



Defining Engineering in K-12 in North Carolina

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A great deal of national attention has recently been focused on STEM (science, technology, engineering, and mathematics) education as an educational innovation. The truth is that science and mathematics have always been taught. Technology, in the sense of instructional tools, has found its way into some places and not into others, and most STEM educational efforts really exclude engineering. More recent conversation has centered on so-called I-STEM, or integrated STEM, with the implication that the four involved subjects are not stand-alone but really have some interdependencies. Some groups want to use the term STEAM to officially recognize the important role of the arts. What is needed going forward is not a debate on semantics, but a true paradigm shift in education. This is the role that engineering can play in K-12 and beyond, using knowledge and experience to solve problems.

The state of North Carolina has had a history of leadership in educational matters. In the state of North Carolina, courses covered by the division of career and technical education (CTE) already address many of the engineering topics that can be so critical to teaching children to think. Unfortunately, CTE courses do not extend into elementary school and are severely limited in some middle schools for budgetary reasons. CTE courses in high school have a distinguished history. Here, however, the teaching of engineering-related topics has become strongly linked to specific engineering content classes. Other CTE courses and other programs throughout the curriculum do not contain engineering content. In addition, courses offered as career and technical education are elective courses, frequently not selected by students who are already underrepresented in STEM careers. Since engineering in North Carolina schools has appeared only in a career-linked capacity, thinking of engineering, not as a discipline but as an integrator and bringer of relevance to *any* class, represents a true paradigm shift.

This paper describes a recent effort to write educational standards for the state of North Carolina that define engineering in the K-12 space. The intent is for engineering to be integrated throughout K-12 education, not as stand-alone classes, but as a part of any class. The effort to develop a description of what all students should know and be able to do with respect to engineering began with the various standards in use in other states and incorporated information from NAE publications, the NAEP Technological and Engineering literacy framework and the original States Career Clusters work. Over twenty separate sources were used to craft the outline of these standards. The standards themselves will be defined as well as how they are incorporated as a set of connections for other, tested, subjects in the Standard Course of Study for North Carolina, which includes the Common Core.

Introduction

The importance and role of engineering in the K-12 classroom is beginning to be understood by engineering educators in way that allows them to relate it to K-12 educators. However, the knowledge and skills that make up the educational area symbolized by the vowel in STEM remain ill-defined in the educational standards that teachers and administrators use as they plan the day to day classroom experience. As a result, engineering can still be viewed as only a career or as a way to incorporate building projects in after school programs or when time allows. There is a temptation to define engineering simply as an approach to solving problems with no specialized knowledge or to define it as the various fields of study that college and university programs offer. The state of North Carolina has chosen to take a different view and to define the knowledge and skills associated with engineering from kindergarten through high school for all students, similar to the way that mathematics or science is defined. With the advent of the Common Core standards and the promise of national science standards, engineering finds a natural home.

In 2005 one of the deadliest hurricanes in history bore down on the Gulf Coast. Thousands of people died and property damage was estimated at over \$81 billion. Who is it that has the capacity to help in the face of such natural disasters? Engineers. In the case of a Gulf Coast hurricane, engineers can work to prevent damage by improving the levee system that protects low-lying cities. They can use GPS and other satellite-based systems (also designed by engineers) to restore and improve the infrastructure of the area. Engineers designed the rescue equipment, including hovercrafts, that was used to help an overwhelmed populace. Engineers help design the weather detection and prediction systems that give early warning.

The engineering profession has organized its priorities for work and research around the fourteen global challenges identified by the National Academy of Engineering as the Grand Challenges for the 21st century. These very relevant and difficult problems are examples of the kinds of real-world problems that can bring education alive in the classroom. They are part of the motivation for placing an emphasis on science, technology, engineering and mathematics in education. In fact, engineering provides a basis for organizing thinking around many examples that bring relevance and excitement to the study of many of the subjects taught in the K-12 classroom.

What is the goal of engineering standards for NC?

Engineering standards are not intended to represent a new subject area to be taught in already overburdened classrooms, nor are they intended to guide every child toward entering the profession of engineering, just as teaching science does not guide every child toward becoming a scientist. What they can do, however, is to add to the educational dialog elements that lack articulation in the current curriculum and that have heretofore been identified as 21st century skills, rigor and relevance and the like.

As the vowel in STEM, engineering-related topics are sometimes confused with the profession of engineering or with studying the elements of an engineering course of study at a college or university. Even more than the other elements of STEM, or of the equally important other curricular areas such as the humanities and the arts, engineering learning objectives do not stand alone but link with other subjects. Just as elements of mathematics, such as data analysis or graphing, must be used in social studies to understand population dynamics, and reading is basic to science instruction, engineering practices, such as design, require the synthesis of disparate topics to arrive at a solution. In fact, engineering can act as an integrator that provides relevance and rigor to the study of virtually any subject.

The project to define engineering for K-12 in North Carolina began with the formation of a committee by the STEM Director for the Department of Public Instruction, Rebecca Payne. She appointed Laura Bottomley of the North Carolina State University Colleges of Engineering and Education and Director of The Engineering Place, Elizabeth Parry of North Carolina State University College of Engineering and Chair of the ASEE K-12 Division, Nancy Shaw of Duke University and State Director of Project Lead the Way, and Pam Townsend, Vice President AECOM and representative of the North Carolina Society of Professional Engineers. Figure 1 shows a flow chart of the standards development process.

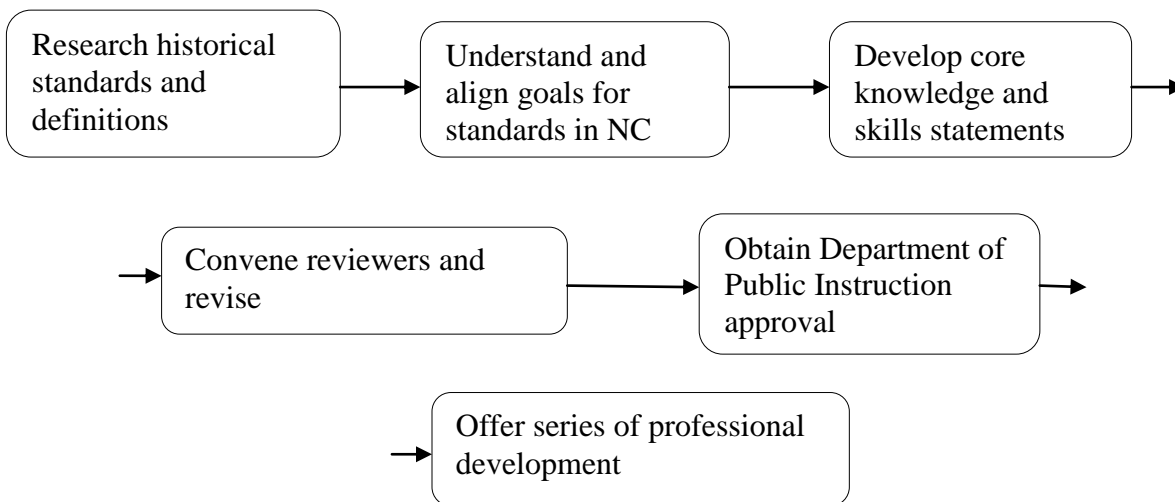


Figure 1: Flow chart of development process

History of defining engineering for K-12

A brief summary of the historical publications/efforts that informed North Carolina’s work is included in this section. One of the driving motivators for curricular reform in the realm of education has been the concept of 21st century skills¹. Skills such as creativity, critical thinking, communication and collaboration are recognized as imperative for the success of students in this

century; however, these skills have not been traditionally enumerated in learning standards. (This is changing in newer standards^{3,4}.) Engineering educators have recognized that these skills are an intimate part of engineering. Additional skills that are emphasized include information and technology literacy. These and other technological literacy standards were included in the International Technology and Engineering Education Association publication, Standards for Technological Literacy in 2000⁹.

The history of the interest in engineering for K-12 is traceable back to at least 2001 with the States' Career Clusters efforts^{2,12}. The Career Clusters effort was initiated by the National Association of State Directors of Career Technical Education Consortium. There were 16 clusters defined, of which one was science, mathematics, engineering and technology. Early in the development of the knowledge and skills statements for this cluster, its name was changed to science, technology, engineering and mathematics to produce a nicer acronym. K-16 educators, industry and government representatives worked together to create a list of knowledge and skills that a student graduating from high school should know and be able to do if they wished to pursue careers in this cluster. The career clusters effort was funded in 2001 with various states coordinating the definition of knowledge and skills statements for various clusters. The state of North Carolina was assigned to the STEM cluster, and two committees wrote statements encompassing science and mathematics and engineering and technology careers.

Various states have defined engineering learning standards, probably beginning with Massachusetts, which defined engineering and technology standards for K-8 in 2001 and high school in 2006⁴. The Massachusetts standards were strongly influenced by the Standards for Technological Literacy⁹. Several states include elements of engineering or engineering practices in their science standards (Minnesota and Oregon^{18a,d}), and a few, like Massachusetts, have stand-alone engineering and technology standards, Tennessee and Georgia^{18b,c}. The standards that stand alone tend to have a more comprehensive definition of engineering. The table below shows examples of the Oregon and Massachusetts objectives. Notice that the Oregon standards are segmented by level K-5, while the Massachusetts objectives are not. The Massachusetts standards also tend to be more specific. At the middle and high school levels, the Massachusetts standards contain much more content than Oregon. These two examples illustrate the range of contrast between standards that are stand-alone and those that are included in science standards.

Table 1: Example of Oregon and Massachusetts engineering (and technology) standards progression

OREGON Core Standard	OREGON Content Standard	MASSACHUSETTS 2006 Central Concept	MASSACHUSETTS 2006 Objectives
Engineering Design is used to design and	(K)Create structures using natural or designed materials and simple tools.	Materials and Tools Central Concept: Materials both natural and human-made have	(K-5)Identify and describe characteristics of natural materials (e.g.,

<p>build things.</p>	<p>Identify basic tools used in engineering design. (1) Demonstrate that designed structures have parts that work together to perform a function. Show how tools are used to complete tasks every day. (2) Use tools to construct a simple designed structure out of common objects and materials. Work with a team to complete a designed structure that can be shared with others.</p>	<p>specific characteristics that determine how they will be used.</p>	<p>wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam). Identify and explain some possible uses for natural materials (e.g., wood, cotton, fur, wool) and human-made materials (e.g., plastic, Styrofoam). Identify and describe the safe and proper use of tools and materials (e.g., glue, scissors, tape, ruler, paper, toothpicks, straws, spools) to construct simple structures.</p>
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In 2009 the National Assessment Governing Board convened a group of experts to define the framework for a new assessment in Technology and Engineering Literacy (TEL)⁵. This process made reference to preceding efforts and resulted in a definition of the TEL framework that is divided into three areas of literacy:

“Technology and Society involves the effects that technology has on society and on the natural world and the ethical questions that arise from those effects.

Design and Systems covers the nature of technology, the engineering design process by which technologies are developed, and basic principles of dealing with everyday technologies, including maintenance and troubleshooting.

Information and Communication Technology includes computers and software learning tools, networking systems and protocols, hand-held digital devices, and other technologies for accessing, creating, and communicating information and for facilitating creative expression.”

and three practices:

“Understanding Technological Principles focuses on how well students are able to make use of their knowledge about technology.

Developing Solutions and Achieving Goals refers to students' systematic use of technological knowledge, tools, and skills to solve problems and achieve goals presented in realistic contexts.

Communicating and Collaborating concerns how well students are able to use contemporary technologies to communicate for a variety of purposes and in a variety of ways, working individually or in teams, with peers and experts.”

Two things are of note from this framework. First, a distinction is made between knowledge and practice, although they are defined as overlapping. Second, engineering and technology are both included, and each is defined separately.

In 2009 the National Academy of Engineering published a report from a study completed on the status of engineering education in K-12 in the United States¹³. The report outlined several recommendations for engineering curricula for K-12. It also enumerates six engineering habits of mind that are important to understanding learning progressions as they apply to engineering: systems thinking, communication, collaboration, optimism, creativity, and ethical considerations.

In 2010 the National Academy completed a study on the feasibility of engineering standards for K-12¹⁴ and concluded: “(1) there is relatively limited experience with K-12 engineering education in U.S. elementary and secondary schools, (2) there is not at present a critical mass of teachers qualified to deliver engineering instruction, (3) evidence regarding the impact of standards-based educational reforms on student learning in other subjects, such as mathematics and science, is inconclusive, and (4) there are significant barriers to introducing stand-alone standards for an entirely new content area in a curriculum already burdened with learning goals in more established domains of study.” Each of these reports was considered by the North Carolina writing group.

In 2011 a Delpi study on concepts in engineering and technology for K-12 education was completed¹⁰, and included a subset of the areas defined in each of the previously published documents. Because the study was conducted by surveying a variety of industry, education and government professionals, it serves to confirm some of the definitions arrived at independently in previous work.

Finally, for the purposes of the North Carolina efforts, the writing group considered the Common Core standards for mathematics and language arts and the framework for the Next Generation Science Standards. These standards are written based on an approach that distinguishes between knowledge and practice and places more of an emphasis on practices than traditional education standards. Some of these emphases align very well with engineering knowledge and practice. The figure below outlines an example of this emphasis in brief.

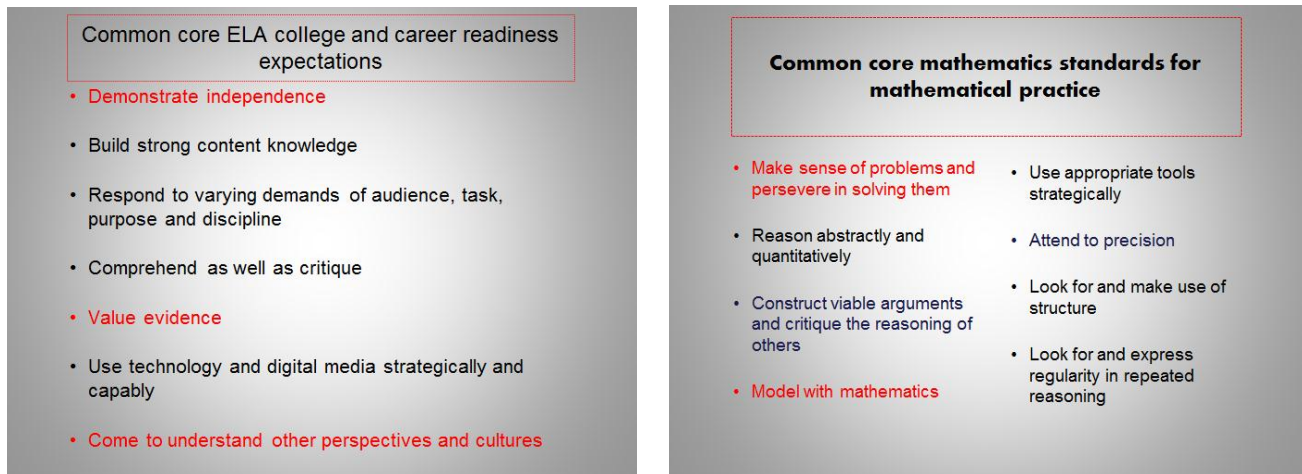


Figure 2: Common core standards elements that align with engineering

Defining engineering for K-12 in North Carolina

The North Carolina writing team, consisting of members from two research intensive engineering universities, industry and government, used the historical information from each of the documents discussed in the previous section. An effort was made to specifically define engineering as a separate area as distinct from technology, especially since technology tends to be misunderstood as consisting of solely instructional technology in North Carolina. This resulted in the identification of four core areas of engineering: engineering habits of mind, engineering design, systems thinking and problem solving. The appendix to this paper enumerates these four areas for grade bands K-2, 3-5, 6-8 and 9-12. The core areas are intended to define elements of engineering that would be incorporated across the curriculum and NOT as stand-alone courses. As such they represent a true paradigm shift for the state of North Carolina.

Some of the more important aspects of the core engineering elements distinguish them from other subject areas, including science, with which engineering is often conflated. A brief list of these aspects follows.

- Engineering uses disciplinary knowledge from a variety of areas, not confined to math and science.
- There are many examples of engineering problems that do not require science.
- Engineering problems frequently involve the establishment of constraints and criteria.
- Engineering involves both design and a systematic problem solving approach.
- The solution to an engineering problem may result in an engineered design or may not.

The engineering design process has been defined many ways. The illustration below contains the engineering design process for elementary school on the outside and a process for middle and high school on the inside that have been selected for use in North Carolina. The inner process was designed by the Museum of Science, Boston for the Engineering is Elementary®²¹ program. The outer process is based on *Engaging Youth through Engineering*²²; adapted from *Engineering the Future*²³, Museum of Science, Boston.

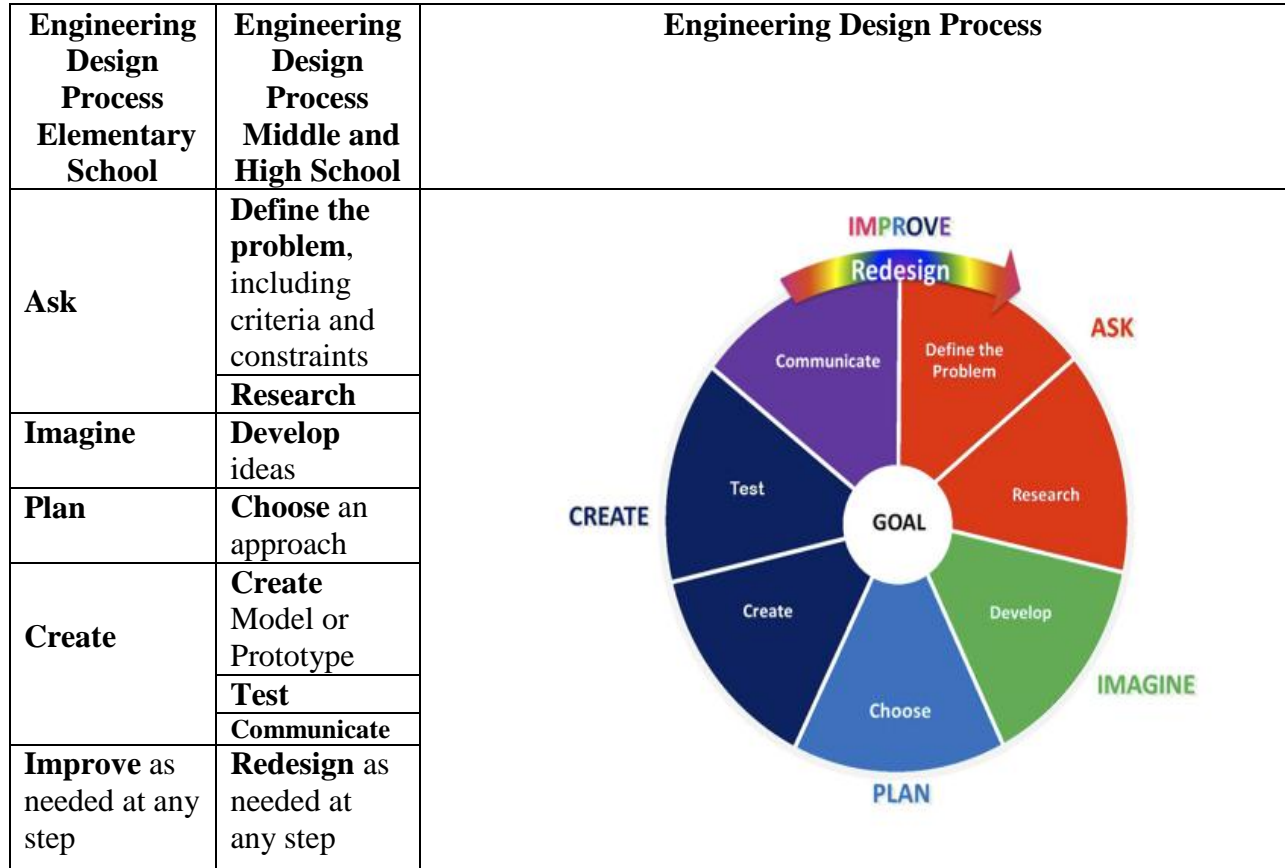


Figure 3: The Engineering Design Process selected for use in North Carolina

Just as with other subjects, engineering is a combination of knowledge and skills. Engineering standards require that existing curricula be examined with a new lens to include the new objectives. In addition, they will require teacher professional development on curricular integration, teaching creativity, teamwork and critical thinking, assessment techniques, and other topics. Companion documents to the standards provide curricular activity examples and techniques for classroom teachers. A series of webinars, the first of which took place in November 2012, will be provided by the NC Department of Public Instruction designed to enumerate the various elements of engineering and how they integrate with the Common Core and NC Essential standards. Over 100 registrations were received for the first webinar. Teachers and administrators were among the registrants, although the breakdown is unknown, since multiple attendees could be at a single registered site. Participants were self-selected and were asked to complete an assessment at the conclusion of the presentation. The exact response rate is unknown.

The first webinar was prepared and given by the standards design team and provided an overview of engineering and examples of applications and engineering in the everyday. The elements that make something engineering, including the presence of constraints and criteria, the expectation of failure as a normal part of the process, an iterative solution approach, the use of modeling and the importance of tradeoffs were also discussed. After the introduction, the four key engineering elements were discussed as follows:

- Engineering habits of mind...included practical examples of each in a k-12 classroom
- Engineering design...showed engineering design processes (see figure 3)...talked about parallels with writing process and mathematical problem solving
- Systems thinking...show systems in science, economics, politics...give examples of engineers using systems thinking
- Problem solving...systematic approach...linkages to problem solving across disciplines

The webinar continued with comparisons of the key elements of engineering with the Common core mathematics standards for mathematical practice and the Common core English Language Arts college and career readiness expectations as a brief way to demonstrate the commonalities.

Assessment of the webinar yielded interesting and promising results from the school and district administrators, teachers and STEM coordinators in attendance.

The primary reasons for attending the webinar were:

- Share information with their staff-and broaden their thinking about STEM
- Need guidance and direction-especially the engineering portion of STEM for new STEM schools

- Expand their knowledge of STEM and the Engineering Design Process

Most beneficial/valuable aspect of the webinar were listed as:

- The project ideas: very informative
- Time to discuss with peers
- Obtain ideas to implement in our school and even some suggestions for the middle school
- Work with colleagues: face to face Professional Learning Community

The extent they agreed to the following: (was based on responses from: Strongly Agreed, Agreed, Neutral, Disagree, and Strongly Disagree)

1. Webinar was relevant to their PD needs	2/3 Strongly Agreed	1/3 Agreed
2. Webinar provided useful resources	2/3 Strongly Agreed	1/3 Agreed
3. Webinar increased my understanding of the material presented	1/3 Strongly Agreed	2/3 Agreed
4. Webinar will be valuable to my professional practice	2/3 Strongly Agreed	1/3 Agreed
5. Webinar will likely result in positive changes in my professional practice	2/3 Strongly Agreed	1/3 Agreed

Summary: The groups' responses agreed the webinar content was well received, valuable, and beneficial to result in positive changes. The group also indicated a need for opportunities to receive constructive feedback. Since the response rates were low, the results are only considered advisory.

In addition to the webinar, a group of 25 state educational leaders from government, state and local educational institutions and informal educational agencies was convened to review the documents. Feedback was solicited from this group and from others through email distribution of approximately 200 additional educators (K-20), policy-makers and practicing engineers. A summary of responses included:

- Excitement; enthusiasm for creativity and collaboration
- Particular liking for the way engineering emphasizes the natural role of failure in problem solving
- Concern about need for extensive professional development, including preservice
- Concern about how these ideas are to be melded into middle and high school classrooms
- Enthusiasm about how naturally these ideas fit into elementary school classrooms

What does engineering look like in the classroom?

The most important piece of how standards can influence classroom instruction is to point out that *teachers already use engineering*. Teachers use integration, they use problem solving, and they use relevant examples. The difference lies in deliberately claiming all of these things and applying a systematic approach to their teaching. The following lists contain some examples for various grade levels of what integrated STEM, including engineering, looks like in the classroom. They are not a complete set by any means, but serve to illustrate further how these standards can affect instruction.

Grade Band K-2 Activity Example

Students will work in teams to design a neighborhood

- a. List the places that belong in a neighborhood.
- b. Using a large poster board lay out all the places that are in your neighborhood and put streets between them.
- c. Using non-standard measurements, measure the distance between different sets of places. Which places should be closest together?

Grade Band 3-5 Activity Example

Students will work in teams to choose the best surface for an elementary school gymnasium floor.

- a. Test how different balls bounce on three different floor surfaces by measuring how far they bounce up from a fixed drop height.
- b. Make a data table, find averages and compare results.
- c. Write a letter to a school system official making a recommendation for building a school gym floor.

Grade Band 6-8 Activity Examples

Students will work in teams to:

1. Design a growth chamber for plants on another planet.
 - a. Research and identify constraints imposed by the alien environment and the growth requirements of the plants.
 - b. Identify areas where insufficient information exists and make assumptions to proceed in design.
 - c. Identify connections to the Engineering Grand Challenge of carbon sequestration.
2. Reverse engineer the interstate highway system.

- a. Research the history of its creation
 - b. Interview civil engineers and/or adult drivers to develop an opinion of whether it is efficient.
 - c. Suggest modifications.
 - d. Identify the consequences of modifying the existing system.
 - e. Connect to the Engineering Grand Challenge of restoring and improving urban infrastructure.
3. Explore the costs/benefits of a new energy exploration technique such as fracking
- a. Prepare data-based arguments that represent pros and cons for an area where fracking takes place.
 - b. Identify areas where science does not exist to allow evaluation of the implications of fracking.

Grade Band 9-12 Activity Examples

HS Students will work in teams to:

1. Rewrite The Lion King
 - a. Write an original or rewrite a major play (ex: The Lion King). A committee of students from different grades and core subjects will work together to write a shortened version of the play.
 - b. A student team must design the stage for the play and all costumes and props.
 - c. Using the design process, students will consider how to use engineering processes to create authentic characters, make them more interesting, or provide them with superhuman powers.
 - d. In the case of The Lion King, the cast of animals should move in a realistic manner. For example, the elephant, giraffe, or other animal/beast in The Lion King must appear on stage, move its legs, trunk, and ears in a realistic manner and look and behave as the animal does in nature; birds should look like they are really flying.
 - e. The student team must design the stage to fit the play enacted. For example, if the play requires a moving stage, students will use the design process to create an appropriate stage, build it, test it and finally use it the student production.
 - f. At the end of the term, students may offer a live performance.
2. Design a Golf Course
 - a. Design a 9-nine or 18-hole golf course for professional golfers.

- b. The course must be challenging for professional players with specific constraints such that golfers with a handicap of 2 or less can complete the course with a score of 34 for 9 holes or 68 for 18 holes.
 - c. Natural and manufactured hills, sand traps, waterways or ponds must be included.
 - d. When designing the putting course for each hole, design a golf ball pathway for a hole-in-one shot.
2. Robots versus Humans
- a. Consider the ways in which robots are like humans. Are either or both systems?
 - b. Evaluate the effects of human-robot interaction (HRI) and how robots will change the way we live in the future.
 - c. Classify existing models of robots as tools or task completers.
 - d. Connect to the Engineering Grand Challenge of reverse engineering the brain.

Folding Engineering into the State STEM Rubric

The state Department of Public Instruction has defined a rubric for STEM schools that allows each school to evaluate their level of commitment to STEM education. This rubric is defined separately for elementary, middle and high school levels. The engineering ideas described in this document have been distilled and written in a similar rubric format to add to the overall STEM rubric. Engineering has its own set of objectives, as it needs more definition than some of the educational terms, such as project-based learning, that are used in the general STEM rubric. The Department will begin an evaluation program this year in which schools can be evaluated as STEM schools according to the state rubrics. The complete rubrics are available at : <http://www.ncpublicschools.org/stem/schools/> and were approved in December 2012.

Conclusions

In summary, these proposed connections to STEM for engineering are not intended to represent an additional workload for educators but a set of tools to enhance the rigor and relevance of instruction. This type of teaching has the potential to reach children of all learning styles at all educational performance levels and maybe to enhance the love of learning that children acquire in the classroom every day. Professional development will need to be done for both practicing and preservice teachers, but the shift to Common Core standards is already necessitating a sea change in classroom practice in North Carolina. By engaging in engineering design-based integration early and often in their educational careers, students will have a broader exposure to the important role all the subjects they learn have in moving society forward. This will enable them to use their experience to choose coursework that will best prepare them for the workforce

and postsecondary education. The state of North Carolina has implemented a program to include all of the elements of STEM into every classroom, K-12.

Engineering is...

- Use of knowledge and experience to solve problems
- Accessible to all students
- A defined and iterative process to solve any problem
- In the everyday
- Challenging
- Fulfilling
- Helpful
- Making a difference in the world

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APPENDIX: Engineering foundations expanded

	ENGINEERING FOUNDATION AREA	ENGINEERING CORE IDEA	ENGINEERING CONTENT STANDARDS TO SUPPORT CORE IDEA
GRADE BAND: K-2	1. Engineering Habits of Mind <ul style="list-style-type: none"> • Systems thinking • Communication • Collaboration • Optimism • Creativity • Ethical Considerations 	a. Recognize that engineering has a way of thinking and solving problems that includes: Systems thinking; communication; collaboration; optimism; creativity and ethical considerations.	i. Work productively in group for a particular purpose, e.g. solve a problem. ii. Ask and respond to questions from teacher and other group members. iii. Recognize frustration. iv. Recognize how a neighborhood is a system. v. Document learning in STEM notebooks: <ul style="list-style-type: none"> • Brainstorm ideas, • Use graphic organizers, • Draw pictures, • Use creative spelling to spell independently as needed,

			<ul style="list-style-type: none"> • Add descriptive words and details.
	2. Engineering Design Process	<ol style="list-style-type: none"> a. Use the engineering design process to design things to solve problems or meet a need. 	<ol style="list-style-type: none"> i. Identify and use the engineering design process of ASK-IMAGINE-PLAN-CREATE-IMPROVE to design a specific product or way of doing something. ii. Work with a team to complete a design challenge that can be shared with others. iii. Describe an engineering design that is used to solve a problem or meet a need.
	3. Systems Thinking	<ol style="list-style-type: none"> a. Understand that systems can be natural (found in nature) or technological (designed by humans). b. Understand that systems require energy and have parts that work together to accomplish a goal. 	<ol style="list-style-type: none"> i. Identify and describe characteristics of natural materials (e.g. wood, cotton, fur) and human-made materials (e.g. plastic, Styrofoam). ii. Identify and describe basic technologies used for a specific purpose. iii. Invent designs for simple products. iv. Identify and describe possible uses of natural and human made materials and technologies.

	<p>4. Problem Solving</p>	<ul style="list-style-type: none"> a. Identify problems that need to be solved. b. Understand that there are many types of problems. c. Use a systematic approach to solve several different types of problems. d. Use critical thinking to suggest solutions to problems. 	<ul style="list-style-type: none"> i. Solve a problem that requires non-standard measurement. ii. Solve a problem that requires peer negotiation. iii. Understand how the engineering design process could be used as a problem solving process. iv. Solve a problem that requires a picture to be drawn. v. Identify a problem from a story book, E.g. Corduroy.
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	ENGINEERING FOUNDATION AREA	ENGINEERING CORE IDEA	ENGINEERING CONTENT STANDARDS TO SUPPORT CORE IDEA
GRADE BAND: 3-5	<p>1. Engineering Habits of Mind</p> <ul style="list-style-type: none"> • Systems thinking • Communication • Collaboration • Optimism • Creativity • Ethical Considerations 	<p>a. Recognize that engineering has a way of thinking and solving problems that includes: Systems thinking; communication; collaboration; optimism; creativity and ethical considerations</p>	<p>i. Write for a variety of purposes in STEM notebooks:</p> <ul style="list-style-type: none"> • to document progress through engineering design process, • inform, • demonstrate knowledge, • answer questions, • tell a story • reflect. <p>ii. Identify essential tasks for a team to successfully complete a design challenge.</p> <p>iii. Work productively in roles to accomplish challenge.</p> <p>iv. Describe different ways in which a problem can be represented, e.g. models, sketches, diagrams, graphic organizers, and lists.</p> <p>v. Describe both positive and negative impacts of how recent technologies have significantly changed the way people live.</p>

	2. Engineering Design Process	a. Use the engineering design process to design things to solve problems or meet a need.	<ul style="list-style-type: none"> i. Apply the engineering design process of ASK-IMAGINE-PLAN-CREATE-IMPROVE to solve design challenges. ii. Identify a problem or need that can be addressed through engineering design and given criteria and constraints, propose multiple solutions, design and build a model, test and address what happens if the solution fails. iii. Describe how one solution may be better in some way than others in terms of cost, safety, appearance, materials or environmental impacts. iv. Explain that solutions or technologies designed or invented for one purpose may be used for other purposes.
	3. Systems Thinking	<ul style="list-style-type: none"> a. Understand that systems can be natural (found in nature) or technological (designed by humans). b. Understand that systems require energy and have parts that work together to accomplish a goal. 	<ul style="list-style-type: none"> i. Identify materials, natural or human made, used to accomplish a design task such as building a model based on specific properties such as strength, hardness, permeability, flexibility. ii. Identify and explain the differences between simple and complex machines, such as a hand mixer that includes gears, wheels and levers. iii. Compare natural systems with human designed systems that are designed to serve similar purposes. iv. Explain how the solution applied to one part of a

			<p>system may create problems or have an impact elsewhere in the system.</p> <ul style="list-style-type: none">v. Reverse engineer a simple design or system.vi. Identify the cause of failure in a system and suggest ways to avoid failure in the future.
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	<p>4. Problem solving</p>	<ul style="list-style-type: none"> a. Identify problems that need to be solved in daily life. b. Understand that there are many types of problems. c. Use a systematic approach to solve several different types of problems. d. Use critical thinking to suggest solutions to problems. e. Understand how tradeoffs affect the problem solving process. 	<ul style="list-style-type: none"> i. Solve a problem that requires analyzing data. ii. Identify tradeoffs in a problem that requires peer negotiation. iii. Justify the choice of solution to a problem that involves tradeoffs. iv. Solve a problem that requires a physical model to be made. v. Suggest alternative solutions a problem solved by the characters in a book.
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GRADE BAND: 6-8	<p>1. Engineering Habits of Mind</p> <ul style="list-style-type: none"> • Systems thinking • Communication • Collaboration • Optimism • Creativity Ethical Considerations 	<p>a. Apply creativity to identify multiple solutions to a given problem</p> <p>b. Exhibit optimism in the process of problem solving and design when addressing a problem that is unfamiliar to them</p> <p>c. Apply teamwork and collaboration skills</p> <p>d. Apply technical communication skills</p> <p>e. Apply attention to ethical considerations in engineering design and problem solving</p>	<p>i. Identify unique elements of a solution</p> <p>ii. Generate multiple ideas</p> <p>iii. Display adaptability in situations where materials are constrained</p> <p>iv. Distinguish between multiple solution paths</p> <p>v. Identify frustrations</p> <p>vi. Continue to try after failure</p> <p>vii. Identify team roles needed to address a project plan</p> <p>viii. Work on a team in multiple roles</p> <p>ix. Complete a hands-on project as a part of a team</p> <p>x. Keep an engineering (or a STEM) notebook</p> <p>xi. Give presentations</p> <p>xii. Present in-process or unfinished designs for critique (design review)</p> <p>xiii. Write project papers summarizing design process steps</p> <p>xiv. Identify both positive and negative implications of a particular engineering design</p> <p>xv. Trace the life cycle of a product from construction to disposal</p>
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GRADE BAND: 6-8

	<p>2. Engineering Design Process</p> <ul style="list-style-type: none"> • identify the problem, • identify criteria and constraints, • brainstorm possible solutions, • generate ideas, • explore possibilities, select an approach, • build a model or prototype, refine the design 	<ol style="list-style-type: none"> a. Identify the steps of the engineering design process: b. Apply the engineering design process to a specific problem c. Use iteration to move from a prototype to a final design d. Identify constraints e. Distinguish between different types of models f. Design and conduct an experiment to gather data required for an engineering design g. Reverse engineer a simple design or system h. Identify examples of engineered designs that have mimicked nature (biomimicry) i. Define the ways in which a specific design can fail and suggest preventative or reactive approaches j. Recognize failure as an important step in engineering design k. Identify how design 	<ol style="list-style-type: none"> i. Design a product, or ii. Design a process, or iii. Design a system iv. Use models v. Use scientific visualization vi. Identify constraints in a problem to be solved vii. Identify constraints in a situation that requires the production of a design viii. Identify constraints that molded an existing product ix. Recognize: <ul style="list-style-type: none"> • Physical models of a design, e.g. a model of a playground • Mathematical models, e.g. a curve fit to data • Digital models, e.g. a Solidworks™ design x. Use data analysis and interpretation xi. Use appropriate measurements xii. Analyze a design problem from the US perspective and that of another country such as China
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	<p>considerations might be affected by a global viewpoint</p>	
<p>3. Systems Thinking</p>	<p>a. Identify how human action can affect a system in nature and vice versa</p> <p>b. Define ethical considerations for an engineering solution based on systems thinking</p>	<p>i. Focus on systems in lithosphere</p> <p>ii. Focus on systems in atmosphere</p> <p>iii. Focus on systems in hydrosphere</p> <p>iv. Identify how a subsystem can have an impact on a larger system</p> <p><i>E.g. community use of water for irrigation from the Colorado River and effect</i></p>

			<p><i>downstream</i></p> <p>v. Identify unintended consequences from an engineering design <i>E.g. effect of bioengineered corn on butterflies, effect of increase in ethanol production on tortilla prices, effect of school system policies on individual classrooms</i></p>
	4. Problem solving	<p>a. Define a problem that requires multiple steps to solve</p> <p>b. Propose multiple solution pathways for the defined problem</p> <p>c. Identify the knowledge base required to solve the defined problem</p> <p>d. Recognize that some problems have multiple correct answers</p> <p>e. Solve a problem where insufficient information requires making an assumption to proceed</p> <p>f. Distinguish between types of problems</p> <p>g. Identify how others have solved problems by using observation skills</p>	<p>i. Suggest specific content from science, mathematics, social studies, music, technology, art, etc. that could aid in the solution of a specific problem</p> <p>ii. Apply knowledge from at least two distinct classes to the solution of a specific problem</p> <p>iii. Distinguish between problems that</p> <ul style="list-style-type: none"> • Require the production of an engineering design • Require the modification of an existing design • Require a paradigm shift in thinking

		<p>h. Identify the fourteen Grand Challenges for Engineering</p>	
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	<p>1. Engineering Habits of Mind</p> <ul style="list-style-type: none"> • systems thinking • creativity • optimism • collaboration • communication • ethical considerations 	<p>a) Demonstrate the ability to effectively communicate the need for ethical policies to protect life and the environment.</p> <p>b) Generate multiple ideas.</p> <p>c) Exhibit openness and courage to explore ideas.</p> <p>d) Demonstrate unwillingness to accept authoritarian assertions without critical examination.</p> <p>e) Exhibit optimism in the process of problem solving and design when addressing a problem that is unfamiliar.</p> <p>f) Apply teamwork and collaboration skills.</p>	<p>i. Develop communication skills: speaking, listening, writing, working in groups, presentations, discussions, debates.</p> <p>ii. Document learning in an engineering (or STEM) portfolio.</p> <p>iii. Identify authentic problems in a subject, which if solved, would improve the quality of <i>life</i> <i>E.g.: The Black Plague which is estimated to have killed 30–60 % of Europe's population, most likely traveled from China on the Silk Road or carried by <u>Oriental rat fleas</u> living on <u>black rats</u> that were regular passengers on <u>merchant ships</u>. In Europe during the end of the 13th century, high fertility rates (5 births/woman) led to food shortages and famine resulting in malnutrition and weakened immune systems and an increased susceptibility to infection caused by the bacteria pathogen, <u>Yersinia pestis</u>.</i></p> <p>iv. Compare and contrast how engineering in a field of science has evolved and what impacts, positive and negative, it has had on the human condition and the natural world.</p> <p>v. Demonstrate persistence and perseverance.</p> <p>vi. Choose student teams and evaluate team member performance.</p>
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GRADE BAND: 9-12

ENGINEERING FOUNDATION AREA	ENGINEERING CORE IDEA	ENGINEERING CONTENT STANDARDS TO SUPPORT CORE IDEA
2. Engineering Design Process	a) Recognize that the engineering design is a process of formulating problem statements, identifying criteria and constraints, purposing and testing possible solutions, incorporating modifications based on test data, and communicating the recommendations. b) Design experiments c) Interpret data d) Use the design process to determine solutions to an authentic problem or hazard.	i. Define a problem and specify criteria for a solution within specific constraints or limits based on science principles. Generate several possible solutions to a problem and use the concept of trade-offs to compare them in terms of criteria and constraints. ii. Identify design process steps. iii. Create and test or otherwise analyze at least one of the more promising solutions. Collect and process relevant data. Incorporate modifications based on data from testing or other analysis. iv. Analyze data, identify uncertainties, and display data so that the implications for the solution being tested are clear. v. Recommend a proposed solution, identify its strengths and weaknesses, and describe how it is better than alternative designs. vi. Identify further engineering that might be done to refine the recommendations. vii. Describe how new technologies enable new lines of scientific inquiry and are largely responsible for changes

			<p>in how people live and work.</p> <ul style="list-style-type: none"> iii. Evaluate ways that ethics, public opinion, and government policy influence the work of engineers and scientists, and how the results of their work impact human society and the environment. ix. Document learning through the use of an engineering (or STEM) portfolio. x. Demonstrate the chosen design solution through the use of a model or prototype.
	<p>3. Systems Thinking</p>	<ul style="list-style-type: none"> a) Understand energy flow in systems. b) Identify technological systems embedded within larger technological, social, natural, and environmental systems. 	<ul style="list-style-type: none"> i. Describe a natural process as a system. ii. Explain how humans interacting with natural systems alter the system in both beneficial and harmful ways (Ex: Levee system in New Orleans -- hurricane surge protection failures in New Orleans) iii. Trace energy flow through a complex

			<p>system</p> <p>iv. Define, identify and evaluate ethical responsibilities in solutions to natural problems.</p> <p>v. Forecast ethical, health, safety, political and environmental issues that are affected by engineering solutions to problems.</p> <p>vi. Reverse engineer a complex product or system.</p>
	4. Problem Solving	<p>a) Use optimization to select a solution to a problem.</p> <p>b) Understand the process of making assumptions.</p> <p>c) Understand that problems have multiple solution pathways and multiple solutions</p> <p>d) Identify how the fourteen (14) Grand Challenges are related.</p>	<p>i. Recognize when there are inherent assumptions being made.</p> <p>ii. Become comfortable making assumptions to simplify the solution of a problem.</p> <p>iii. Justify any assumptions being made.</p> <p>iv. Define the limits of a system and solution.</p> <p>v. Find best solution within constraints.</p> <p>vi. Boundaries of solution are defined by the constraints of a solution.</p> <p>vii. Recognize an optimal solution may not be a best solution, such as the long time debate among users of Windows PC versus Apple computers.</p> <p>viii. Recognize how high school course content relates to the fourteen NAE Grand Challenges.</p>