engineering and literature experience, *Journal of Pre-College Engineering Education*, **4**(2), 2014, pp. 29–46.
29. C. Shields, Barriers to the Implementation of Project Lead The Way as Perceived by Indiana High School Principals, *Journal of Industrial Teacher Education*, **44**, 2007, pp. 43–70.
30. C. Sabo, A. Burrows, L. Childers, Shaking Up Pre-Calculus: Incorporating Engineering into K-12 Curricula, *Advances in Engineering Education*, **4**(2), 2014, pp. 1–26.
31. V. Dave *et al.*, Re-enJEANeering STEM Education: Math Options Summer Camp, *Journal of Technology Studies*, **36**, 2010, pp. 35–45.
32. L. Hotaling *et al.*, SENSE IT: Teaching STEM principles to middle and high school students through the design, construction and deployment of water quality sensors, *Advances in Engineering Education*, **3**(2), 2012, pp. 1–34.
33. J. D. Goedert, R. Pawloski, S. Rokooeisadabad and M. Subramaniam, Project-Oriented Pedagogical Model for Construction Engineering Education Using Cyberinfrastructure Tools, *Journal of Professional Issues in Engineering Education & Practice*, **139**(4), 2013, pp. 301–309.
34. Women in Global Science and Technology, *National Assessments on Gender Equality in the Knowledge Society*, The Elsevier Foundation, 2012.
35. S. S. Ullas, Girls are for biotech, boys for engineering, *The Times of India*, 2014.
36. S. Thompson and J. Lyons, Engineers in the Classroom: Their Influence on African-American Students' Perceptions of Engineering, *School Science & Mathematics*, **108**(5), 2008, pp. 197–211.
37. M. Knight and C. Cunningham, Draw an Engineer Test (DAET): Development of a Tool to Investigate Students' Ideas about Engineers and Engineering, *American Society of Engineering Education*, Salt Lake City, Utah, 2004.
38. C. M. Cunningham, C. Lachapelle and A. Lindgren-Streicher, Assessing Elementary School Students' Conceptions of Engineering and Technology, *American Society of Engineering Education*, Portland, OR, 2005.
39. C. P. Lachapelle and C. M. Cunningham, Engineering is Elementary: Children's Changing Understandings of Science and Engineering, *American Society of Engineering Education*, Honolulu, HI, 2007.
40. E. Oware, B. Capobianco and H. Diefes-Dux, Gifted students' perceptions of engineers? A study of students in a summer outreach program, *American Society of Engineering Education,* Honolulu, HI, 2007.

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