An Overview of the Literature: Research in P-12 Engineering Education

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ABSTRACT

This paper presents an extensive overview of preschool to 12th grade (P-12) engineering education literature published between 2001 and 2011. Searches were conducted through education and engineering library engines and databases as well as queries in established publications in engineering education. More than 50 publications were found, including books, articles, and reviews that discussed P-12 engineering education research efforts. With the synthesis of literature and distinct criteria to classify the literature, a rubric was developed. This rubric allowed authors to synthesize retrieved publications in seven ways: (1) overarching agenda, (2) nature of the engineering program or intervention, (3) assessment methods, (4) object of the study/unit of analysis, (5) population/scale of interest, (6) informing theory, and (7) standards addressed. Discussions of the current levels of research based on recommendations of National Agencies are presented along with a set of recommendations for the advancement of the P-12 engineering education research.

INTRODUCTION

Several national trends are driving the advancement of engineering education within the United States. These trends include a declining interest of U.S.-born students in engineering (Melsa, 2007); a decrease in national achievement in mathematics and sciences at pre-college levels (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine of the National Academies, 2007); and a lack of technological literacy for all Americans (Pearson and Young, 2002).
Adding to these concerns are expectations that in the U.S. government, science and engineering professionals reaching retirement age will not be replaced by a younger generation of professionals (National Science Board, 2006a; Selingo, 2008). In mathematics and science, U.S. pre-college students “perform at or near the bottom on international assessments” (National Science Board, 2006b, p. i).

In order to pose alternatives to improve situations facing science, technology, engineering, and mathematics (STEM) education, several authors have identified the necessity of focusing on the education of pre-college populations (National Academy of Engineering, 2005). For example, the National Science Board (2006b), via the companion to the 2006 Science and Engineering Indicators, identifies the following priorities for developing high quality STEM education:

- Strong public support of STEM education for all students and citizens,
- A high quality teaching workforce,
- Appropriate learning opportunities for all students,
- Effective guidance counseling on STEM education and careers, and
- Assessment tools that reinforce learning in STEM fields (p. ii).

Experts also advocate the integration of engineering activities in current curricula to increase students’ interest in STEM (Schunn, 2009; Katehi, Pearson, and Feder, 2009; Brophy, Klein, Portsmore, and Rogers, 2008). One discipline that is focused upon operationalizing these priorities is engineering education.

Engineering education is an emerging field of study that is gaining momentum and recognition within the United States. Within the last eight years, Purdue University, Virginia Polytechnic Institute and State University, Utah State University, and Clemson University have created doctoral-granting engineering education schools/departments within their respective Colleges of Engineering that are devoted to developing engineering education scholarship. Other universities throughout the country are developing innovative models to conduct engineering education research across the educational continuum (e.g., the Colorado School of Mines’ Center for Engineering Education and Washington State University’s Engineering Education Research Center).

The development of formal departments and centers in engineering education has occurred concurrently with the development of a number of engineering education initiatives targeting preschool to 12th grade (P-12) students. Some of the most widely known research-based P-12 efforts are being conducted by the following groups:

- The National Center for Technological Literacy Initiative, the Boston Museum of Science (http://www.mos.org/nctl/)
- Project Lead the Way (http://www.pltw.org/)
- The Infinity ProjectSM (http://www.smu.edu/lyle/infinity.aspx)
Two macro-initiatives for P-12 education include the recently extinct National Science Foundation’s Graduate Teaching Fellows in K-12 Education Program (GK-12) and the American Society for Engineering Education’s (ASEE) Engineering K-12 Center. In addition to these initiatives, public high schools in states such as Arkansas, Florida, Maryland, Massachusetts, New Hampshire, and Texas require engineering coursework for their students (Field, 2004; Meyers-Sharp, 2004).

The literature is abundant in engineering education pre-college programs. Through an extensive literature review, this paper organizes, analyzes, and synthesizes recent P-12 engineering education research efforts using detailed criteria and categories. The authors provide detailed information about the publications included in the literature review and provide recommendations for the advancement of future scholarship in this area.

**Purpose and Research Questions**

The purpose of this investigation is to understand and to inform audiences about the current state of research in the P-12 engineering education area. Using engineering education publications, including peer-reviewed journals, conference proceedings, and dissertations, the authors extract key points and synthesize the literature to inform engineering education and other audiences about the current state of P-12 engineering education research and to offer suggestions for future work within this area. The research questions of interest in this paper ask, (1) What is the current state of research in the P-12 Engineering Education area?, and (2) How can this research be classified and synthesized?

**Operationalization of Research within This Study**

To identify P-12 engineering education literature that would be included in this paper, the authors developed criteria for inclusion and developed a working definition of research. For a paper to be included in this paper, it had to meet all of the criteria listed in Table 1 and had to align with the authors’ definition of research as derived from pertinent literature.

An emphasis on research in this paper is needed, since engineering education is an emergent field in which most engineering professors are not familiar with rigorous educational research frameworks (Borrego, Streveler, Miller, and Smith, 2008; Borrego, Douglas, and Amelink, 2009). Following Boote and Beile’s (2005) guidelines of educational literature reviews, this section presents the authors’ definition of “research,” which has been developed from a previous review of foundational works...
within the field and the community. With this definition, readers who are engaged and are not engaged in engineering education research might understand the types of publications included and not included in this synthesis of P-12 engineering education research.

Research methods are “the procedures used to support the data collection process and are an important consideration in any educational research design” (Rogers and Sando, 1996, p.13). The methods, under this framework, are divided in two overarching types, descriptive and experimental. Descriptive studies are defined as those that describe the current state of a phenomenon or that try to answer the question, “What is happening”? (Olds, Moskal, and Miller, 2005; Shavelson and Towne, 2002). Descriptive methods encompass surveys, interviews and focus groups, conversational analysis, observations, ethnographic studies and meta-analyses. Experimental and quasi-experimental studies, on the other hand, are defined as those that examine how a phenomenon changes as a result of an intervention or examines the effects of a treatment (Fraenkel and Wallen, 1990; Olds et al., 2005). Experimental or quasi-experimental methods might encompass randomized controlled trials and matching trials, baseline data, post-test-only, and longitudinal designs.

Another division in methodological approaches pertains to the nature of the data and its analysis. Quantitative approaches involve numerical data that may be statistically analyzed whereas qualitative approaches involve other types of information such as words or images for analysis of their meaning in descriptions and themes (Creswell, 2002; Olds et al, 2005). Finally, mixed methods “focus on collecting, analyzing, and mixing both quantitative and qualitative data in a single study or series of studies.” (Creswell and Plano Clark, 2007, p. 6).

**METHODOLOGY**

Taking into account the abundance of approaches that P-12 engineering education studies have incorporated in their respective works, this literature review synthesizes studies that emphasize
assessment-focused, research-based evidence of data collection used to answer classroom, curricular, or research questions. Details about data collection methods are included in the next section.

**Data Collection**

Publications retrieval occurred in four phases. In the first phase, we retrieved references from educational and engineering library databases such as Academic Search Premier, Omnifile, Compendex, WorldCat, and ProQuest Dissertation Abstracts. Key terms such as “engineering”, “engineering education,” “K-12,” “outreach,” “elementary,” “secondary,” “evaluation,” and “assessment” served as the initial filtering mechanisms. Further reading of retrieved abstracts provided the necessary information to parse out publications that fully met the criteria. The second phase of the bibliographical inspection included browsing the websites of the established engineering education initiatives (listed previously) to investigate reports or chronicles. For example, the Boston Museum of Science and the National Center for Engineering and Technology Education (NCETE) websites provided links to publications that were used in this review. The third phase involved a systematic search in acknowledged forums within the engineering education research community such as the *Journal of Engineering Education*, the *International Journal of Engineering Education*, the *Journal of Professional Issues in Engineering Education and Practice*, the *European Journal of Engineering Education*, and *IEEE Transactions in Education*. A final phase consisted of using, for a second time, library databases (such as EBSCO and Wilson), and inspecting closely non-acknowledged engineering education forums such as the *Teacher Education* or the *Journal of Industrial Teacher Education*. The purpose of this final phase was to identify studies that might meet the selection criteria but might have been overlooked by previous searches.

**DATA ANALYSIS**

The search resulted in the retrieval of over 50 publications that met the criteria described in Table 1. Previous literature reviews, not necessarily focused on research, informed our initial approach to the publications (Lewis, 2007; Jeffers, Safferman, and Safferman, 2004; Garmire and Pearson, 2006; and Douglas, Iversen, and Kalyandurg, 2004). The initial criteria and research definitions developed by the authors were used to narrow studies in this paper. Inspired by previous literature reviews and given the common elements located across the 55 documents, seven themes or categories emerged (Table 2)—(1) overarching agenda, (2) nature of the engineering program or intervention; (3) assessment methods,
A brief overview and justification of these seven themes follow. To contextualize each study in P-12 engineering education, an overarching agenda was identified. This agenda was usually presented in publications’ abstracts and introductions. Next, using the initial criteria for selecting publications, assessment/research methods and populations/samples were categories that detailed what was studied, how it was studied, and who was studied, respectively. The object of study/unit of analysis was inspired by the evaluation schema for professional development written by Lawless and Pellegrino (2007) and Tech Tally’s “primary purpose” of the instruments (Garmire and Pearson, 2006). In Lawless and Pellegrino’s schema, the unit of analysis refers to the “focus of any research/evaluation on the outcomes and efficacy of that program” (p. 582). When the publications were analyzed, they were placed in this pre-established category. The last categories, informing theory and standards addressed, were inspired by academic understanding that research is closely related to the development and advancement of theoretical frameworks and that the P-12 classroom is largely influenced by policies and standards.

<table>
<thead>
<tr>
<th>Theme or Category</th>
<th>Findings addressed in the literature to date</th>
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| Overarching agenda | • Math & Science achievement improvement  
|                    | • Pathways to increase the number of engineers  
|                    | • Technological literacy improvement  |
| Nature of the engineering education program or intervention | • Teacher Professional Development or Outreach activity  
|                    | • Engineering Design Process  
|                    | • Hands-on Math & Science  
|                    | • Engineering Disciplines  |
| Assessment Method | • Descriptive and Quasi-experimental (pre- and post-tests)  |
| Object of Study/Unit of Analysis | • Students’ attitudes and knowledge  
|                    | • Teachers’ attitudes and knowledge  
|                    | • Principals’ perceptions  
|                    | • Parents’ perceptions  
|                    | • University students’ perceptions  |
| Population/Sample | • Students  
|                    | • Teachers  
|                    | • Parents and caregivers  
|                    | • Principals  |
| Informing Theory | • Constructivism (Constructionism, Guided Inquiry, Communities of Practice)  
|                    | • Self-efficacy  |
| Standards Addressed | • National and State Mathematics, Science and Technology  
|                    | • Massachusetts Technology/Engineering  |

Table 2: Summary of Literature Synthesis, Rubric of Research in Engineering Education at the P-12 Grade Levels.
Synthesis of Literature across Themes

The synthesis that follows is based upon the themes depicted in the rubric in Table 2. These themes could serve the purpose of locating future publications or current unpublished studies that meet the selected criteria and can provide additional opportunities for further research and practice. The extended analysis across documents is located in the Appendix. The following sections situate the retrieved literature into the themes in Table 2.

Overarching Research Agenda

All publications provided a rationale that fell into one or more of three categories; (1) pathways to increasing the number of engineers; (2) math and science achievement improvement; and (3) technological literacy improvement. We called this elemental group of categories the “overarching research agenda.”

Pathways to increasing the number of engineers is a popular topic. Documents such as “Educating the Engineer of 2020: Adapting Engineering Education to the New Century” (National Academy of Engineering, 2005) provide persuasive arguments to authors when implementing engineering education activities. However, due to the difficulty in measuring how many students are attracted to engineering as a result of an intervention, most of the studies measure other outcomes such as mathematics, science, technological literacy, or perceived satisfaction with the interventions. Thirteen studies provided as its unique justification information about the number of students pursuing an engineering or STEM career. Some of them such as DeBartolo and Bailey (2007), Boynton and Hossain (2010), and Martin (2011) focus on certain populations such as women, rural students, or black high school students. The way they measure the impact of the interventions relates to perceptions of teachers, students, or parents/caregivers. According to DeBartolo and Bailey (2007), more long-term impact studies are expected to take place in the future. Three dissertations address this rationale (Oware, 2008; Martin, 2011; and Lanigan, 2009).

Math and science achievement improvement is a favored rationale in the publications reviewed, in combination with pathways to increasing the number of engineers. Authors make a case for improving mathematics and science at the same time that students are introduced to engineering. As could be expected, the interventions that occurred within the studies in this category are informed by national and state science and mathematics standards. McKay and McGrath (2007) present new documents to the already compelling pool of materials that support this rationale. They are the “Excellence: Comparison of International Eighth-Grade Mathematics and Science Achievement from a U.S. Perspective, 1995 and 1999” and “The Nation’s Report Card: Science Highlights 2000” (as cited by McKay and McGrath, 2007). In their study, McKay and McGrath (2007) report the result of an initiative geared towards developing Internet-based real-world applications in order “to
provide students with problem-solving opportunities that are similar to the engineering problem-solving process” (p. 37). The unit of analysis in this study was students’ knowledge in mathematics and science. The study showed improvement in students’ knowledge through standardized and “in situ” tests, when engineering concepts are incorporated into the curriculum via online activities. Cantrell, Pekcan, Itani, and Velasquez-Bryant (2006) report an intervention in the form of a teacher professional development program that upgrades “content knowledge in engineering to facilitate integrated technology that supports effective science and mathematics instruction” (p. 301). The target population was science teachers and their respective students. The results of the science standardized tests were statistically compared to the tests developed by eight teachers during the program. The author converted mean performance scores from each group across assessments to a percentage of deviation from the overall mean for each assessment (p. 305, Cantrell et al., 2006). The results show increases and decreases in students’ science knowledge with respect to gender, ethnicity, economic status, special education, and type of assessment (such as project-based versus pencil/paper unit test).

Church, Gravel, and Rogers (2007) present an innovative science intervention based on a movie-making approach. The students were expected to present parabolic motion principles in the manner of animations. The purpose of the study was to present a new way of teaching science and no comparisons were performed against standardized models of testing science. Barnett (2005) analyzed physics knowledge from a conventional perspective (via the district’s final exam) and pre-posttests, therefore this study is also considered to be focused on improving science knowledge. Similarly, Hardre, Nanny, Refai, Ling and Slater (2010) focused on science and mathematics teachers. Two dissertations, Marculu (2010), and Martinez Ortiz (2010), explored math and science teachers and students’ math knowledge.

In addition to these studies, which can be considered “purely” science and math driven, there are other studies that maintain a mathematics and science emphasis but also present their rationale as providing increases in numbers of students attracted to engineering (Bergin, Lynch, Khanna, and Nair, 2007; Cunningham, Knight, Carlsen, and Kelly, 2007; DeGrazia, Sullivan, Carlson, and Carlson, 2001; Elton, Hanson, and Shannon, 2006; Lumpp, Bradley, and Haines, 2007; Mooney and Laubach, 2002; Moskal, Skokan, Kosbar, Dean, Westland, Barker et al., 2007; Pickett, Oliver, Giles, Fridman, Fetters, and Cooks, 2000; Poole, DeGrazia, and Sullivan, 2001; Richards, Hallock, and Schnittka, 2007; Iskander, Kapila, and Kriftcher, 2010; Mehalik, Doppelt, and Schuun, 2008; Nugent, Barker, Grandgennett, and Adamchuk, 2009; Klein, 2009; and Caldwell, McCoy, Albers, Smith, and Parry, 2007). Baker, Yasar-Purzer, Robinson-Kurpius, Krause, and Roberts (2007) expose the linkages between science and technology education and the implied impact in increasing the engineering ‘pipeline’. They make a case for an intervention targeting participants of a graduate course in science
education centered on the inclusion of Design, Engineering, and Technology (DET) concepts into the curriculum. As a result of infusing DET into the graduate content, participants (two in-service teachers and one museum curriculum specialist) changed their knowledge and attitudes towards engineering. Cunningham et al. (2007) provided a different rationale for merging science and engineering, and noted that “in this model, engineering concepts are one tool for teaching science and mathematics” (p. 3). This statement shows a subordination of engineering to other subject agendas. In this study, the outcomes under measure were teachers’ self-reported knowledge and comfort with teaching engineering and technology.

The last overarching research agenda is technological literacy improvement. It involves the importance given to infusing engineering and technology in the education of all citizens, or in the words of Rogers and Portsmore (2004), “it becomes increasingly important that we make sure that students are comfortable with technology when they graduate from high school” (p. 17). Except for Powers, Dewaters, and Venczel (2011), the studies inspired by this category tend to address early grade levels such as kindergarten and elementary school. Tufts University’s Rogers and Portsmore (2004) report their intervention, “ROBOLAB,” and the impact it has on teachers and students from kindergarten to 5th grade. Bers (2007) cites “Technically Speaking: Why All Americans Need to Know More About Technology” (Pearson and Young, 2002) as a vehicle for stressing the need of increasing technological literacy. She looks into families with children between 4-7 years old. Portsmore’s dissertation looked into first graders’ understandings of technology and engineering design.

To conclude, there are also studies that address all aspects of the overarching research agenda (Rogers, 2006; Rogers, 2007; Sorby and Schumaker-Chadde, 2007; Yasar, Baker, Robinson-Kurpius, Krause, and Roberts, 2006; Tran and Nathan, 2010; Nathan, Tran, Atwood, Prevost, and Phelps, 2010; Asunda and Bill, 2008; and DeBartolo and Bailey, 2009). However, as will be presented later, their units of analysis, nature of interventions, assessment methodologies and theoretical frameworks vary.

Nature of the Engineering Education Program or Intervention (Curriculum Content)

The majority of the programs across studies attempt to integrate mathematics and science content to technology and engineering. Therefore, most of the interventions that target the P-12 classrooms try to build alliances with teachers in already established science and math fields. Teacher-oriented programs are very popular (Baker et al., 2007; Barnett, 2005; Cejka et al., 2007; Moskal et al., 2007; Pickett et al., 2000; Poole et al., 2001; Rogers, 2006; Rogers and Portsmore, 2004; Richards et al., 2007; Sorby and Schumaker-Chadde, 2007; Brockway, McGrath, McKay, and Schultz, 2009; Hardre et al., 2010; Iskander et al., 2010; Mehalik et al., 2008; Nugent et al., 2009; Klein, 2009; Nathan et al., 2010; and Asunda et al., 2008). Other studies, with or without the emphasis in science and mathematics, focus more on students (pre-college or college) via outreach activities. These outreach
studies, including dissertations within this exploration, are not as interested in building alliances with teachers. Both approaches seem to complement each other well and both share common curriculum content regardless of the primary populations they are targeting. DeBartolo and Bailey (2007) describe a very interesting set of interventions at the Rochester Institute of Technology. Targeting girls as early as 6th grade, the activities are aimed to attract women to engineering. Park rides, a robot competition, sleepovers, and weekend visits are part of these activities. Another innovative approach is presented by Church et al. (2007) in which parabolic motion is introduced through a movie making-animation approach. A commonality of all interventions is that they introduce their content in a “hands-on” manner. It is observable that at the heart of these hands-on experiences is the engineering design process, although design may not be referred explicitly. Therefore, the engineering design process can be comfortably used to define engineering education at the P-12 levels. In addition, other constructs related to engineering are also part of these interventions; for example, communication and teamwork skills (Bergin et al., 2007; Cantrell et al., 2006), engineering as a career choice (DeBartolo and Bailey, 2007; Elton et al., 2006; Mooney and Laubach, 2002; Cantrell and Ewing-Taylor, 2009; Zhe, Doverspike, Zhao, Lam, and Menzemer, 2010), physical and/or economic constraints to design (Bergin et al., 2007; Richards et al., 2007), and some specific disciplinary content such as manufacturing and bioengineering technologies (Hynes and Dos Santos, 2007; Davis, Maltbie, Myers, Forry, and Wolf, 2009; and Klein, 2009), electronic circuits (Lumpp et al., 2007; Reisslen, Moreno, and Ozogul, 2010; Mehalik et al., 2008), robotics (Bers, 2007; Cejka et al., 2007; Rogers and Portsmore, 2004; Nugent et al., 2010; Marulcu, 2010; Martinez Ortiz, 2010; and Portsmore, 2009), civil engineering (Elton et al., 2006; Boynton et al., 2010), environmental (Rose and Miller, 2009; Hardre et al., 2010; and Powers et al., 2011), and computer (Maxim and Elenbogen, 2009).

Only three of the studies reported do not assess any type of intervention. Yasar et al. (2006), report the development of an instrument to assess teachers’ attitudes, Lyons and Ebert (2005) report on an exploratory survey applied to Engineering Education Centers in order to know how they incorporate K-12 activities, and Beck, Diefes-Dux, and Reed-Rhoads (2009), report on counselors’ perceptions of engineering.

**Assessment Method**

As previously mentioned, assessment methodologies in this review are explored under a framework of descriptive/quasi-experimental/experimental and qualitative/quantitative. In this sense, almost all studies involve descriptive and quasi-experimental approaches via surveys, observations, interviews, and questionnaires applied either once or in a pre-post fashion. Only four studies, including one dissertation, involved a control group (Mooney and Laubach, 2002; Mehalik et al., 2008; Tran &
Nathan, 2010; and Marulcu, 2010). For qualitative and quantitative perspectives, almost all surveys and questionnaires were analyzed statistically. Observations and interviews were qualitatively analyzed in the form of “inductive-generative-constructive-subjective” techniques (Lincoln and Guba, 1985) also known as open coding (Strauss and Corbin, 1998). Non-traditional assessment was applied in the form of rubrics for project evaluation. Poole et al. (2001), at the University of Colorado at Boulder, provided an extensive study of assessment approaches to outreach activities. An array of different instruments is proposed and used in this publication in the form of a matrix they call an “embedded assessment matrix” (p. 44).

Object of Study/Unit of Analysis

This category, in general terms, refers to what is assessed or how the learning of engineering is measured. In a simplistic definition, learning entitles the changes in intellectual skills, attitudes, or psychomotor skills exhibited by participants (Gagné, 1985). In this review the majority of the studies focus on knowledge or attitudes of teachers and/or students in a self-reported fashion. In this review knowledge is attributable to the cognitive domain and exemplified by content-concepts acquisition (Barnett 2005; Church et al., 2007; McKay and McGrath, 2007; Reisslein et al., 2010; Nugent et al., 2010; Powers et al., 2011; Iskander et al., 2010; Mehalik et al., 2008; Tran & Nathan, 2010; DeBartolo and Bailey, 2009; Marulcu, 2010; Martinez Ortiz, 2010; and Portsmore, 2009). Attitudes include perceptions, beliefs, level of comfort-confidence, enjoyment, or satisfaction (Bergin et al., 2007; Baker et al., 2007; Cejka et al., 2007; DeBartolo and Bailey, 2007; Lumpp et al., 2007; Rogers, 2006; Rogers, 2007; Sorby and Schumaker-Chadde, 2007; Yasar et al., 2006; Boynton, et al, 2010; Cantrell et al., 2009; Zhe et al., 2010; Thompson and Lyons, 2009; Rose et al., 2009; Maxim et al., 2009; Davis et al., 2009; Beck et al., 2009; Zarske, Sullivan, Knight, and Yowell, 2008; Brockway et al., 2009; Hardre et al., 2010; Klein, 2009; Caldwell et al., 2007; Nathan et al., 2010; Asunda and Bill, 2008; Oware, 2008; Martin, 2011; and Lanigan, 2009). The psychomotor domain was not directly addressed by any assessment in this review. However, anecdotal information was provided in the sense that the “hands-on” approach afforded opportunities for learning content other than the traditional paper-and-pencil ones or it fostered spatial abilities (Barnett, 2005; Bergin et al., 2007).

Population/Sample

It became evident that the population of interest of most publications is teachers or students. DeBartolo and Bailey (2007), Bers (2007), Rose and Miller (2009), Caldwell et al. (2007), are the only four studies involving parents’ assessment. The first aimed to assess perceptions of parents or caregivers’ as a measure of success in attracting women to engineering, and the second examined the interactions between parents and children through robotics activities. Rose and Miller (2009)
looked into parent’s perceptions of summer camps devoted to raise interest in engineering careers and Caldwell et al. (2007) examined the feedback of parents’ nights. Administrators, specifically principals and counselors (and their perceptions) are the populations of interest for Rogers (2007), Sorby, Schumaker-Chadde (2007), and Beck et al. 2009. For universities implementing these programs, few studies address faculty, undergraduate, graduate students, or university administrators (Baker et al., 2007; Lyons and Everts, 2005; Moskal et al., 2007; Sorby and Schumaker-Chadde, 2007; Thompson et al., 2009; and Zarske et al., 2008).

The population sample sizes of these reports vary but are not much greater than a thousand. At the extremes of the spectrum, there was a case study of three participants (Baker et al., 2007) and a study involving more than a thousand students (Mehalik et al., 2008). Twenty two publications reported a sample between 3 and 46 participants, fourteen studies a sample between 46 and 150 participants, eight between 151 and 500, one with 519, and one with 1053 participants.


**Theoretical Frameworks**

Perhaps the most interesting perspectives relate to researchers’ explanations or predictions of engineering education phenomena in the P-12 arena. Because of the emergent nature of the field of engineering education, the studies’ theoretical underpinnings are interesting from a research perspective. In this sense, only eleven references included a clear theoretical perspective. The most prevalent educational perspective among these authors was constructivism. Seven publications, including a dissertation, used constructionism, one explored experiential learning, two referred to communities of practice, and one focused upon guided inquiry.

Constructionism, termed by Seymour Papert (Papert and Harel, 1991) at the Massachusetts Institute of Technology, is a learning theory that contains the elements of constructivism through learners’ cognitive construction but has an additional hands-on attribute. In the words of Hynes and Dos Santos (2007), this attribute involves the “construction of a real-world or virtual-world artifact” (p. 25). With strong emphasis on robotics and computer design, Barnett (2005), Bers (2007), Cejka et al. (2006), Church et al. (2007), Hynes and Dos Santos (2007), and Martinez Ortiz (2010) use constructionism as a theoretical justification for their interventions. Only one of them challenged or added to the model, however. In this sense, the theory of constructionism is, in general, not expanded.

Kolb’s (1984) experiential learning, used by Cantrell et al. (2006), engages students in experiences, reflections, conceptualization and experimentation. In their study, this theory inspired the way...
the module content was delivered to students. Communities of practice is the second theoretical framework that Bers presents in her parent-child study, and the way she introduces it is innovative in the sense that it is called a “constructionist community of practice” based in the situated learning work of Lave and Wenger (as cited by Bers 2007). Although she does not present a case for marrying both traditions, the way she describes the family dynamics through this doubled-concept could be considered an expansion to both communities of practice and constructionism. Guided inquiry and learning by design, understood as a subset of inquiry-based science or a “learning by doing” approach to learning science, was mentioned by Richards et al. (2007), Mehalik et al. (2008), and Tran et al. (2010), as the pedagogical technique used to develop their intervention.

Finally, in a more cognitivist trend, Bergin et al. (2007), Brockway et al. (2009), Powers et al. (2011), and Nugent et al. (2010) used self-efficacy as the theoretical foundation in which they created a scale to assess confidence to learn about electricity, fuels, traffic control, math, hands-on building, and how to become an engineer. This operationalization of self-efficacy to create an instrument expands this theoretical perspective in engineering education.

Standards Addressed

We found that seventeen of the fifty five studies incorporated national mathematics, science, and/or technology standards. Twelve incorporated state mathematics, science, and/or technology standards and six incorporated the Massachusetts Technology/Engineering standards.

DISCUSSION

This literature review analyzed and synthesized current P-12 engineering education research initiatives. Fifty-five studies were analyzed and synthesized based upon the categories presented in Table 2. This rubric was developed to understand, in greater detail, the roles that recent P-12 engineering education studies play in developing a “big picture” of engineering education research at the P-12 grade levels. In this section, we summarize and discuss our findings in an effort to substantiate later recommendations. Following Boote and Beile’s (2005) guidelines of educational literature reviews, the authors seek to build a “thorough, critical examination of the state of the field” (p. 9).

In the overarching agenda category, we found that 34 studies use the rationale of improving mathematics and science achievement through engineering education interventions. In ten of these studies, short term measures of impact are possible via paper-and-pencil tests and/or via comparisons with standardized tests. A plausible explanation about the preference given to this rationale is precisely this “facility” of measuring this type of impact. In this sense, engineering education seems
to attempt a point of entry through established P-12 subject areas. The downside of this rationale is that engineering education appears to be a subfield of other more well-established areas, thereby raising questions about the field's identity and visibility.

The second rationale mentioned in the literature is pathways to increasing the number of engineers. As stated above, to measure the impact in this area is quite a challenge, although some authors have attempted to do so. For example, Cantrell and Ewing-Taylor (2009) administered weekly questionnaires to high school students asking their career goals. Another example is Zhe et al. (2010), who checked if their participant high school students enrolled in STEM majors. A possible explanation to this is that in order to provide significance for their studies, authors take ideas from major national reports. However, when posing research questions or units of analysis, the authors take other routes such as Lanigan (2009), who focused on student motivation based on surveys and observations. Authors might consider implementing longitudinal studies or other innovative approaches.

The last rationale of preference among engineering education publications is technological literacy improvements. Considering the knowledge base coming from the technology education community, it is surprising that technological literacy is practically excluded from the P-12 engineering education research agenda. The possible explanation to this phenomenon is that the engineering education community is building its own knowledge base while differentiating itself from technology education. In the quest of its own knowledge, however, interventions seem to be more preoccupied on validating their engineering education content (their own identity) instead of finding intersections with literacy in technology education. Smith and Burghardt report this tension in the Technology Teacher (2007). The disadvantage of this approach is that by not widening the scope and pertinence of P-12 engineering education to impact all citizens, the desired changes in educational policies, standards, and curriculum are limited.

The nature of the engineering education program or intervention has been confined primarily to either teacher professional development or outreach activities. Few programs or interventions explicitly state research as their primary focus. The disadvantage of this approach is that engineering education research seems to be incidental or dependent upon initiatives devoted mainly to service. In addition, as part of the nature of the program, this review paid attention to the curricular content reported in the literature. Without a solid knowledge base, it was most interesting to see what constituted engineering education across initiatives and to what extent the curriculum content aligned to engineering literacy as described by guidelines and standards (Dym, Agogino, Eris, Frey, and Leifer, 2005; Massachusetts Department of Education, 2001; Hill, 2006). As expected, the content incorporated only partially the nature of engineering as described in the aforementioned guiding works. Again, the novelty aspect of the field is the attributing cause, since by the time these guidelines and standards were developed, many of the initiatives have or were taking place. This
should constitute a motivation for educational researchers interested in engineering, since it affords multiple opportunities to explore new questions.

In the assessment methods, most studies incorporated descriptive or quasi-experimental research designs in self-reported fashions. The possible causes might be the newness of the field as well as the researchers’ struggles with rigorous educational research (Borrego, 2007). One problem with this advancement within the area of assessment is the lack of progression of engineering as an educational field of study. This implies tardy maturation of the field. Lawless and Pellegrino (2007), in the technology integration-professional development arena, speak about this in the following manner:

Case studies are a useful first step to illuminate which variables are important to examine in more depth, but we need to push ourselves to take the next step and design more controlled studies that are more experimental in nature...Finally, new and more innovative approaches to collecting evidence and measuring change are desperately needed. The common practice of using self-report measures is not going to yield the type of data required to make evidence-based decisions regarding the adoption of professional development programs (p. 601).

In addition, *Scientific Research in Education* (Shavelson and Towne, 2002) provides advice about advances in assessment in educational research by stating:

An area of research that, for example, does not advance beyond the descriptive phase toward more precise scientific investigation of causal effects and mechanism for a long period of time is clearly not contributing as much to knowledge as one that builds on prior work and moves toward more complete understanding of the causal structure (p. 101).

The object of study or unit of analysis of studies was primarily focused upon students’ and teachers’ knowledge and attitudes in engineering. Knowledge and attitudes are important aspects of learning that should be studied. However, the variety of knowledge concepts and attitudinal constructs among studies is very limited. Most studies report about the same kind of knowledge base or the same type of self-reported perceptions. Pellegrino, Chudowsky and Glaser (2001) stress the need of “translating what is already known in cognitive science to assessment practice, as well as on developing additional cognitive analyses of domain-specific knowledge and expertise” (p. 104).

The populations/samples targeted by studies were primarily teachers and students. A scarce number of publications reported details about parents (or caregivers) or administrators (principals or counselors). This phenomenon might inadvertently hinder the establishment of engineering education in the P-12 classroom, since it disengages interested groups that play significant roles in the education of P-12 students.

Perhaps the most neglected factor in the analysis of interventions and literature in P-12 engineering education has been the use of theoretical frameworks, particularly in educational fields.
Guidelines on scientific research are emphatic about the importance of informed research for the advancement of knowledge. They state that “studies that do not start with clear conceptual frameworks and hypotheses may still be scientific, although they are obviously at a more rudimentary level and will generally require follow-on study to contribute significantly to scientific knowledge” (Shavelson and Towne, 2002, p.101)

A small number of articles in this review incorporated a theoretical framework, and an even fewer number attempted a critical analysis of these frameworks in order to modify and to add to existing theories. The disadvantage of this approach is diminished contributions to the advancement of scientific knowledge when given the opportunity and the resources.

The last factor analyzed in this literature was the standards addressed. National and state standards in mathematics, science, and technology dominated the articles that referred to standards. This is a positive aspect; however, in the era of the “No Child Left Behind Act,” (2002) more influence of these standards is expected when conducting interventions at these grade levels.

IMPLICATIONS AND CONCLUSIONS

Based on the previous discussion, the implications of practice are clear. First, practice should be informed by research on an ongoing basis. The emerging nature of the field of engineering education requires that the content and the nature of interventions should be related to advances about the understanding of engineering. It also implies that the targeted populations should include not only student and teacher groups if the field is to establish itself as a P-12 content area. The final aspect to consider in practice has to do with standards. Again, in an effort to connect P-12 interventions to standards, more development in engineering standards and more incorporation to curricula is expected if the community is to become a leader in the development of engineering specific policies and the incorporation of these policies into P-12 classrooms.

In addition, more theoretical frameworks are expected to be incorporated, to be advanced, or to emerge out of P-12 classroom environments. With clear theoretical perspectives, more experimental designs are needed. It is also expected that advances on understandings of what constitutes engineering (whether a noun or a verb) emerge out of the P-12 classroom. It is finally expected that increases in literacy for all citizens and in the number of students attracted to engineering be attributable to interventions or treatments within the research agenda. Although material resources are in place for these research activities, more engineers and educational researchers must reach consensus about these efforts. It is anticipated that this integrative literature review will serve as a basis for research and practice advances.
This paper provides information about the current state of research in engineering education at the P-12 levels and offers a rubric for future exploration of research within this community. Although numerous articles have been disseminated about P-12 engineering education interventions over the past few years, few consistently include rigorous research methods that are connected to diverse theoretical perspectives. In addition, the breadth of P-12 engineering education work is relatively narrow given its primary focus upon students and teachers and upon its exploration of students’ and teachers’ knowledge and attitudes. Within this paper, we encourage multiple communities (e.g., engineers, engineering education researchers, interdisciplinary K-12 educators, and policymakers) to work collaboratively to increase the quality of work produced within the P-12 engineering education community. Given the increasing number of private and public funding that is being awarded to conduct such studies and the number of national policy bodies and agencies that request evidence about the effectiveness of P-12 efforts to increase the number of students within the STEM pathway, we anticipate that the number of P-12 articles informed by theoretical frameworks and thorough assessments such as those recommended within this review will increase.

VIDEO: [http://youtu.be/bdaT GhHopOc](http://youtu.be/bdaT GhHopOc)

ACKNOWLEDGEMENTS

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REFERENCES


An Overview of the Literature: Research in P-12 Engineering Education


An Overview of the Literature: Research in P-12 Engineering Education


**AUTHORS**

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**Monica F. Cox, Ph.D.,** is an Associate Professor in the School of Engineering Education at Purdue University. She obtained a B.S. in mathematics from Spelman College, a M.S. in industrial engineering from the University of Alabama, and a Ph.D. in Leadership and Policy Studies from College of Vanderbilt University. Teaching interests relate to the professional development of graduate engineering students and to leadership, policy, and change in science, technology, engineering, and mathematics education. Primary research projects explore the preparation of engineering doctoral students for careers in academia and industry and the development of engineering education assessment tools. She is a NSF Faculty Early Career (CAREER) award winner recipient of a Presidential Early Career Award for Scientists and Engineers (PECASE)
### Agenda 1: Pathways to increase the number of engineers

<table>
<thead>
<tr>
<th>Authors</th>
<th>Description</th>
<th>Methodology</th>
<th>Findings</th>
<th>Sample Size</th>
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<tbody>
<tr>
<td>Zhe, J., Doverspike, D., Zhao, J., Lam, P., &amp; Menzemer, C. (2010)</td>
<td>High-school bridge program: A multidisciplinary STEM research program.</td>
<td>Descriptive based on: (1) Enrollment to colleges in STEM majors (2) Focus groups in students’ expectations, interests and skills</td>
<td>Students’ enrollment and attitudes.</td>
<td>Thirty-three high school students</td>
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<tr>
<td>Zarske, M., Sullivan, J., Knight, D., &amp; Yowell, J. (2008).</td>
<td>The impact on engineering graduate students of teaching in K-12 engineering programs.</td>
<td>Descriptive- Likert type survey, focus groups and observations.</td>
<td>Twenty-seven graduate students and undetermined number of teachers.</td>
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<tr>
<td>Church W., Gravel B., &amp; Rogers C. (2007)</td>
<td>Teaching parabolic motion with stop-action animations.</td>
<td>Descriptive based on observations</td>
<td>High School students in New Hampshire</td>
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### Agenda 2: Math and Science achievement improvement

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<tbody>
<tr>
<td>Cantrell &amp; Pekcan</td>
<td>The Teachersintegrating Engineering into Science (TIES) program (professional development program). Emphasis given to the engineering design process and communications skills.</td>
<td>Descriptive for students and teachers with: 1. Students’ Unit Tests 2. Students’ Rubric for the design project 3. Students’ Interview Protocol 4. Teachers’ journals 5. Teachers’ interviews 6. Teachers’ final questionnaire</td>
<td>Student Knowledge as compared to a State standardized Criterion Referenced Test (CRT) in science. Teachers’ attitudes and beliefs about the results of the program.</td>
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### Agenda 3: Technological literacy improvement

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Report on two studies:  
1. Descriptive and Quasi-experimental with Pre-post tests and observations of students use.  
2. Analysis of student achievement on the Grade Eight Proficiency Assessment (GEPA).  
**Student Impact**  
For study one, 78 students in grades 3rd, 7th, 10th and 11th located in Cleveland, Phoenix and Miami. For study two, middle school students of a urban New Jersey district.

Teacher six-week resident learning experience focused on specific engineering disciplines:  
- Industrial Engineering  
- Computer Engineering  
- Environmental Engineering  
**Teacher Impact**  
Seventeen teachers (science and mathematics).

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**Agenda 3: Technological literacy improvement**

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<tr>
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<tr>
<td>Rogers C., &amp; Portsmore M. (2004).</td>
<td>Bringing engineering to elementary school.</td>
<td>Descriptive based on observations</td>
<td>Students’ knowledge</td>
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### Agenda 1-2: Pathways to increase the number of engineers and Math and Science achievement improvement

<table>
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<tr>
<th>Study as a component of a graduate course in science education. Emphasis given to (1) Engineering Design process, (2) Discussion of articles related to using Design, Engineering, and Technology (DET), (3) Development of hands-on activities for the classroom.</th>
<th>Descriptive and quasi-experimental (all qualitative). 1. Open-ended pre/post questions 2. Seven reflection papers written by each participant 3. DET units designed by participants 4. Interviews with participant teachers.</th>
<th>3 case studies of teachers’ practice perceptions, reflections, and intentions</th>
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<td>First case (Boat) used a descriptive “individual reflection” post-test. Second case (Bulldozer) used also descriptive assessment in the form of: 1. Observations 2. Self-efficacy survey 3. Survey of interest in hands-on units.</td>
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<td>Professional development program titled “Pre-College Engineering for Teachers” (PCET) focused around the engineering design process targeting science, mathematics, and technology teachers. A two-week institute and mentorship with experts (Massachusetts partners) during the school year.</td>
<td>Descriptive and Quasi-experimental. 1. Background Survey 2. Pre-Post Survey assessing knowledge and comfort with teaching engineering and technology 3. Teacher’s project plan. 4. Interviews with a random sample of 10 participants.</td>
<td>Program Effectiveness through teachers’ knowledge and comfort with teaching engineering and technology.</td>
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<th>Participants</th>
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<tbody>
<tr>
<td>Elton D. J., Hanson J. L., &amp; Shannon D. M. (2006)</td>
<td>Soils Magic: Bringing civil engineering to the K-12 classroom</td>
<td>Program titled “Soils Magic” based on units of experiments centered on increasing interest in civil engineering.</td>
<td>Descriptive based on a survey</td>
<td>102 elementary school students</td>
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<tr>
<td>Moskal, B. M., Skokan, C., Kosbar, L., Dean, A., Westland, C., Barker, H., et al. (2007)</td>
<td>Four programs emphasizing the teaching of mathematics and science through hands-on experiences and exposure to engineer role-models</td>
<td>Descriptive and quasi-experimental via: 1. Teachers’ focus groups 2. Teachers’ open-ended questionnaires 3. External evaluator observations 4. Teachers’ pre-and post-tests 5. For one program (Tech Camp 101), students’ pre- and post-test</td>
<td>Teachers’ perceptions and knowledge as well as students’ knowledge</td>
<td>142 teachers in Colorado</td>
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*(inquiry-based writing assignments)*

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<th>Findings</th>
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<tbody>
<tr>
<td>Richards L. G., Hallock A. K., &amp; Schnittka C. G. (2007)</td>
<td>Getting them early: Teaching engineering design in middle schools. <em>International Journal of Engineering Education, 23</em>(5), 874-883.</td>
<td>Engineering Teaching Kits (ETKs) built and delivered through the Virginia Middle School Engineering Education Initiative (VMSEEI), ETKs focusing on (1) Discussion of the nature of engineering and science, (2) Design process, (3) Physical and economic constraints. All ETK’s field-tested on math and science and/or math classes.</td>
<td>Descriptive and Quasi-experimental through 1. Teacher focus groups 2. Observations of students 3. Pre-Post student knowledge tests</td>
<td>(1) Teachers perceptions of the ETK’s through focus group via workshop (2) Students knowledge (1) 17 Middle school teachers (2) 34 eight grade science students</td>
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Recognizing accelerated math potential in underrepresented people program (RAMP-UP) Descriptive-Likert-type surveys Parents attitudes and perceptions. Undergraduate student satisfaction Graduate student perceptions Undetermined number of parents, undergraduate and graduate students.

Agenda 1- 2-3: Pathways to increase the number of engineers, Math and Science achievement improvement, and technological literacy improvement


Project Lead the Way, design activities linked to science and mathematics content. Descriptive design via a Likert-type survey Teachers’ perceptions 34 technology education teachers in the state of Indiana


Project Lead the Way, design activities linked to science and mathematics content. Descriptive design via a Likert-type survey Principals’ perceptions and attitudes 37 high school principals in the state of Indiana.


Internship program for university engineering major students who might get certified as teachers. Curriculum centered on hands-on activities. Descriptive and quasi-experimental 1. Pre-post survey applied to university student (quantitatively). 2. Post-survey applied to elementary students. 3. Post-survey applied to school principals. Program Evaluation -internship program through assessment of (1) University student confidence, interest in teaching, and perception of importance of teaching. (2) Students enjoyment (3) Principals’ observations and perceptions. University students, elementary level students and school principals (number unspecified). Michigan
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<th>Methodology</th>
<th>Research Question</th>
<th>Sample Size</th>
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<tr>
<td>Rogers, G. E. (2006).</td>
<td>Project Lead the Way curricula in developing pre-engineering competencies as perceived by Indiana teachers.</td>
<td>Descriptive design via a Likert-type survey</td>
<td>Teachers' perceptions</td>
<td>34 technology education teachers in the state of Indiana</td>
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<td>Asunda, P. A. &amp; Bill, R. B.</td>
<td>Preparing technology teachers to teach engineering design</td>
<td>Observations, video footage, interviews</td>
<td>Teacher beliefs and attitudes</td>
<td>Fifteen middle school and high school technology teachers.</td>
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<tr>
<td>DeBartolo, E., &amp; Bailey, M.</td>
<td>The TEAK project: Students as teachers</td>
<td>Descriptive involving pre-post-test</td>
<td>Students’ knowledge and attitudes</td>
<td>One hundred middle school and high school students.</td>
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### DISSECTATIONS

#### Agenda 1: Pathways to increase the number of engineers

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<tr>
<th>Author</th>
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<tbody>
<tr>
<td>Oware, E. A. (2008)</td>
<td>Examining elementary students' perceptions of engineers.</td>
<td>CONSTRUCTIVISM (Vygotsky)</td>
<td>Descriptive and Quasi-experimental—Perception Questionnaire, Drawing Analysis, Interviews.</td>
<td>(1) Nine 3rd and 4th GERI students&lt;br&gt;(2) Nine 5th and 6th GERI students&lt;br&gt;(3) One course developer&lt;br&gt;(4) Two instructors</td>
</tr>
<tr>
<td>Martin, B. R. (2011)</td>
<td>Factors influencing the self-efficacy of black high school students enrolled in PLTW pre-engineering courses.</td>
<td>Self-efficacy</td>
<td>Descriptive-Motivated Strategies for Learning Questionnaire (MSQL)</td>
<td>Seventy-six high school students</td>
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<tr>
<td>Lanigan, D. (2009)</td>
<td>Increasing student motivation to become a successful industrial engineer.</td>
<td>VIE Theory of Motivation</td>
<td>Quasi-experimental: Pre-Post Surveys and observations</td>
<td>Thirty-six middle school students</td>
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#### Agenda 2: Math and Science achievement improvement

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<tr>
<td>Marulcu, I. (2010)</td>
<td>Investigating the impact of a LEGO®-based, design-oriented elementary science curriculum compared to an inquiry-based curriculum of fifth graders’ content learning of simple machines.</td>
<td>Conceptual development-Piaget</td>
<td>Experimental—Pre and Post-tests and interviews, observations of videos and students workbooks</td>
<td>(1) Fifty-three elementary students and one teacher in the treatment group&lt;br&gt;(2) Twenty-six elementary students and one teacher in the control group</td>
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<tr>
<td>Source</td>
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<tr>
<td>Martinez Ortiz, A. (2010)</td>
<td>Students’ understanding of ratio and proportion within engineering robotics.</td>
<td>LEGO-Robotics integrated engineering and mathematics program, focused on ratios and proportions.</td>
<td>Experimental via post-tests, interviews and observations.</td>
<td>Thirty fifth grade students, 15 in the treatment group and 15 in the control group.</td>
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<tr>
<td>Portsmore, M. D. (2009)</td>
<td>Exploring how experience with planning impacts first grade students’ planning and solutions to engineering design problems.</td>
<td>LEGO®-based, engineering-oriented curriculum inspired by Goldilocks and the three bears.</td>
<td>Descriptive involving: (1) Pre-post interviews on engineering design problems (2) Observations and rubrics of artifacts. (3) Observations of videos.</td>
<td>Twenty-four first grade students.</td>
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