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A Targeted Study of the DR K–12 Engineering Education Projects

Community for Advancing Discovery Research in Education

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1. Introduction

Innovative K–12 science, technology, engineering, and mathematics (STEM) education has been recognized by policy-makers as important to future economic growth.[1] However, in practice, the science and mathematics domains receive more attention than technology and engineering. This may change given the prominence of engineering in the *Next Generation Science Standards* (NGSS),[2] which could drive innovation within the engineering and technology domains, resulting in the long-term, in greater representation of these domains in K–12 education.

In 2009, the National Research Council (NRC) released a report on the state and future prospects of K–12 engineering education.[3] The report authors advocated for the inclusion of engineering in K–12 education, arguing that engineering is an intrinsically important content area, and in addition, "K–12 engineering education may improve student learning and achievement in science and mathematics; increase awareness of engineering and the work of engineers; boost youth interest in pursuing engineering as a career; and increase the technological literacy of all students. The committee believes engineering education may even act as a catalyst for a more interconnected and effective K–12 STEM education system in the United States." [4]

The report presented a set of principles for the future of engineering education in K-12 (and post-secondary) classrooms:

1. Emphasize engineering design, an iterative approach to defining and solving problems.
2. Incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills.
3. Promote engineering habits of mind: (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations. [5]

In addition to principles for educational approaches, the committee made seven recommendations to the U.S. policy and research community on the types of actions required for developing a research base for engineering education and for implementing engineering-influenced curriculum and pedagogical approaches in classrooms.[6] These recommendations include increasing funding for research on the following topics related to engineering education: how students develop design practices, the impact of engineering education on students, identifying successful models of engineering education, defining STEM literacy, and integrating science inquiry, mathematical reasoning, and design practices. They also advocated for beginning a national dialogue on preparing K-

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1 See for example, http://www.whitehouse.gov/issues/education/k-12/educate-innovate

2 Next Generation Science Standards, www.nextgenscience.org/next-generation-science-standards.

3 Katehi, L., Pearson, G., & Feder, M. A. (2009). *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press.

4 Katehi, et al (2009). p.1.

5 Katehi, et al (2009). pp.4-6

6 Katehi, et al (2009). pp. 7-14.

12 engineering teachers and maintaining a focus on underrepresented groups when developing materials for K-12 engineering and publicly promoting engineering education.

Because engineering education is drawing increased attention from STEM policy-makers, it is an opportune time to take stock of the current status of ongoing innovation in K–12 engineering education; therefore, the Community for Advancing Discovery Research in Education (CADRE)[7] conducted a brief targeted study to investigate the work that is being funded in K-12 engineering education within NSF's Discover Research K–12 (DR K–12) program. NSF's DR K–12 program seeks to enhance the teaching and learning of STEM in the nation's K–12 education system by funding the "development, testing, deployment, effectiveness, and/or scale-up of innovative resources, models and tools"[8] in a range of STEM areas, including engineering.

The NRC report's guiding principles for engineering education as well as a few of the recommendations for research and development formed the conceptual base of the current study. Additional guidance was provided by a subset of DR K–12 PIs that participated in an engineering special interest group organized by CADRE. Both the NRC report and the feedback from PIs guided our examination of the activities, products, and foci in engineering-related projects funded by the DR K–12 program.

The remainder of this document describes the K–12 engineering education work that is being furthered within this specific important program funded by NSF. It begins with a description of the methodology used in this targeted study, and then describes findings related to engineering definitions, products and activities, content and practices, integration, context, outcomes, and variation by project characteristics. (See pop-ups for further information). In the Appendix we include short summaries of the projects included in this review. These summaries give a sense of each project's activities, goals, and the components related to engineering education.[9]

2. Methodology

As part of its work, CADRE annually compiles a descriptive overview of the characteristics of projects in the DR K–12 portfolio. [10] In addition, CADRE also conducts targeted studies on topics of interest to DR K–12 PIs, NSF and the broader research community. The current targeted study was designed to provide insight into the research and product development conducted in K-12 engineering education, using the DR K-12 projects as selected cases. The research questions, data, and analytic methods used in the study are described below.

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7 CADRE is the resource network that was established by NSF to support the DR K–12 community in advancing the state of research and evaluation in STEM education. Organizational partners of CADRE include the Education Development Center, Abt Associates Inc., and Policy Studies Associates.

8 National Science Foundation (2011). Discovery Research K–12 (DR K-12): Program Solicitation 11-588.

9 This appendix excludes 2 of the 26 projects that were reviewed for this report. PIs of these projects did not give active consent to feature a summary of their project in this targeted study.

10 The latest portfolio review can be found at: http://cadrek12.org/sites/default/files/CADRE%20YR%205%20Portfolio%20Overview%20v7_stl.pdf

2.1 Research Questions

As previously discussed, the NRC report, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, along with feedback from DR K–12 PIs, guided the conceptual base of the current study's examination of engineering-related projects funded by the DR K–12 program. The research questions guiding the analysis were:

1. How do the DR K–12 engineering education projects **define engineering** and/or the engineering design process?
2. What are the **activities and products** of the DR K–12 projects that involve engineering education?
3. What **content and practices** are included in these projects?
4. Is engineering treated independent of other STEM subjects, or is it **integrated** with other STEM content?
5. What is the general **context** for the materials being developed?
6. What **outcomes** are examined in these projects and how are they measured?
7. For the above questions, are there systematic similarities and differences between these projects based on grade band, project type, or any other emergent factors? If so, what are they?

2.2 Data

The sources of data used in this study were collected for CADRE's annual portfolio overviews of the DR K-12 program. To collect data for the annual reviews, CADRE solicited materials from DR K-12 Principal Investigators (PIs).[11] Each year, PIs of newly funded projects were asked to provide CADRE with their project's proposals and responses to review panel questions. Additionally, PIs of existing projects initially funded in prior years were asked to provide project updates in the form of annual reports, project publications, and other information about their plans, activities, and achievements. For the current study, 34 projects were identified as addressing engineering. Upon closer inspection, eight of these projects were removed from the sample because they addressed issues relating to STEM as a whole, but did not specifically address engineering nor did they collect data that related to engineering-specific outcomes, resulting in a final 26 projects included in this targeted study. Summaries of the projects included in this review are presented in the Appendix.

2.3 Coding Methodology

This study drew on coded data that comprise: (1) general project characteristics that were coded for the annual portfolio overview; and (2) more in-depth coding conducted specifically for this study.

[11] CADRE operates under a cooperative agreement (rather than a contract) with the NSF so we do not have access to the data and materials maintained by NSF.

To generate data on general project characteristics, as part of CADRE's annual activities, the collection of all DR K-12 project materials were reviewed and coded by a team of CADRE researchers using a protocol designed to capture information on project attributes and characteristics as well as the DR K-12 program goals being addressed.

More in-depth coding, specific to the research questions of this targeted study, was then conducted on the subset of engineering projects. Project materials were analyzed qualitatively by a team of trained coders guided by a detailed set of instructions. Coders read projects' materials and sorted information into the six areas of interest: engineering definitions, activities and products, content and practices, integration, context, and outcomes. Within each of these areas, coders analyzed commonalities and contrasts across projects and used an inductive coding process to identify emergent themes. Additionally, systematic differences by grade band, context, and project activity were examined. The themes and contrasts that emerged from this analysis are presented in the findings section of this targeted study.

2.4 Study Limitations

The materials reviewed and coded for this analysis were created by investigators for purposes other than this review. Thus, across projects the information is reported in diverse and unsystematic ways. As a result, the level of detail reliably extracted and coded varied and was at times limited. Additionally, often projects reported on planned activities. For convenience, this study uses phrases like "projects used," but in fact, we likely only know what projects proposed to use or discussed considering in their annual reports. While CADRE asked for additional materials including responses to NSF reviewers, annual reports, final reports, publications and products, there were no materials beyond the proposal for six projects.

An additional limitation is that the insight gained through this study is limited to the set of DR K-12 engineering projects, and it is unclear how representative the DR K-12 funded projects are of the larger state of research in engineering education. While the findings cannot be generalized to the wider field of engineering education, they do provide a snapshot of the current status of support for innovation in K-12 engineering education within the DR K–12 program.

3. Findings

Study results are presented in this section, organized by research question, with one exception. The seventh research question, "For the above questions, are there systematic similarities and differences between these projects based on grade band, project type, or any other emergent factors? If so, what are they?" is addressed, as appropriate, throughout the sections that address the other research questions.

3.1 Definitions and Characteristics of Engineering

Few of the DR K–12 engineering projects explicitly included a definition of engineering in their materials, though many of them described its features and processes. All but one of the 26 projects in the sample contained some description of engineering, and 24 projects referenced "engineering design" explicitly. These descriptions, taken together, revealed some commonalities across projects in the way that engineering and the engineering design process are conceived of in this segment of K–12 education.

Five themes in projects' descriptions of engineering are described below: (1) the use of engineering design processes in educational activities; (2) the view that engineering is a practical application of abstract concepts; (3) collaboration; (4) engineering habits of mind; and (5) overlap between engineering design and scientific inquiry.

3.1.1 USE OF ENGINEERING DESIGN PROCESSES IN EDUCATIONAL ACTIVITIES

An important theme found across most of the engineering projects was a focus on the use of the engineering design process as a learning tool in K-12 educational settings. Of the 26 projects in the set, 25 contained some description of engineering, and 24 referenced engineering design.

A majority of projects (19) described the engineering design process as being problem-based, where students are required to define and design a solution to a problem. These descriptions referenced other learning models, including Model Eliciting Activities (MEAs), Learning by Design (LBD), and Scientific Inquiry, all of which have problem-solving components. One project drew considerably on scholarly research to describe the relationship between engineering design and problem-based learning, for example citing, "Sheppard et al. (2009) summarize the design process to include three broad areas of focus: defining the problem, generating candidate solutions, and evaluating and implementing candidate solutions."[12] The project proposal goes on to outline the eight phases of problem-based learning as they apply to engineering design challenges:

> **Problem Definition**: Defining what the problem really is. **Gather Information**: Searching for and collecting information needed to solve the problem. **Generating Ideas**: Thinking up potential solutions (or parts of potential solution) to the problem. **Modeling**: Detailing how to build the solution (or parts of the solution) to the problem. **Feasibility Analysis:** Assessing and passing judgment on a possible or planned solution to the problem. **Evaluation**: Comparing and contrasting two (or more) solutions to the problem on a particular dimension (or set of dimensions) such as strength or cost. **Decision**: Selecting one idea or solution to the problem (of parts of the problem) from among those considered. **Communication**: The participants' communicating elements of the design in writing, or with oral reports, to parties such as contractors and the community. (Mosborg et al., (2006, p. 15) [13]

Eight projects specified that, in the engineering design process, there is not one correct answer but rather multiple solutions to each problem. The process of identifying the optimal solution in terms of feasibility, results, and a range of other constraints and considerations is a cornerstone of the engineering design process.

Twelve projects emphasized the link between technology and engineering design. Projects used technology either to model various solutions to the design challenge or to collect data related to the various solutions. Use of technologies like sensors, to collect data to inform solutions distinguishes the engineering design process from simplistic "crafting based on simple hunches".[14] One project argued that, in fact, engineering design *creates* technologies – any man-made object or process that

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[12] Becker, NSF – 0918621, Proposal, Page 5

[13] Becker, NSF – 0918621, Proposal, Page 10

[14] Xie, NSF – 0918449, Annual Report, Page 7

solves a problem or serves human needs and wants.[15] According to multiple projects, the relationship between engineering design and technology grows ever tighter and more important in our increasingly digital and technological world.

Nine projects also conceived of engineering design as a process of innovation in the face of constraints. One project explained the breadth of these possible constraints:

> …the most fundamental of these constraints is the laws of nature. Engineers designing a solution to a particular problem must, for example, take into account how physical objects behave in motion. Other constraints include time, money, available materials, ergonomics, environmental regulations, manufacturability, reparability, and political considerations.[16]

In addition to defining and describing the engineering design process, they also specified what engineering design was *not*. Engineering, one project noted, "is more than the mere act of making something"[17], and as another project describes, does not follow a single, linear path[18].

In summary, as expressed by one PI: "Engineering design challenges explicitly specify a problem to be addressed as well as constraints and requirements on the solution. There are many possible solutions; there is no single, correct answer. Engineering design challenges engage students in the application of science content and processes. Students use both math and science to design solutions to challenges."[19]

3.1.2 PRACTICAL APPLICATION OF ABSTRACT CONCEPTS

Nineteen projects described engineering and engineering design as a "real-world" or practical application of abstract science or math concepts. This practical application approach, according to PIs, enhances learning and builds understanding of complex concepts such as force, load, motion, heat transfer, and electricity by allowing students to explore and manipulate otherwise intangible ideas. One proposal noted:

> Design practices have long been proposed as powerful tools for education. Dewey (1933, 1938) suggested design activity as the pedagogical foundation for developing understanding of a discipline's practices and principles. Contemporary efforts suggest prospectively fruitful relations between engineering design and learning about the natural world. Sadler, Coyle, and Schwartz (2000) suggest that engineering design challenges often improve students' scientific investigation skills and also their understanding of how systems function. For example, middle-school students who designed a two-dimensional suspension bridge uncovered causal links between structure and load-bearing.[20]

[15] Fowler, NSF – 1019672, Responses to Questions

[16] Pearson. NSF – 0733584, Annual report, Page 6

[17] Zubrowski, 2002 as cited in Benenson NSF - 0733209, Proposal, Page 3

[18] Custer NSF – 1119167, Responses to Questions

[19] Cunningham, NSF-1220305, Proposal, page 7

[20] Benenson, NSF–0733209, Proposal, page 2.

Additionally, a subset of these projects described the hands-on nature and the real-world context of engineering and engineering design as being inherently engaging and more accessible to students. For example, one proposal described:

> Design has the potential of making science more accessible for all students. Many students who might be intimidated by science may discover through the problem-based approaches of design that science can be fun and a subject worth pursuing. Mousetrap vehicles, solar-powered devices, rocketry, or the design of structures such as bridges are authentic means of introducing scientific principles to students. Such approaches stimulate interest and increased learning in an increased number of students, many who may otherwise turn away from science.[21]

Interestingly, focus on the practical and hands-on nature of engineering and the engineering design process received less focus among projects targeting older grades. For example, 80 percent of projects targeting elementary-aged students (8 of 10) emphasized that engineering provided real-world context for STEM concepts. This was only true of 60 percent of projects targeting high-school students (9 of 15). Similarly, half of projects targeting elementary school students (5 of 10) noted the hands-on nature of engineering and engineering design, while less than a third of projects targeting high school students highlighted this (4 of 15). This may be because as students' progress towards college, they encounter more abstract and computational tasks, or that, foundational concepts enhanced by practical demonstration and hands-on exploration are highly utilized in the elementary and middle grades.

3.1.3 COLLABORATION

Collaboration also emerged as an important aspect of engineering and engineering design. Thirteen projects described the importance of collaboration and communication for the success of any engineering challenge, as "the complexity of the task is often beyond the skills of a single student, and diversity of perspectives creates opportunities to detect, debug, and integrate partially successful understandings of the task."[22] The focus on collaboration was emphasized in fewer projects targeting higher grades than lower grades. While almost two-thirds of projects targeting elementary school students identified the importance of collaboration for engineering, only a third of projects targeting high school students emphasized it.

3.1.4 ENGINEERING HABITS OF MIND

Without explicitly defining engineering, several projects (4) identified specific engineering habits of mind that characterize engineering, including the ability to "apply knowledge of mathematics, science and technology through the engineering design process; analyze and interpret data when presented in multiple forms; identify, formulate and solve problems; communicate effectively; function as part of a multidisciplinary team; use the techniques, skills and tools necessary in the modern workforce; and recognize the need for, and engage in, ongoing learning."[23] Within these habits of mind are elements of the descriptions of engineering design presented above. They characterize engineering as a real-

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[21] Fowler, NSF–1019672, Proposal, page 9.

[22] Schunn, NSF–1027629, Questions and Responses May 28, page 3.

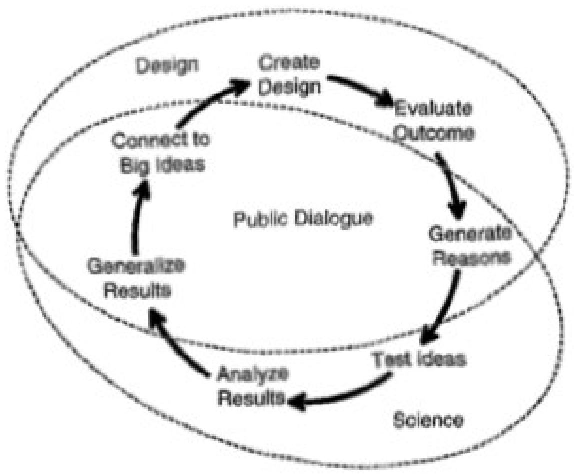
[23] Pruet, NSF–0918769, Responses to Questions, Page 3.

world problem-context that requires communication, application of content knowledge, and catalyzes inquiry.

3.1.5 OVERLAP BETWEEN INQUIRY AND DESIGN

Finally, approximately half of the projects in the set identified the overlap between scientific inquiry and engineering design. One project explained that "both scientific inquiry and engineering design are methods of solving problems, must be conducted within physical and design constraints, and require creative thinking, communication, and collaboration. There is significant potential in articulating engineering design with science content and scientific inquiry."[24]

Another proposal included the figure below which offers a slightly different view of the overlap between science inquiry and engineering definition:[25]



3.2 Project Activities and Products

Findings presented in this section describe broad trends related to the activities and products across projects. The 26 DR K–12 engineering projects included in this study were undertaking a range of activities and generating a variety of products. Summaries presented in the Appendix provide an overview of each of the engineering projects.[26]

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[24] Fowler, NSF – 1019672, Proposal, Page 2.

[25] Apedoe, X.S., Reynolds, B., Ellefson, M., and Schunn, C.D. (2008). Bringing Engineering Design into High School Science Classrooms: The Heating/Cooling Unit. *Journal of Science Education and Technology* (online only), 17(5).

Cited by Millman, NSF–0918618, Questions and responses May 18, page 1.

[26] The Appendix excludes 3 of the 26 projects that were reviewed for this report because PIs of these projects did not provide active consent to feature a summary of their project in this report.

The major activities of the engineering projects fell into four categories: design and test, study, convene, and/or synthesize. These activities focused on various components of educational innovations: student learning materials, professional development, and models (Table 1).

Table 1: Project Activities

	Student Learning Materials	Professional Development	Models
Design and Test	16	13	5
Study	1	3	4
Convene	0	0	1
Synthesize	0	0	2

Projects can include multiple activities and components.
N=26 projects.

Most of the activities in the engineering projects focused on student learning materials and teacher professional development. Student learning materials ranged from full curricula, stand-alone activities, or supplemental materials to add to existing curricula. These materials sometimes included innovative physical and digital tools like a robotics kit[27] or simulation software[28] that were key components of the student learning materials being developed or studied. Not surprisingly, the student learning materials and professional development were frequently related; 14 projects included activities addressing both curriculum and professional development components.

There also were a number of projects studying and creating information on models. Two projects synthesized information on models, one of which also convened a workshop to disseminate the knowledge gained through the synthesis. Activities involving models in the engineering projects included investigating the feasibility of K-12 engineering standards, developing learning trajectories, and developing professional development frameworks, among others.

Notably, most of the engineering projects incorporated multiple types of activities into their scope. Seventeen projects engaged in two or more types of activities. For example, projects might develop a curriculum coupled with a professional development plan, or might study an existing professional development program and develop a model.

Researchers anticipated that project activities would result in products that could be used by the education community, for research and educational activities. Most commonly, these products could be characterized as student learning and/or teacher professional development products. This aligns with the target of project activities depicted in Table 1. A more specific break down of these anticipated products are displayed in Table 2. This table illustrates that these projects are not just studying or researching engineering education, but are creating products to be used for teaching and learning.

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[27] Chen, NSF – 0733228

[28] Xie, NSF – 0918449

Table 2: Anticipated Products

	Number	Percentage
Student learning products	**17**	**65**
Computer or Internet activities and resources	7	23
On-line gaming, interactive learning, or virtual environments	*4*	*15*
Online networking or collaborating tool	*4*	*15*
Online course or class	*1*	*4*
Information resource	*1*	*4*
Other computer or internet activities and resources	*1*	*4*
Curriculum	12	46
Other activities, materials or equipment used for student learning	11	42
Teacher professional development products	**17**	**65**
Stand-alone instruction, manuals, guides, or information resources	14	54
Full course	7	27
One or two sessions, classes, or meetings	5	19
Networks	5	19
Curriculum for a course or class	3	12
Supervision or mentoring	3	12
Other teacher professional development products	1	4
Models	**5**	**19**
Model or demonstration of ideal educational practice	2	8
Standards	2	8
Student curriculum frameworks	2	8
Student learning progression	2	8
Teacher professional development frameworks	1	4
Student assessments	**1**	**4**
Syntheses	**2**	**8**

Notes:

Projects may have had multiple anticipated products.

N=26 projects.

3.3 Content and Practices Addressed in Projects

The content areas addressed in DR K–12 engineering projects were diverse. They included an array of STEM disciplines as well as crosscutting concepts and practices. The disciplines addressed in projects are described below, followed by a discussion of crosscutting concepts and science and engineering practices that unify the study of science as described in the NGSS.[2]

3.3.1 DISCIPLINARY CONTENT

Overall, DR K-12 engineering projects included a diversity of disciplines and math and science sub-topics. In terms of the major disciplines addressed, all of the projects focused on engineering, but more than half also included science content, and more than a third included mathematics content (Table 3). Other disciplines, such as computer and information science and technology, were also addressed in a few of the projects.

Table 3: Major Disciplines Addressed

	All Grades (N=26)	Elementary (N=10)	Middle (N=12)	High (N=15)
Engineering	26	10	12	15
Science	14	4	7	7
Mathematics	9	4	5	4
Computer and information science	2	1	1	1
Other discipline	2	1	1	0

Projects can address multiple disciplines and include multiple grade bands.
N=26 projects.

Among the projects that included mathematics content, a variety of sub-disciplines from general math to trigonometry were included (Table 4). Three projects addressed multiple mathematics sub-disciplines. The science topics covered (Table 5) were similarly diverse with slightly more projects including biology (6), physical science (4), and chemistry (3). Eleven of the science projects involved multiple science topics, and 10 engaged students and teachers in scientific inquiry.

Table 4: Mathematics Sub-Disciplines Addressed

	All Grades (N=26)	Elementary (N=10)	Middle (N=12)	High (N=15)
Any mathematics topic	**9**	**4**	**5**	**4**
Multiple mathematics topics	3	1	1	1
Fractions and decimals	2	1	1	0
General mathematics	2	1	1	1
Measurement	2	1	1	0
Rational numbers, proportional reasoning	2	1	1	0
Higher algebra (high school+)	1	0	0	1
Statistics	1	0	0	1
Trigonometry	1	0	0	1
Whole number arithmetic	1	1	0	0

Projects can include multiple grade bands and address multiple sub-disciplines.
N=26 projects.

Table 5: Science Sub-Disciplines Addressed

	All Grades (N=26)	Elementary (N=10)	Middle (N=12)	High (N=15)
Any science topic	**14**	**4**	**7**	**7**
Multiple science topics	11	3	4	5
Use of scientific inquiry procedures	10	2	5	4
Biology	6	1	2	4
Physical science	4	1	2	1
Chemistry	3	0	2	3
Geosciences	2	1	1	0
Physics	2	1	1	1
Astronomy	1	1	0	0
Environmental sciences	1	0	1	0
General science	1	1	0	0
Specific science topics, not identified	1	0	0	0

Projects can include multiple grade bands and address multiple sub-disciplines.
N=26 projects.

3.3.2 NGSS CROSSCUTTING CONCEPTS AND PRACTICES

The recently released NGSS builds on the crosscutting concepts and science and engineering practices introduced in *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts and Core Ideas*.[29] The science and engineering practices in NGSS outline how students can engage with science and engineering, understand how science develops, the work of engineers, and links between science and engineering. The practices and crosscutting concepts are interconnected and widely applicable across grade levels and disciplinary topics (see tables 6 and 8 for a list of the concepts and practices, respectively). In addition to reviewing the major disciplines addressed in the DR K–12 engineering projects, we analyzed project materials to examine if their activities allowed students or teachers to engage with these concepts and practices.

CROSSCUTTING CONCEPTS

Twenty-two of the 26 engineering projects included one or more of the crosscutting concepts. The four remaining projects organized conferences, developed syntheses, or created a student assessment and did not directly engage students or teachers with the crosscutting concepts.

Three of the projects that included crosscutting concepts focused on a single concept, but most (19) included multiple crosscutting concepts. For instance, nine projects addressed cause and effect, and all of these also included structure and function. Three projects addressed all of the crosscutting concepts. The most common crosscutting concept was structure and function and the least common was stability and change (addressed by 16 and 6 projects, respectively).

Table 6: Crosscutting Concepts by Grade Bands

	All Grades (N=26)	Pre-Kindergarten (N=3)	Elementary (N=10)	Middle (N=12)	High (N=15)
Patterns	13	0	5	7	5
Cause and effect	9	2	4	5	4
Scale, proportion, and quantity	13	1	6	6	5
Systems and system models	15	2	5	7	8
Energy and matter	15	1	5	9	7
Structure and function	16	3	6	7	7
Stability and change	6	1	2	4	4

Projects can include multiple grade bands and address multiple concepts.
N=26 projects.

One goal of the crosscutting concepts is to unite the disciplines and identify how core concepts can be applied across disciplines and grade levels. However, among DR K-12 engineering projects, there were some differences by grade (Table 6) and by other disciplines the projects address (Table 7) in the crosscutting concepts included.

[29] National Research Council. (2012). A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts and Core Ideas. National Academies Press, Washington, DC.

Table 7: Crosscutting Concepts by Discipline

	Mathematics	Science
***Any* crosscutting concepts**	**8**	**13**
Patterns	7	9
Cause and effect	2	6
Scale, proportion, and quantity	7	7
Systems and system models	3	10
Energy and matter	5	11
Structure and function	5	10
Stability and change	1	4

Projects can include multiple concepts.
N=26 projects.

PRACTICES

Central to engaging students in engineering are the practices used to address engineering problems and develop solutions. The NGSS incorporates eight interrelated practices in science and engineering from *the Framework* (See Table 8 for a list of practices). Six of these practices are the same for science and engineering, and two practices articulate the differing goals and products of the two disciplines.

Table 8: Projects that Apply the NGSS Practices

	Number
Planning and carrying out investigations	21
Constructing explanations (for science) and designing solutions (for engineering)	20
Asking questions (for science) and defining problems (for engineering)	20
Using mathematics and computational thinking	18
Developing and using models	18
Analyzing and interpreting data	17
Obtaining evaluating and communicating information	17
Engaging in argument from evidence	14

Projects can include multiple practices.
N=26 projects.

Twenty-one of the DR K-12 engineering projects included one or more of the eight practices. For example, one project described its engineering design activities as follows:

> Through the design of these artifacts, students engage in the behaviors and activities of designers, engineers, and architects—they analyze a challenge, generate ideas to answer the challenge, investigate the science and math concepts governing the challenge, build or test models to obtain feedback, reflect, and then redesign the solution based on feedback to better meet the challenge.[30]

All of the component activities in this description directly correspond to NGSS practices, which outline a similar process highlighting problem evaluation, solution development, data analysis, and collaboration to share and further develop solutions. Twenty-one projects applied two or more of the NGSS practices and 11 utilized all eight practices. Further, projects included the practices regardless of participant age. Between 60% and 75% of the projects targeting each grade band were using

[30] Millman, NSF–0918618, Proposal, page 6

multiple practices in their engineering design tasks (pre-kindergarten (67%), elementary (60%), middle (75%), high (73%)).

Generally, projects were focused on developing and designing solutions to problems and therefore included some activity that could be classified as "planning and carrying out investigations" (21 projects). Most projects also included "designing solutions" and "defining problems" (20 projects each). In addition, many projects also included the use of mathematics and computational thinking, models and modeling, and data to support the development, testing, and analysis of designs (18, 18, and 17 projects, respectively). Fewer projects addressed whether students communicated their ideas and evaluated each other's designs. This practice, "engaging in argument from evidence", was included by the least number of projects (14) but this was still more than half of all projects included in the study. Projects that did include this practice emphasized the use of feedback and collaboration to optimize designs and facilitate the engineering process for all.

Three projects specifically mentioned the NGSS practices in their project materials. Two of these projects began in 2012, when NGSS were introduced, and used the practices as a framework to support their engineering research activities. In the years prior to NGSS, six projects outlined their own sets of "steps," "strategies," or "essential elements of engineering." These other sets of practices varied from three stages to eight categories that were developed by a number of different sources. For example, one project referenced categories in *Engineering Design Expertise Study Codebook;*[31] and another described "the NCETE professional development approach [which] emphasizes eight essential elements of the engineering design process appropriate for high school learners (Childress & Maurizio, 2007, p. 3):

1. Identification of a need
2. Definition of the problem/specifications
3. Search
4. Develop designs
5. Analysis
6. Decision
7. Test prototype and verify the solution
8. Communication"[32, 33]

These various sets of engineering approaches aligned closely with the NGSS practices.

31 Mosborg, S., Cardella, M., Saleem, J., Atman, C., Adams, R. S., & Turns, J. (2006). Engineering Design Expertise Study Codebook, CELT Technical Report CELT-06-02. Seattle: University of Washington.

32 Becker, NSF–0918621, Proposal, page 4.

33 As cited by Becker: Childress, V., & Maurizio, D. (2007). Infusing Engineering Design into High School Science, Technology, Engineering and Mathematics Instruction: An Exemplary Approach to Professional Development. Unpublished NCETE Internal Document. Utah State University.

3.4 Integration of Disciplines

The various disciplines and topics covered by these projects demonstrate how engineering is sometimes conceptualized as being fundamentally interconnected with other fields. There were many interesting examples of how engineering was integrated with other topics to address complex topics. For instance, engineering with integrated with:

- Environment (2 projects): Building algae farms (including setting up a carbon source from exhaust gases and 'green retrofit[ing]' model homes to study the environment;
- Health (6 projects): Modeling a blood clot, and studying food preparation/food chemistry, and designer bacteria to study health and medical topics;
- Mobility/Transportation (7 projects): Involving gravity-powered cars, LEGO robotics/mechanics, ways to move objects from one point to another; locomotion of humans and other animals, engineering transportation robots, comparing and contrasting human, animal, and robot parts and movement to study mobility and transportation;
- Shelter (3 projects): Building emergency shelters to study shelter and home related topics.

The majority of projects included other STEM content as well as engineering, however, eight projects focused only on engineering among the STEM disciplines (Table 9). The most common combination of STEM disciplines was science and engineering. Most of the projects that included engineering and no other STEM disciplines targeted high school, though a few also targeted the younger grades.

Table 9: STEM Discipline Combinations

	All Grades (N=26)	Elementary (N=10)	Middle (N=12)	High (N=15)
Engineering	8	3	4	7
Science and engineering	7	2	2	3
Science, mathematics, and engineering	5	2	3	3
Mathematics and engineering	3	2	1	1
All other combinations[a]	3	1	2	1

Projects can include multiple grade bands.

N=26 projects.

[a] Engineering, Computer Science, and Other; Science, Engineering, and Computer Science; and Math, Science, Engineering, and Other.

When considering non-STEM content along with STEM disciplines, 24 of the 26 projects reviewed for this study integrated engineering with other disciplinary content, including non-STEM content. The two projects that did not integrate engineering with other content at all were primarily concerned with personal attitudes towards engineering (general perceptions and attitudes as well as beliefs about one's own capabilities) of groups that are traditionally underrepresented in STEM.

The set of 24 projects that did integrate engineering with other content were further reviewed to ascertain the type of content integrated. Ten projects integrated content from all STEM areas and either discussed the integration of all four STEM areas generally or individually identified science, mathematics, technology and engineering content in their products; eleven integrated engineering content with science, but not other STEM areas; six integrated it with mathematics content, but not other STEM areas; six with technology; three with robotics; and one with computer science. Robotics projects were skewed toward the younger grades (pre-kindergarten (1), elementary (1), middle (2)), while the computer science project targeted older grades (middle and high school).

Interestingly, projects also integrated engineering with non-STEM content. Six projects integrated engineering with other disciplines such as fine arts, language arts/literacy, and/or social studies. For example, one project developed materials to explore the potential for introducing engineering concepts in grades 3-5 through design challenges based on stories in popular children's literature.

> The units are designed around addressing grade-appropriate literacy concepts while incorporating engineering design challenges. Each unit is based on a grade-level appropriate reading comprehension topic, tied to both literacy and STEM standards, and example books that lend themselves to these activities and are appropriate for many students at the grade level.[34]

One example from this curriculum introduced children to the concepts of natural and human-made materials while students designed houses for the three little pigs.

3.4.1 APPROACHES TO CONTENT INTEGRATION

The ways in which engineering was integrated with other content areas varied across projects. The most common approach was for an engineering problem or an engineering design challenge to serve as the overall context for learning skills and content. For example, one project proposed to teach third through fifth graders about force and motion by having students create rubber-band and balloon powered vehicles.[35] In this example, students are learning science content through the design challenge of building vehicles. Another project proposed, "…to design and implement an 8th-grade Physical Science inquiry-based curriculum that uses engineering design and LEGO Robotics as the context with which to teach science content and process skills."[36] More than half (14) of the 24 projects that integrated engineering with other content used this approach.

This method of integration was employed equally across all grade bands. Thirty percent of the projects that targeted elementary students, 50% of projects that targeted middle school students and 46% of projects that targeted high school students used an engineering or engineering design problem to serve as the overall problem context for the content being taught.

One project used a similar model of integration where a problem in one discipline sets the stage for learning core concepts or skill in another disciplines, but switched the role of engineering. In this project chemical design was the context for acquiring and practicing engineering design skills.

> Using chemical design as an organizing principle in chemistry curriculum and instruction could help us achieve the level of integration advocated by the new Framework for science education. The design, investigation, and implementation of strategies to identify and synthesize chemical substances require the simultaneous application of core scientific (inquiry) and engineering (design) practices."[37]

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[34] Rogers, NSF–1020243, Proposal, page 4.

[35] Benenson, NSF–0733209, Proposal

[36] Millman, NSF–0918618, Proposal, page 1.

[37] Sevian, NSF–1222624, Proposal, page 2.

Four projects explicitly reported that they were integrating content using infusion and/or mapping models (infusion only:1, mapping only: 2, both: 1). The 2010 NRC report on engineering standards[38] defines infusion as "including the learning goals of one discipline—in this case engineering—in educational standards for another discipline" (p. 23) and mapping as "drawing attention explicitly to how and "where" core ideas from one discipline relate to the content of existing standards in another discipline" (p. 28). These concepts are introduced as two complimentary methods that can be used to leverage current standards in other disciplines to bolster engineering education. While these four projects use these terms explicitly and refer to the NRC report, it was difficult to identify these methods of integration in other projects when they were not explicitly labeled as such.

3.5 Context

The DR K–12 Engineering projects involved a broad range of populations and were implemented in diverse settings. The following section describes projects' contexts in terms of populations addressed, whether projects were designed for school or extracurricular enhancement, and where projects were implemented.

Together, the DR K–12 projects demonstrated the variety of ways in which engineering education can be explored, developed, and advanced. The projects also had a range of target participants. Table 10 depicts the number of projects directed at each type of participant: students, teachers, and district professionals.

Table 10: Populations Targeted by Projects

	Number	Percentage
Students	25	96
English Language Learners	*2*	*8*
Students in low performing schools or districts	*2*	*8*
Other specific student populations[a]	*5*	*19*
Teachers	19	73
School administrators	1	4
Doctoral students	1	4
Other populations[b]	4	15

[a] artistically gifted students; large, urban school district; racially and ethnically diverse; racial/ethnic minorities; Latino/a students

[b] U.S. K-12 STEM communities; education policy makers; Parents; first-year college students; curriculum writers; Community members

Projects may have targeted multiple groups.

N=26 projects.

Nearly all projects, whether they focused on student learning, professional development, or models, targeted students. Table 11, outlines the number of engineering projects that involved students or teachers in each grade band. Nine of the projects addressed multiple grade levels. The majority of projects (58%) targeted high school students or teachers.

[38] National Research Council. *Standards for K–12 Engineering Education?* Washington, DC: The National Academies Press, 2010.

Table 11: Grade Levels in Projects

	Number	Percentage
Pre-kindergarten	3	12
Elementary school	10	38
Middle school	12	46
High school	15	58
First-year college students	1	4

Projects may have targeted multiple grade bands.
N=26 projects.

Projects were primarily developing for and studying typical classroom experiences. Only four projects targeted extracurricular settings like afterschool clubs and summer camps.

DR K–12 engineering projects were most often embedded in urban contexts; eight projects explicitly specified this feature of their setting. Half as many were implemented in rural settings (4), and fewer still identified their environment as being suburban (3).

3.5.1 DIVERSITY

About two thirds of the engineering projects involved groups that are traditionally underrepresented in STEM fields (18 projects). This was true even when projects were not directly targeting students, as nine of these projects were primarily concerned with professional development for teachers, research syntheses, or conferences for educators/professionals.

Project materials commonly noted that certain populations are underrepresented in STEM fields, and some also discussed issues of diversity in other ways. Five projects, without specifically mentioning “underrepresented” groups, described being interested in serving a “broad range” of students, often describing this range in terms of race, ethnicity, language fluency, socioeconomic status, and special education status.

Projects demonstrated a range of perspectives on how these diverse and underrepresented groups factored into their project and the field of engineering education. In some cases, underrepresented groups were used as a pilot sample to test the feasibility of project implementation (curriculum, etc.) with *all* students.

> To assure feasibility, materials will be developed primarily in low-income schools, serving mostly racial and ethnic cultural minority students. Initial development and trials will take place in bilingual and Special Education settings, as well as science labs and regular elementary classrooms, distributed nationally in four major cities. [39]

Other projects understood the needs, skills, and perspectives of underrepresented groups to be qualitatively different from those of more typical populations of STEM students.

> In order to understand features of K–12 engineering programs that appeal to underrepresented groups, we will study a successful outreach program whose focus has been on populations underrepresented in engineering. We will examine the influence of five MESA activities on three constructs: students’ engineering self-efficacy, interest in engineering and perceptions of

[39] Benenson, NSF–0733209, Proposal, page 1.

engineering. These constructs contribute to decisions to pursue careers in engineering and are predictors of career success.[40]

Two of the projects integrated their work with MESA (Mathematics, Engineering, Science Achievement http://mesa.ucop.edu/), an established organization that focuses on the needs of underrepresented students in STEM. Five projects focused on serving students who were identified as gifted or those already engaged in STEM activities, where previous engagement ranged from robotics clubs to students taking advanced classes in STEM subjects.

3.6 Data Collection Methods and Outcomes

This section of the study looks more closely at projects' data collection methods and the kinds of teacher and student outcomes that were investigated in these studies—either as part of evaluation or research activities.

3.6.1 DATA COLLECTION

The engineering projects employed a diverse set of data collection methods. Interviews were the most common, but observations were also frequently used, typically to assess implementation of project materials. Both student learning and teacher practice were the subject of these observations, which sometimes involved norm-referenced observation tools such as the CLASS. Fifteen projects used comparative assessments or other tests of performance knowledge to judge the impact of their project materials. Table 12 highlights the data collection strategies commonly used by the engineering projects.

Table 12: Data Collection Methods

	Number	Percentage
Interviews	20	77
Observations	18	69
Assessments or tests of performance or knowledge	15	58
Surveys	15	58
Document or artifact reviews	13	50
Focus groups	10	38
Diaries, journals, records, or activity logs kept by study subjects	5	19
Assessments of data collection instruments	4	15
Computer usage data	3	12
Extant records	3	12

Projects may have used more than one data collection method.
N=25 projects. There was 1 project with insufficient information to identify data collection methods.

3.6.2 TEACHER OUTCOMES

Nineteen of the 26 engineering projects assessed teacher-related variables. The most commonly assessed variables are presented in Table 13. Overall, projects most commonly assessed teachers' content knowledge but did not often specify what content knowledge they would assess. Less frequently, projects assessed teachers' pedagogical content knowledge (PCK) and two projects explained that they would assess PCK by asking teachers to reflect upon or represent their

[40] Wilson, NSF–1222566, Proposal, page 1.

understanding of the engineering design process. Nine of the 14 projects that planned to assess teachers' attitudes and beliefs focused on their comfort and confidence in teaching engineering.

Table 13: Teacher Outcomes Most Commonly Assessed

Outcome Measured	Number of Projects
STEM content knowledge	15
Attitudes and beliefs	14
Classroom practice	13
Program feedback	13
Pedagogical content knowledge	10
Implementation Fidelity	8

Projects may have assessed multiple outcomes.
N=19 projects

Additionally, projects collected data from teachers that were unrelated to teacher outcomes. Teachers were asked to provide feedback to project teams about the curricula, professional development, or other activities in which they engaged. In eight projects, researchers assessed the fidelity of program implementation and used online project logs, interviews, or classroom observations to assess how teachers implemented resources. More often, the feedback provided by teachers was formative and contributed to the design or redesign of project materials, including lesson plans and professional development activities (13 projects). Projects used a range of approaches to collect this information from teachers, including online feedback forms, online teacher networks, and interviews.

3.6.3 STUDENT OUTCOMES

Twenty-two of the 26 projects assessed student outcomes and the most common outcomes assessed were student attitudes (20) and student achievement and knowledge (19) (Table 14). Interestingly, only five of the 19 projects that evaluated student achievement specifically measured understanding and knowledge of engineering concepts, while fourteen examined non-engineering areas of STEM. Three projects evaluated student outcomes in language and literacy; one examined both engineering and academic vocabulary gains; and another investigated whether integrating engineering into a literacy curriculum facilitated literacy gains. The paucity of engineering-specific outcomes measured by these projects reifies the notion that engineering is a discipline that is deeply integrated with other STEM subjects.

Table 14: Student Outcomes Most Commonly Assessed

Outcome Measured	Number of Projects
Attitudes	20
Achievement and knowledge	19
Engagement	13
Knowledge application skills	9
Perceptions	9
Solutions to design challenges	9

Projects may have assessed multiple outcomes.
N=22 projects

Twenty projects examined outcomes related to student's attitudes about engineering and STEM. These projects looked at how students feel about engineering, students' self-efficacy, or interest in

STEM careers. Five of these projects assessed student attitudes towards engineering and 11 evaluated students' attitudes towards STEM subjects in general. Seven projects collected information on students' interest and attitudes towards pursuing a career in STEM, all of which included engineering as a possible career. In addition to attitudes, nine projects specifically mentioned examining students' perceptions, with three looking specifically at perceptions of engineering.

There were 13 projects that measured student engagement; however, there was considerable variability in projects' definitions of "engagement." For example, some projects defined student engagement as sustained interest in an activity or attention,[41] while others define it more broadly as motivation, interest, self-efficacy, self-concept and interest in STEM.[42] The former was often assessed through observation, while the latter was more commonly assessed though surveys and interviews. Across projects that measured student engagement, two distinct types of student engagement emerged: student engagement in STEM generally and student engagement with the project materials specifically. Four projects examined students' perceptions of and engagement with project-specific curricula or resources. As such, students, though less frequently than teachers, provided formative feedback used for project development.

Nine projects examined outcomes related to knowledge application skills—general thinking skills not unique to any one discipline. Three of the 9 projects assessed outcomes related to transferrable skills. These projects were interested in determining if students are transferring knowledge gained during the engineering intervention into other domains. For example, one project "test[ed] the range of children's understandings, and their ability to transfer their concepts to other domains."[43] Another project was interested in determining if students connected engineering concepts to their daily lives by "introduce[ing] students to engineering concepts and how science is directly related to them," and then measuring how "students will be able to see the connection between these concepts and their daily lives."[44]

Within the group of nine projects that examined knowledge application skills, there were five projects that examined thinking skills related to engineering design and the NGSS practices. These skills encompass engineering habits of mind, 21st century skills, and real-world skills. For example, one project was developing rubrics "to ascertain the extent to which students are making progress toward developing 'engineering habits of mind' such as identifying problems, analyzing data, and communicating effectively."[45] Another project was developing a 21st Century Workplace Skills Reflection instrument to ask students "21 questions...about common workplace skills such as speaking, writing, and listening, within a STEM context."[46]

Nine projects also assessed students' solutions to engineering design problems. These projects examined all aspects of the design process including how students made design decisions (teamwork,

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41 McWayne, NSF–1221065, Proposal.

42 Millman, NSF–0918618, Year 1 Annual Report.

43 Benenson, NSF–0733209, Proposal, page 7.

44 Xie, NSF–0918449, 2011 Annual Report, page 18.

45 Pruet, NSF–0918769, Proposal, page 11.

46 Chen, NSF–0733228, 2012 Annual Report, page 70.

collaboration, time allocation, prioritization, etc.), how students overcame obstacles they encountered, and what students learned about engineering concepts from completing a design challenge. One project, for example, was conducting interviews to "elicit information about [students'] design processes, social resources, language and literacy practices, challenges in completing the project, and approaches to overcoming those challenges."[47]

4. Summary

This targeted study revealed a variety of themes, as well as contrasts, that characterize engineering education across the DR K–12 Engineering projects. Primarily, we found that engineering in these projects was functionally synonymous with engineering design, and that engineering content tends to be integrated with other STEM content. Finally, professional development played a key role in these projects.

4.1.1 ENGINEERING DESIGN

The NGSS defined the core components of engineering design as "defining and delimiting engineering problems", "designing solutions to engineering problems", and "optimizing the design solution".[48] In the DR K–12 projects, engineering education was characterized by solving engineering design challenges. Many of these projects used an engineering design challenge to serve as the overall context for teaching or acquiring knowledge. In their descriptions of engineering, projects agreed that engineering design provides a real-world problem context through which students can learn and apply science, math, and technology (as well as engineering) concepts, often through hands-on activities. Further, almost all of the projects included at least one of the eight practices from the NGSS, which together outline the processes of inquiry and engineering design. Though most projects collected traditional outcomes data such as student achievement or changes in attitudes and beliefs, a few projects more closely examined students' solutions to design challenges.

4.1.2 INTEGRATION

In addition to focusing on the engineering design process, engineering in these projects was intertwined with other STEM content. The DR K-12 engineering projects consistently described engineering as a discipline that was integrated with other STEM subjects, rather than a distinct content area. The majority of the projects integrated engineering with some other content and included at least one of the NGSS' cross-cutting concepts. The integration of engineering and other STEM subjects was also evidenced by projects' measurement of student outcomes. Commonly, projects measured content knowledge, attitudes and beliefs towards STEM, and 21st century skills. These assessments were typically grounded in all STEM disciplines, rather than being specific to engineering.

4.1.3 SUPPORTING ENGINEERING EDUCATION

Students from groups underrepresented in STEM were of particular interest to many projects. Most projects recognized that effort must be made to ensure that historically disadvantaged groups do not

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[47] Wilson, NSF–1222566, Proposal, Figure 2.

[48] Next Generation Science Standards, www.nextgenscience.org/next-generation-science-standards, Appendix I, page 2.

get left behind. However, projects varied in the way they thought of these students and their relationship to engineering materials. One set seemed to think of students from underrepresented groups as a litmus test for the feasibility of their materials, while another set believed that these students' need and skills were qualitatively different from their more mainstream counterparts.

The DR K–12 engineering projects typically focused on one principal task such as developing a curriculum or robotics toolkit, and the majority of projects shored up its principal objective with support products and activities. For example, projects that concentrated on curriculum development also designed professional development to support teachers in their implementation of the new curriculum.

5. Appendix: Summaries of DR K-12 Engineering Projects

Summaries are organized by the last name of the PI, which is followed by the NSF award number, project title, and a brief description.[49]

Becker – 0918621

Exploring Engineering Design Knowing and Thinking as an Innovation in STEM Learning

This exploratory project investigates how high school students' understanding about design compares to that of experienced practitioners and whether participation in a multiyear sequence of courses focused on engineering correlates with changes in design thinking. The engineering design thinking of students will be evaluated based on their strategies for designing a playground under realistic constraints, their prioritization of design activities, and reflective interviews of their own thinking. Outcomes of this research will highlight student understanding and misconceptions of engineering design. Student participants selected for this study will be enrolled in an articulated sequence of courses with engineering design as the focus which enables the research team to draw conclusions on student change over time.

Benenson – 0733209

Physical Science Comes Alive: Exploring Things that Go

This project creates eight half-year units in two subject areas—force and motion, and energy systems—for three grade bands, pre-K–1, 2-3 and 4–6. The curricula and accompanying professional development integrate engineering, science, math, literacy and art in the context of design, construction, and testing of toys using inexpensive or recycled materials. Through these activities, students develop facility with materials, plus an understanding of systems, models, design, constraints, redesign and troubleshooting, which are core concepts in engineering education. In the course of this work, students write their own equipment lists, instruction manuals, trouble-shooting guides and analyses of how their devices work. To understand the role of engineering design as a context for elementary science learning, the evaluation will investigate (1) children's strategies to meet the design challenges posed in each unit, at individual and classroom levels of analysis; (2) children's engagement and forms of participation in design; and (3) their learning of science concepts.

[49] The projects described are at varying stages of completion, but for convenience all summaries are written in future tense.

Bers – 1118897

Ready for Robotics: The missing T and E of STEM in early childhood education

This project investigates the use of robotics in early childhood education. It address two objectives: (1) to develop and evaluate a low-cost, developmentally appropriate robotic construction kit specifically designed for early childhood education (PreK-2) and; (2) to pilot a robotics-based professional development model for early childhood educators to teach engineering and technology. The professional development will center on themes of sensing as tools for observation and how things move. By the end of the workshop, each teacher participant will design a robotics-based curricular unit and implement it in their classroom using the robotics kits. The impact on the teachers' engineering knowledge, skills, and instructional practice will be assessed to examine the effectiveness of the robotics kit and professional development model.

Brockway – 0917540

An Investigation of Strengthening the "T" and "E" Components of STEM in High School Biology and Chemistry Courses

The project is developing and testing high school biology and chemistry instructional materials that incorporate engineering design and inquiry activities closely linked to the content, while simultaneously introducing students to cutting-edge research in STEM fields. The goal of the project is to strengthen the technology and engineering components in high school STEM courses taken by a majority of students. Professional development for teachers will also be conducted prior to classroom implementation. Instruction in the treatment group will include an engineering design activity in addition to the existing curriculum. Instruction in the control group will consist of the existing curriculum and an additional activity using traditional methods. The research will determine whether incorporating engineering design activities into existing high school biology and chemistry curricula improve student learning of science content and the acquisition of 21st century skills.

Chen – 0733228

SPIRIT 2.0: Silicon Prairie Initiative for Robotics in Information Technology 2.0

The SPIRIT 2.0 project is developing instructional robotics modules for Grades 5-8 that are organized into a flexible, internet-accessible curriculum focused on topics in science, technology, engineering, and mathematics. The curricula will enhance student learning of STEM concepts using the CEENBoT platform and include a series of interactive and focused assessments that help teachers determine what STEM concepts students are learning. Teachers can create a tailor-made sequence of activities for classroom learning and students can use the open-source and flexible CEENBoT robotics platform in three problem-based ways: building, moving, and programming. The intent is to scale up to a cyber-infrastructure that supports the national distribution and implementation of the curriculum. Outcomes of teacher instructional practice, student attitudes, and student learning will be assessed to test the effectiveness of the curricular modules.

Cunningham – 1220305

Exploring the Efficacy of Engineering is Elementary (E4)

This project is examining the implementation of *Engineering is Elementary* (EiE), a curriculum that integrates engineering and science topics for grades 3-5. The EiE curriculum addresses students' innate perceptions of science and engineering concepts. The curriculum then uses real-world connections and interactive projects to facilitate understanding. This project strives to determine the impacts of EiE on science and engineering learning, along with impacts on interest in STEM careers. The project will also describe implementation challenges and adaptations across classrooms.

Custer – 1119167

An Examination of Science and Technology Teachers' Conceptual Learning through Concept-Based Engineering Professional Development

This project is exploring the possibilities associated with an engineering-driven approach to professional development. This is motivated by the growing awareness that including engineering concepts in preK–12 provides an authentic contextual base for learning math and science. The project is developing curricular resources and a professional development model for teachers at the secondary level. The goal of the professional development is to infuse engineering design and content into other science curricula, more specifically, life science, physical science and technology education. The project is examining how teachers learn engineering concepts and what implementation issues are encountered by teachers as they incorporate engineering concepts into curricula and activities.

Diefes-Dux – 0822261

R&D: Quality Cyber-Enabled, Engineering Education Professional Development to Support Teacher Change and Student Achievement (E2PD)

This project is developing a learning progression of elementary school teachers' ability to adopt and refine engineering learning materials in their classroom. There is also a cyber-component that links teachers with researchers/educators at Purdue University to establish a community of practice to increase the potential for teachers to implement engineering education in their curriculum. Additionally, there is an assessment component that will allow teachers to continually conduct formative assessments to more closely monitor students' progress. This project has adopted the *Engineering is Elementary* curriculum and mathematical model-eliciting activities as the curricular base for the teacher professional development, and so engineering is integrated with both math and science. The project is assessing outcomes in teacher and student knowledge of engineering.

Fowler – 1019672

Discovery Research K-12

Ten fifth and sixth grade science teacher specialists and their students in a high needs district in Ohio are engaged in this design-based research project. Within a three-year professional development effort with faculty in several university departments, the collaborative team will study how the engineering design process can be used effectively as a pedagogical strategy in science instruction to improve student interest, learning and skill development. The professional development system will be a pervasive and embedded three-year effort using teacher learning teams and content coaches. The first stage of research will identify effective curriculum structures and instructional strategies that articulate science content, scientific inquiry, and engineering design as well as to develop instructional materials. The second stage will focus on student outcomes, specifically investigating how the curricular articulation of scientific inquiry and engineering design impacts student achievement and learning of science content and improves student problem solving skills.

Hacker – 0821965

Simulation and Modeling in Technology Education (SMTE)

SMTE studies a 6-week hybrid instructional model that infuses computer simulations, modeling, and gaming into technology education programs. These prototypical materials use 3-D simulations and educational gaming to support students' learning of STEM content and skills through developing solutions to engineering design challenges. Through an interactive, 3-D virtual world, small groups of middle school students engage in a quest to build an emergency shelter following an Alaskan earthquake. With the support of screen-based tools and physical modeling materials, students apply a variety of STEM concepts such as energy and structural design to build a shelter and produce a final design report. The impacts on student content knowledge, attitudes, and engagement during and after engaging in the simulations and games are evaluated.

Hailey – 1020019

The Influence of MESA Activities on Underrepresented Students

The *Math, Engineering, Science Achievement* (MESA) outreach program is an academic preparation program that supports K–12 educationally disadvantaged students by providing pathways for minority students to succeed in science, mathematics, and engineering disciplines and to increase diversity in these disciplines. This exploratory project is identifying student-oriented activities within the MESA program that have an influence on underrepresented students' engineering self-efficacy, interest in engineering, perceptions of engineering, and their subsequent decisions to pursue careers in engineering. The study will examine student-oriented activities which can be categorized into five distinct groups: a) field trips, b) guest lecturers, c) design competitions, d) hands-on activities, and e) student advisement. These five MESA activities represent the independent variables for this study. This project provides insights on activities used in informal settings that can be employed in the classroom practice and instructional materials to further engage students in their STEM studies, especially students from underrepresented groups.

Lehrer – 1252875

Spatial Mathematics, Engineering, and Science: Toward an Integrated STEM Education

This project is creating a learning progression about space topics for grades K-5. The progression will demonstrate how spatial understanding is affected by learning in engineering, math, and science and will be used in professional development sessions. The professional development encourages teachers to explore spatial topics from a student perspective, which allows them to appropriately adapt classroom practices. In addition, the researchers will use classroom observations to revise the learning progression. The learning progression will measure how students form concepts of spatial properties, quantify spatial relationships, and develop understanding of STEM subjects.

McWayne – 1221065

Partnerships for Early Childhood Curriculum Development: Readiness through Integrative Science and Engineering (RISE)

The RISE project is creating curriculum resources for dual language learners (DLLs) in science, technology and engineering (STE). Participants include teachers in pre-K programs in the Boston area selected to target Hispanic and Chinese students and their families. The curriculum will be based on the Massachusetts standards and integrate STE through the central concept of form and function in living and non-living systems. Parent leaders and teachers co-construct the curricular activities with the RISE researchers to incorporate home-school connections. The evaluation of the project will examine how teachers are engaging their students in STE topics in addition to the attitudes and learning of the student and teacher participants.

Millman – 0918618

Science Learning: Integrating Design, Engineering and Robotics (SLIDER)

The SLIDER project is developing and implementing a rigorous eighth grade physical science program that utilizes engineering design, LEGO™ robotics and mechanics, and a problem-based learning approach to teach mechanics, waves, and energy. The program will include three 4-6 week instructional modules and a professional development component. Instructional materials will use robotics as the learning tool and be developed using an approach which will intentionally marry the benefits of engineering design (iterative, need-based, technology driven, solution-oriented practices) and inquiry-based learning (rooted in discovery, understanding, knowledge, and skill development). Impacts on 8th graders' physics and reasoning skills as well as student engagement, motivation, aptitude, creativity and STEM interest will be measured.

Pearson – 0733584

Exploring Content Standards for Engineering Education in K-12

This project is assessing the potential value and feasibility of developing and implementing content standards for K–12 engineering education. The project is reviewing existing efforts to define what students should know; identifying elements of existing standards for related content areas that could link to engineering; considering how purposes for engineering education might affect content and implementation of standards; and suggesting changes to policies, programs, and practices necessary to develop and implement engineering standards.

Pearson – 0935879

National Symposium on K-12 Engineering Education

This project will hold a workshop to disseminate the findings of a privately-funded, two-year study of the status and nature of efforts to teach engineering to U.S. K–12 students. The symposium and other dissemination activities inform key stakeholders about the role and potential of engineering as an element of K–12 STEM education and also inform the programmatic activities of organizations and individuals concerned about engineering education.

Pearson – 1114829

Toward Integrated STEM Education: Developing a Research Agenda

This project is creating a research agenda to determine the value of integrating K–12 STEM education (iSTEM). This study focuses attention on the potential benefits of teaching and learning that combine or integrate essential content and processes of two or more of the four STEM disciplines with particular emphasis on technology and engineering. The principle product of the study will be a consensus report containing a summary of the research conducted along with the committee's findings and recommendations on K–12 STEM education.

Pruet – 0918769

Engaging Youth in Engineering Module Study

This project is developing and studying a set of supplemental curriculum resources that will result in a coordinated sequence of nine engineering modules designed for 6th, 7th, and 8th graders. Each module addresses an engineering design challenge of relevance to industries in the region and fosters the development of engineering habits of mind. The modules integrate technology and other resources to facilitate the understanding of selected mathematics and science content. The goals of the project are to shift students' and teachers' attitudes, interest, and self-efficacy in STEM careers, coursework, and instruction. This study is part of a comprehensive and community-driven K-12 workforce and economic development initiative that addresses the region's growing demand for highly-skilled and technology-savvy workers.

Rogers – 1020243

Integrating Engineering & Literacy

This project is designing engineering curriculum units for grades 3-5, which focus on activities based on grade-appropriate children's literature. The researchers propose that the interdisciplinary connection of engineering and literature will benefit both students and teachers. Along with professional development courses, teachers who use these curriculum units will be supported by a website with posted materials and interactive forums. The hands-on activities are intended to facilitate student interest in engineering. The researchers are investigating whether these integrated curriculum units develop engineering, literacy, and critical thinking skills in students. They are also examining how teacher attitudes and knowledge about STEM affect their teaching practices.

Schunn – 1027629

Collaborative Research: Modeling Engineered Levers for the 21st Century Teaching of STEM

This project is developing and testing three biology curriculum units, which incorporate mathematics and engineering through demonstrative "model-eliciting activities." Specifically, the researchers propose units focused on genetics and cell regulation, homeostasis, and matter/energy flow and conservation. These curriculum units will allow students to develop critical thinking, reasoning, and problem-solving skills which can be applied science, mathematics, and engineering concepts. The researchers are investigating the curriculum units' impacts on student STEM knowledge and interest.

Sevian – 1222624

Collaborative Research: An Initial Learning Progression in Chemical Design

This project is developing and studying a learning progression (LP) for 8-12 grade students transitioning into undergraduate learning. The LP will describe likely pathways of how students' implicit assumptions about chemical design develop. In this project, chemical design is defined as the coherent integration of scientific and engineering practices, cross-cutting concepts, and disciplinary core ideas in the design and use of curriculum, instruction, and assessment in chemistry. This exploratory project has two goals: 1) to develop a framework that can be used to compare and contrast more and less sophisticated ways of thinking about key foundational ideas for the understanding of chemical design, and 2) to derive hypotheses about intermediate levels or 'stepping stones' in the understanding of the practice and implications of chemical design. A concise and clear summary of the learning progression is produced with an intended audience of teachers, curriculum developers and publishers who are implementing or revising curriculum.

Wilson – 1222566

Community-Based Engineering Design Challenges for Adolescent English Learners

This project is creating a model of engineering learning within the contexts of the Latino community and culture. Prior sociological research indicates that students' routine discussions and practices affect their understanding of STEM concepts. A student's daily routine is often impacted by the student's cultural background and community. The researchers propose that connecting engineering knowledge with cultural context will encourage more interest in STEM careers. The model will describe the problem-solving techniques, social connections, and language skills that Latino students use in learning about engineering.

Xie – 0918449

Enhancing Engineering Education with Computational Thinking

This project investigates the educational value of computer technologies capable of accurately modeling engineering problems. High school students learn engineering through designing, building, and evaluating an energy-efficient model house with the aid of computer simulation and design tools. The tool, SimEng, teaches heat transfer concepts and supports the full cycle of engineering practices. An accompanying curriculum book with four instructional units has been developed to challenge students using the tool to improve the energy performances of their model houses step by step, allowing students to learn and apply science to solving engineering problems. Student learning processes are evaluated to understand if the computer tools increase learning of science concepts and engineering design and how well students can apply science to engineering.

Young – 0733137

Mathematics Instruction using Decision Science and Engineering Tools

A collaboration among educators, engineers, and mathematicians in three universities; this project is creating, implementing, and evaluating a one-year curriculum, accompanying textbook, and assessments. This curriculum will use decision-making tools to teach non-calculus mathematics concepts, in a fourth-year high school mathematics course. While this project is mostly concerned with students' mathematical ability, the curriculum uses the mathematics and models of *Operations Research and Industrial Engineering* to teach mathematics concepts. In this way Operations Research and Industrial Engineering serve as a context for learning mathematical content. The project mainly assesses outcomes in mathematics. The projects main goals are to enhance student mathematical competence (particularly solving multi-step problems), improve students' attitudes toward mathematics, and adoption of the curriculum in two states.