Teacher's Guide to Using Engineering Design in Science Teaching and Learning

Middle School Edition

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Table of Contents

Objective - to further the implementation of the Engineering Design portion of the Science Standards in Oregon classrooms and improve teachers' effectiveness at teaching science.

Why this Guide Exists

A change is coming – Educators in many states are discovering that engineering is a great way to support, improve and enhance the teaching of science. Oregon started riding this wave in 2009 when it added Engineering Design as one of four core standards in its Science Standards. Using the Engineering Design process gives teachers an additional way to succeed with 21st Century students. It can lead to increased student retention, engagement and confidence. This guide will help teachers use Engineering Design to reinforce science content in the classroom.

Oregon is one of 26 states providing leadership in the Next Generation Science Standards (NGSS) development process. Oregon has shown a strong commitment to standards-based learning through its adoption of the Common Core State Standards (CCSS). Oregon's current standards are based on some of the same research that underlies the ongoing development of the NGSS.

http://cicobb.typepad.com/es/2012/05/index.html

http://www.achieve.org/ngss-states

Because Engineering Design is in the Oregon standards and engineering practices will be in the NGSS, the time is right for Oregon to use the Engineering Design process to teach science alongside the Scientific Inquiry process. Incorporating Engineering Design will not only benefit Oregon students immediately it will help prepare Oregon teachers for what's coming next – the Next Generation Science Standards.

Overview and Introduction

Goals of the Guide

This guide was developed in collaboration between the Industry Partnerships Department of the Oregon University System and the Oregon Department of Education (“ODE”) to further the implementation of the Engineering Design portion of the Oregon Science Content Standards (the ‘Standards”) in classrooms and improve teachers’ effectiveness at teaching science.

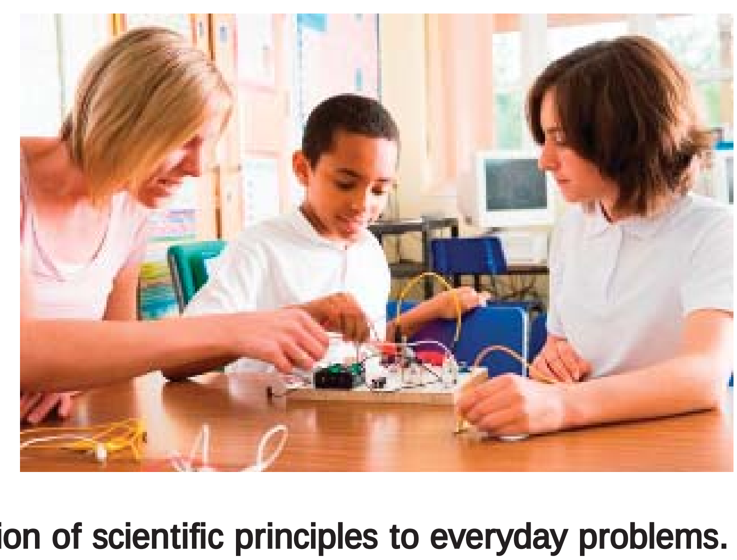
The NGSS take engineering design further by including Scientific and Engineering Practices:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information.

While this primer focuses on Oregon’s current standards, it also anticipates the NGSS’s use of scientific and engineering practices.

Oregon Science Content Standards

The Oregon Science Content Standards define the scientific content, knowledge, and process skills that all Oregon students are expected to learn during science instruction in K-8 and high school. The adopted science content standards include four core standards at each grade from kindergarten through eighth grade and for high school. These core standards provide the major unifying concepts and processes that will be the primary focus of teaching and learning across the grades. Underneath each of these core standards are from one to seven content standards, which provide the details necessary for instruction and assessment.



Since 2009, the Standards have included Engineering Design as a core Science Process Skill. In the context of the Standards, the term **Engineering Design describes the concept of using the application of scientific principles to everyday problems.**

Overview and Introduction

Engineering Design is a key skill and describes what students should know about how engineers use science as well as providing a way for students to learn about science in addition to Scientific Inquiry.

Scientific Inquiry Process & Engineering Design Process

Within Oregon's *Science Standards Framework: The big ideas organized by science discipline and core strand*, Scientific Inquiry and Engineering Design are both considered Science Process Skills. Students use inquiry-based science when they apply scientific reasoning and critical thinking to support conclusions or explanations with evidence from their investigations and students use the engineering design process when they define problems and design solutions to support conclusions or explanations with evidence from their investigations.

Dimensions of Scientific Inquiry	Dimensions of Engineering Design
1. Articulate Questions	1. Define Problems
2. Investigate	2. Design
3. Discover Scientific Knowledge	3. Create or Refine Technological Solutions
4. Communicate and Apply	4. Communicate and Apply

Overview and Introduction

Oregon Engineering Design Core and Content Standards

Grade	Core Standards	Engineering Design Content Standards
Grade 6	Engineering design is a process of identifying needs, defining problems, developing solutions, and evaluating proposed solutions.	• Define a problem that addresses a need and identify science principles that may be related to possible solutions. • Design, construct, and test a possible solution to a defined problem using appropriate tools and materials. Evaluate proposed engineering design solutions to the defined problem. • Describe examples of how engineers have created inventions that address human needs and aspirations.
Grade 7	Engineering design is a process of identifying needs, defining problems, identifying constraints, developing solutions, and evaluating proposed solutions.	• Define a problem that addresses a need and identify constraints that may be related to possible solutions. • Design, construct, and test a possible solution using appropriate tools and materials. Evaluate proposed solutions to identify how design constraints are addressed. • Explain how new scientific knowledge can be used to develop new technologies and how new technologies can be used to generate new scientific knowledge.
Grade 8	Engineering design is a process of identifying needs, defining problems, identifying design criteria and constraints, developing solutions, and evaluating proposed solutions.	• Define a problem that addresses a need, and using relevant science principles investigate possible solutions given specified criteria, constraints, priorities, and trade-offs. • Design, construct, and test a proposed solution and collect relevant data. Evaluate a proposed solution in terms of design and performance criteria, constraints, priorities, and trade-offs. Identify possible design improvements. • Explain how creating a new technology requires considering societal goals, costs, priorities, and trade-offs.

Oregon Essential Skills

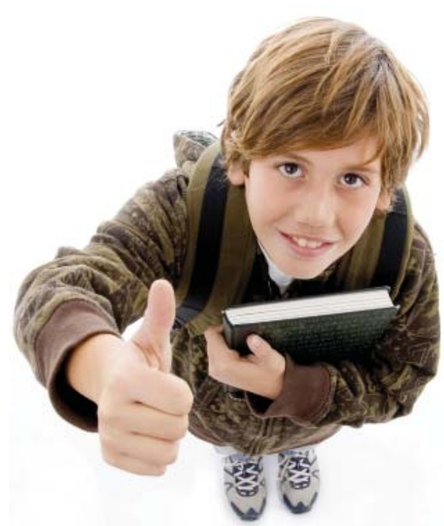
Beginning in 2012, Oregon students must demonstrate proficiency in identified Essential Skills. These are 21st century skills needed for success in college, the workplace, and civic life. The State Board of Education approved three assessment options for students to demonstrate Essential Skill proficiency: (1) OAKS state test, or (2) local assessments consistent with state criteria, or (3) other approved standardized tests (e.g. SAT, PLAN, ACT, PSAT, Work Keys, COMPASS, ASSETT).

Students who use Engineering Design to learn science will also be building essential skills. By the very nature of engineering design, students will be required to read and comprehend a variety of text, write clearly and accurately, and to apply mathematics to projects outside of their math textbook. Engineering design requires students to listen actively, speak clearly and coherently (team-based projects), think critically and analytically, and often to use technology such as a computer and computer software to help solve a problem. If students focus on solving problems to make a better world, they will also be developing the essential skills of demonstrating civic and community engagement and global literacy.

Essential Skills Required for Graduating Class**	Essential Skills to be Phased-In Over Subsequent Years
2012: Read and comprehend a variety of text 2013: Write clearly and accurately 2014: Apply mathematics in a variety of settings **Revised ES timeline adopted by the State Board Aug. 2009.	• Listen actively and speak clearly and coherently • Think critically and analytically • Use technology to learn, live, and work • Demonstrate civic and community engagement • Demonstrate global literacy • Demonstrate personal management and teamwork skills

Next Generation Science Standards

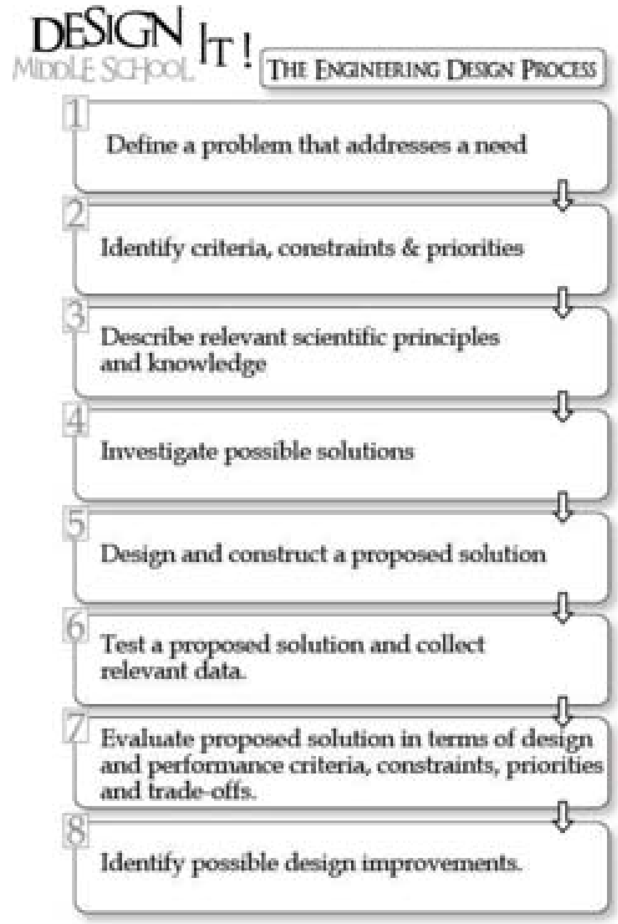
Twenty-six states, including Oregon, participated in the development of the Next Generation Science Standards. According to Leslie Payne of the American Society of Civil Engineers, "The framework for the new standards emphasizes first and foremost the new vision that K-12 science education should reflect real world interconnections in science, including active engagement in scientific AND engineering practices, and the application of intersecting concepts to improve understanding of core ideas. Perhaps most important is the idea that scientific and engineering practices should be included in learning experiences that span student's educational development from the very beginning of their school years. This is a major departure from previous standards that did not integrate scientific principles, engineering application or core concepts from the various disciplines of science learning."



Why use the Engineering Design Process?

Motivating Students to Learn Science

One positive aspect of using the Engineering Design process is that students begin to look at problems, issues and constraints from multiple viewpoints and in relationship to an assortment of situations and scenarios. New problems may arise from one solution, and those problems may lead to new ideas and solutions. There are also usually several different solutions to each problem. A solution may be designed for a particular audience (a passenger van to transport a large family) or it may be more general (a vehicle that can carry up to 5 people). Both solutions work for the problem of transporting people from point A to point B. Good engineering design considers people's needs (gas mileage, size of people or cargo, time spent in the vehicle, etc) to determine the best solution.



By solving problems that consider the needs of people, the doors to creativity open wide and student **engagement increases**. As students build skills in using Engineering Design to learn science, they no longer need to sit back and wait for instructions. Instead, they explore, create, design, innovate, imagine, test and evaluate their solutions. The advantages of using Engineering Design to teach science are similar to using Scientific Inquiry: students see connections to the world around them at the same time they develop problem solving skills that they can use in school and throughout their life.

By using this process, students learn that engineering design, like life itself, is an endless process of solving problems. In dealing with life's many challenges, successful adults take the same steps as the ones that students will use in their engineering design experiences such as stating the problem clearly, collecting information, developing possible solutions, selecting the best solutions, implementing the solution, evaluating the solution, making needed changes and improving the solution, and then communicating their findings.

Why use the Engineering Design Process?

As a society we need to accept math, technology and science as tools to understand the world and solve problems. To motivate and inspire students, educators need to provide exposure, awareness, meaningful interactions, curricula, content, relevance to success, “aha” moments, and sustained engagement leading to a student’s interest in learning more about science and possibly pursuing a degree in science or engineering. Positive attitudes and support are crucial in the classroom. Students need to be encouraged to think of science as a way of opening many doors and making a contribution to the world around them.

According to Cary Sneider, a leading science educator and one of the writers of the Next Generation Science Standards, understanding engineering is essential for all citizens, workers, and consumers in a modern democracy. If the U.S. is to continue to play a significant role in the world economy, it is imperative that students be exposed to engineering design and problem solving thought processes. He goes on to say that the capability to formulate and solve problems is a valuable life skill. By including Engineering Design in the Oregon State Standards, students will have access to a wider range of viable careers because they will be prepared to take the appropriate courses in high school. Exposure to engineering design is also an important equity tool for girls and minority students.

Acquiring Essential Skills While Learning Science

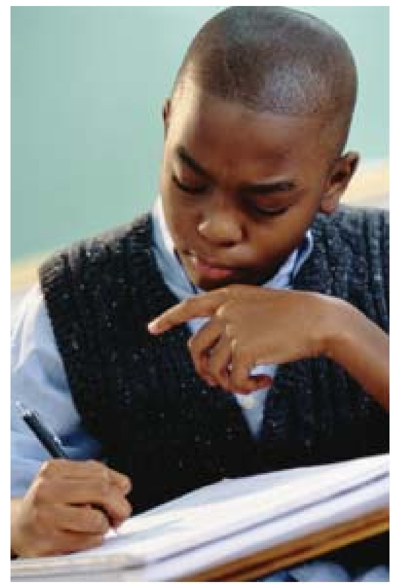
Engineering is ideal for integrating math and science. Using the Engineering Design process is an opportunity to provide a hands-on lesson that allows students to confront their preconceptions about scientific phenomena and how it relates to important learning goals. Lessons that engage students in Engineering Design can be effective whether they are structured or very “open,” with students pursuing answers to their own questions. According to *Effective Science Instruction: What Does Research Tell Us?* (Bainilower, et al, 2010) , “Whatever the mode of instruction, the research suggests that students are most likely to learn if teachers encourage them to think about ideas aligned to concrete learning goals and relate those ideas to real-life phenomena.”

One of the reasons that students’ understanding of science is increased is because of the immersion that hands-on learning offers. Engineering design can provide the **hook to**

Why use the Engineering Design Process?

motivate students, addressing something they have wondered or wanted to know about. Learning science can then be enhanced by building on that knowledge and encouraging students to relate their design to real-world problems and applications (Bainilower, et al, 2010).

As part of the requirements for graduating high school in 2014, an additional element of Oregon's Essential Skills will be required: Apply mathematics in a variety of settings. Engineering design in the context of learning science is one such setting. Engineers use mathematics to analyze problems and develop solutions as well as test and analyze these solutions. The Engineering Design process can serve as a bridge between math and science and offers students a real-world way of thinking through and solving problems. Students benefit by acquiring a deeper understanding of science content at the same time they develop one of the essential skills needed to graduate.



Learning and using the Engineering Design process will help students develop the skill to solve practical problems and they will also help develop the ability to read and comprehend a variety of texts, another essential skill required for graduation. Activity instructions are typically written in language that is somewhat technical, challenging students to lift their comprehension skills to a higher level. Students learn methods used by engineers to design and document their work. This allows them to read and comprehend a variety of text, write clearly and accurately and communicate their design – all skills that are part of Oregon's graduation requirements because they are important life skills.

Models and Simulations

Models are a way of describing a design and simulations are a way of testing designs. Modeling gives students the opportunity to build real things and in the process, use the Engineering Design process to learn science. Using models can change science lessons from passive to active. Models can enhance a student's understanding of how the world operates and open the door to alternative ways of thinking and problem solving.

Models can be small or big, simple or fancy. They can be physical, mathematical, and on the computer (software-based).

Why use the Engineering Design Process?

Models are a discovery tool to help:

- students understand the relationships between parts
- students visualize the interaction of moving or unmoving parts
- explore the consequences of these relationships
- explore new ways to think about the “need” that underlies the problem being solved
- develop spatial problem solving
- jump from a sketch on paper to three dimensions.

Connecting to Real-World Careers

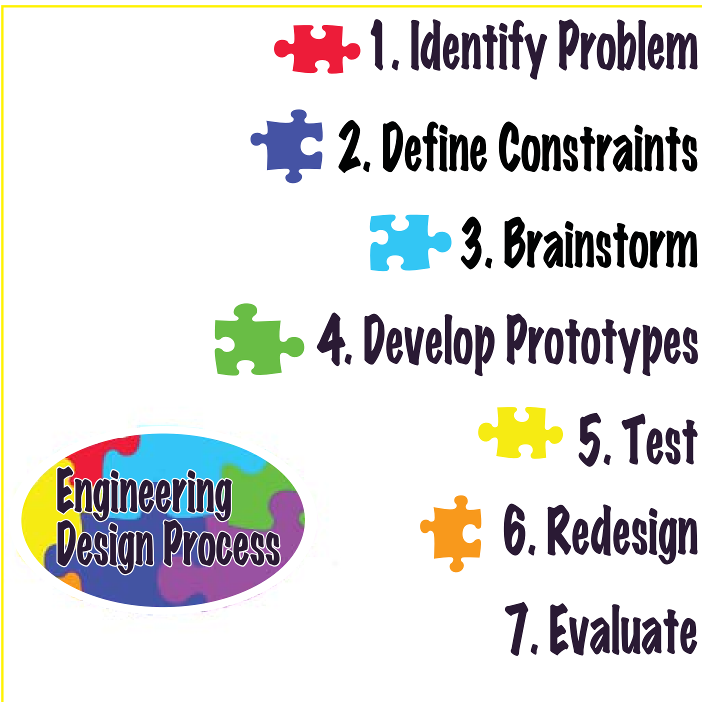
The Engineering Design process teaches students how to think through a problem and use what they know and their creativity as well as materials and technology to make a better world. Using engineering design to learn science can also provide students additional insights into Science, Technology, Engineering and Math (STEM) careers. Because engineering is the application of science, technology, and math, students will be prepared to better understand a wide variety of STEM careers and make more informed choices on high school courses, college plans and an eventual career.

Being successful in any career requires much more than academic knowledge. Projects are done in teams, and products and services must compete in a global economy. The “soft” skills that students develop such as creativity, communication and leadership skills will serve them well in their future employment and life in general. The Engineering Design process, used to learn science content, can provide the tools to merge problem solving, communication, teamwork, leaderships, innovation, creativity, and critical thinking with learning science. Students who can apply concepts and integrate knowledge across academic disciplines and in practical settings will find it easier to find good jobs and succeed in life.

Engineering Design Process Description

Engineering Design Process Overview

Professional engineers use a variety of processes to solve problems. In the context of teaching and learning science we can simplify these processes into a step-by-step problem solving template. In the Oregon Science Standards this process is called Engineering Design and this process is a sister to the Science Inquiry process for teaching science. Just as the Science Inquiry process involves articulating a question and investigating possible answers to the question (leading to a better understanding of natural phenomena), the Engineering Design process involves articulating a problem and investigating possible solutions to the problem (leading to a better solution to the problem). In other words, engineering design is a way to put science to work to solve problems.



The Engineering Design process, at the middle school level, is a process of formulating problem statements, identifying criteria and constraints, proposing and testing possible solutions, incorporating modifications based on test data, and communicating the recommendations. The process is simplified for elementary grades and is a bit more complex at the high school level but still relies on the premise that engineering design exists to design and build things. Human needs, identifying criteria and constraints, proposing and testing solutions, and reworking the design to make it better are incorporated as students advance.

Characteristics of Engineering Design Processes and How They are Used

The Engineering Design process is not a rigid set of rules for solving every problem but more of a tool to focus and direct the process of problem solving and ways of thinking. Each problem is different and the solution may or may not go through each step in the process. For example, a student may discover in the process of researching a problem that there is already a solution available. The solution to the problem may involve using or adapting an existing solution.

Engineering Design Process Description

In the Oregon Standards, the first step in the Engineering Design process is to define a problem associated with a need. In practice, this first step includes learning as much as possible about the problem or opportunity.

Teaching Students About the Engineering Design Process

1. **Encourage teamwork** – Since students and engineers design in teams, this is a critical component. In “Generation Y - The Millennial Generation” in Generational Learning Styles, Julie Coates states that Generation Y’s preferred learning environment combines teamwork and technology. She goes on to say that this generation is made up of confident, optimistic young people that feel valued and wanted. They are the most diverse generation in history, both ethnically and socially.
2. **Develop or encourage projects that are about people and making life better** Projects that include clean water, green energy, and/or low-carbon transportation alternatives can help students think globally and about future technologies.
3. **Start out by separating the boys and girls** – when first beginning projects that include engineering design, you may overcome culturally differentiated experiences by separating the boys and girls. In the early stages of developing spatial analysis skills and learning to build, girls may do much better if you start them out in an all-girl environment. After the girls and boys have been successful and built some self-confidence, having both genders on each team will help both genders. An even mix is best, even for professionals.
4. **Celebrate science and engineering** – Focus on current events in which engineers or scientists save lives, help the environment or serve their communities.
5. **Reverse engineer a favorite gadget** – Have students take apart devices such as cell phones, ipods or vacuum cleaners to see how they were designed and if they can imagine themselves as the designer, what could they do to make the design better? Whatever students are interested in – medicine, robotics, architecture, music or sports – there’s probably a gadget needed to do it.
6. **Make math real-world** – Perceptions about math have changed the course of millions of lives. Tell students that math is just one tool in the engineering design box. Math and science are important tools to understanding the world but they are not the only problem-solving tools available. Without at least three years of high school math, students will be excluded from a wide variety of jobs including: Engineer, Programmer,

Accountant, Biologist, Medical Technician, Architect and Doctor. Math is very important for intellectual development including creativity, constructive processes and problem-solving (Singh, Man pal, 2005). Other tools in the box include passion, communication skills, teamwork skills, common sense, analytical ability, persistence, writing skills, presentation skills and time management.

7. **Use graphics to represent ideas** – Graphics are a form of communication often overlooked. Communication, especially in engineering design, can mean the difference between getting the job done or not. In this age of instant and text messaging, students need to take every opportunity to enhance their communication skills. All forms of communication are valuable and when using graphics or art to convey ideas, you may see the spark in a student's eye that wasn't there before. Tools such as Google Sketchup can effectively create this bridge.

Scientific Inquiry vs. the Engineering Design Process

Theodore von Karman once said:

"Scientists study the world as it is, engineers create the world that never has been."

Both engineering and science involve obtaining knowledge and using a set of practices.

According to *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* by The National Research Council, "the major goal of engineering is to solve problems that arise from a specific human need or desire. To do this, engineers rely on their knowledge of science and mathematics as well as their understanding of the engineering design process." Specifying what is needed and designing a solution for it provides students with an opportunity to practice the application of their understanding of science. The design process is also an important way for K-12 students to develop an understanding of engineering as a discipline and as a possible career path. The work of engineers, like the work of scientists, involves both individual and cooperative effort.

Engineering and science are similar in that both involve creative processes, and neither uses just one method.

Engineering Design Process Description

Scientific Inquiry	Engineering Design
• The goal of science is to develop a set of coherent and mutually consistent theoretical descriptions of the world that can provide explanations over a wide range of phenomena. • Not necessarily driven by immediate practical needs. Could be driven by curiosity or with the aim of answering a question about the world or understanding an observed pattern. • For science, developing such explanations about the world constitutes success in and of itself, regardless of whether it has an immediate practical application.	• The goal of engineering is to evaluate prospective designs and then produce the most effective design for meeting the specifications and constraints. • Driven by practical human needs. • For engineering, success is measured by the extent to which a human need or want has been addressed.

Application to Science in Middle School

Core and Content Standards Summary

	Grade 6	Grade 7	Grade 8
1. Define a problem that addresses a need	x	x	x
Identify criteria, constraints and priorities	Criteria only	Criteria, constraints only	x
Describe relevant scientific principles and knowledge	x	x	x
4. Investigate possible solutions	x	x	x
5. Design and construct a proposed solution	x	x	x
6. Test a proposed solution and collect relevant data	x	x	x
7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs	Criteria only	Criteria and constraints only	x
8. Identify possible design improvements	x	x	x

In grade 6, students are not required to identify **design constraints**. In grade 7, **constraints** are included. Similarly, **priorities and trade-offs** are not explicitly mentioned until grade 8. Criteria should be covered at all middle school grades even though they are not explicitly mentioned in the 6th- and 7th-grade levels, but they are mentioned in the 5th-grade standard.

Assessing students' understanding of the engineering design process is important to understanding how to best create learning environments that successfully use engineering design in the classroom.

Inventions that address human needs and aspirations are everywhere! Some of the most amazing include:

- Calculators
- Shoes
- Clothes
- Indoor Plumbing
- Tools for every job
- Antibiotics
- MP3 Players such as iPods
- Video Games
- Kitchen Appliances
- Robots
- Cell Phones and
- ATM Machines

As a result of the space program, NASA's engineers are responsible for inventions such as:

- the hand held vacuum cleaner
- the firefighter breathing apparatus
- safer runways
- storm warning systems
- better sunglasses
- car crash technology
- freeze dried meals
- baby food
- improved air quality
- artificial limbs and much, much more.

Application to Science in Middle School

Creating a new technology requires considering societal goals, costs, priorities, and trade-offs. Everything in life is a compromise.

Correlation of Essential Skills and the Engineering Design Process

1. Read and comprehend a variety of text* *text includes but is not limited to all forms of written material, communications, media, and other representations in words, numbers, and graphics and visual displays using traditional and technological formats	
Reading Skill	**Steps of the Engineering Design Process**
1. Demonstrate the ability to read and understand text.	1. Define a problem that addresses a need. 3. Describe relevant scientific principles and knowledge.
2. Summarize and critically analyze key points of text, events, issues, phenomena or problems, distinguishing factual from non-factual and literal from inferential elements.	1. Define a problem that addresses a need. 2. Identify criteria, constraints and priorities. 3. Describe relevant scientific principles and knowledge.
3. Interpret significant ideas and themes, including those conveyed through figurative language and use of symbols.	1. Define a problem that addresses a need. 2. Identify criteria, constraints and priorities.
4. Follow instructions from informational or technical text to perform a task, answer questions, and solve problems.	5. Design and construct a proposed solution. 6. Test a proposed solution and collect relevant data – 8th grade only.

2. Write Clearly and Accurately	
Writing Skill	**Steps of the Engineering Design Process**
1. Adapt writing to different audiences, purposes, and contexts in a variety of formats and media, using appropriate technology.	1. Define a problem that addresses a need. 2. Identify criteria, constraints and priorities. 3. Describe relevant scientific principles and knowledge.
2. Develop organized, well-reasoned, supported, and focused communications.	1. Define a problem that addresses a need. 2. Identify criteria, constraints and priorities. 3. Describe relevant scientific principles and knowledge.
3. Write to explain, summarize, inform, and persuade, including business, professional, technical, and personal communications.	5. Design and construct a proposed solution. 7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs – 8th grade only. 8. Identify possible design improvements.
4. Use appropriate conventions to write clearly and coherently, including correct use of grammar, punctuation, capitalization, spelling, sentence construction, and formatting.	4. Investigate possible solutions. 5. Design and construct a proposed solution. 8. Identify possible design improvements.

Application to Science in Middle School

3. Apply Mathematics in a Variety of Settings	
Mathematics Skill	**Steps of the Engineering Design Process**
1. Interpret a situation and apply workable mathematical concepts and strategies, using appropriate technologies where applicable.	3. Describe relevant scientific principles and knowledge. 4. Investigate possible solutions. 5. Design and construct a proposed solution. 6. Test a proposed solution and collect relevant data – 8th grade only.
2. Produce evidence, such as graphs, data, or mathematical models, to obtain and verify a solution.	6. Test a proposed solution and collect relevant data – 8th grade only. 7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs – 8th grade only. 8. Identify possible design improvements.
3. Communicate and defend the verified process and solution, using pictures, symbols, models, narrative or other methods.	7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs – 8th grade only. 8. Identify possible design improvements.

Engineering Design Process for Middle School

1. Define a problem that addresses a need. Engineering begins with a problem that needs to be solved. Sometimes the problem is stated as a question, such as "How can we make sure people are safe in an earthquake? or "How can candy bars become healthier?" Other times, a problem is described as a scenario, for example "People using wheel chairs have said they have had trouble finding an entrance to a public building that they can use. Review the description of the building and design an improvement that will address their concerns." At this stage, you should encourage your students to ask questions to clarify the problem. The problem should be described in terms of solving a human problem or important need.

   To encourage your students to ask questions to better understand the nature of the problem, consider the following scenario: Mr. Avagadro, the 8th grade Science Teacher, likes to conduct science demonstrations for students and also enjoys seeing the students complete hands-on projects but often can't find his demonstration and project materials. He needs to organize the large inventory of supplies - some supplies are used every month but other supplies are only used once a year. Some supplies are chemicals that need to be insulated from the cold at night when the school's heat is off. He needs to know what supplies are available and what needs to be purchased. Tell the students that they should design a solution that would help him and their first step should be to ask questions until they completely understand the problem and can describe it in a clear paragraph starting with “The problem is that ...”. Questions help students learn all aspects of the problem, helping break down the problem and its solution into smaller parts.

2. Identify criteria, constraints and priorities. The Oregon Science Content Standards do not require coverage of criteria, constraints and priorities for 6th-grade students and only requires covering constraints for 7th graders.

   8th grade students should list and describe the criteria, constraints and priorities associated with the problem being solved. They should be encouraged to ask questions to clarify the problem, identify the constraints and determine the criteria for a successful solution. They may also want to survey possible users of the solution to better understand their needs or do library or web research on the need.

   In the case of the organizational system for Mr. Avagadro, students may come up with criteria, constraints and priorities such as:
   - Criteria: need to organize 6 demonstrations and the materials for 4 projects (8th grade only).
   - Constraints: Must be low cost, easy to use and easily and quickly accessible (7th and 8th grades only).
   - Priority: In decreasing order of priority: (1) Must be easy to use; (2) Low cost; and (3) quickly accessible (8th grade only).

3. Describe relevant scientific principles and knowledge. Connecting relevant scientific principles and knowledge to the engineering design process ensures that projects will have broad importance across multiple science and engineering disciplines as well as providing a tool for understanding more complex ideas and solving problems.

   In the case of Mr. Avagadro storing chemicals so that they don’t get too cold at night when the school’s heat is off, students may describe:
   - Ways to measure the physical and chemical properties of a system.
   - Ways to use the data obtained from scientific inquiry.
   - How energy is transferred, transformed and conserved.

4. Investigate possible solutions. Developing ideas for multiple solutions is also not required at the 6th and 7th grade levels but it students working in groups will often come up with more than one possible solution, which should be encouraged.

   In grade 8, students should understand that engineering problems typically have many possible solutions. Students can start by coming up with several ideas even if some of them don't seem to address all the criteria and constraints. The possible solutions can be compared to the criteria and constraints as well as each other. Some students will think of additional solutions after they have analyzed and compared the initial solutions.

For Mr. Avagadro, possible solutions may be:

- Separating demonstrations into clear labeled boxes all stacked in the same area.
- Putting each part for each project in a separate box
- Creating an inventory list.
- Creating a list that tells where everything is located.

5. Design and construct a proposed solution. Teachers of grades 6 and 7 may want to choose a solution and encourage students to build a prototype or model of the solution. Class discussions should include extra time to fully understand the problem and how the solution will solve the problem. Diagrams and a parts list for the model are suggested at this stage.

   In grade 8, students should choose a particular solution from those previously considered and describe it in more detail and with additional refinements than when it was only one of several solutions. If time and materials permit, the student should then build a model of the proposed solution or something like it.

6. Test a proposed solution and collect relevant data – 8th grade only. Students should use the solution they have built to make and record measurements. The most important measurements are those that relate to the criteria and constraints associated with the problem. Note, however, that the Standard does not require a quantitative analysis of the solution; a qualitative analysis is acceptable. If it is not possible to build the proposed solution or something similar to it, students should find another way of analyzing their solution by reviewing their sketches and descriptions.

   In the case of Mr. Avagadro, students can record measurements such as:

   - Time how long it takes to collect all of the parts needed for a demonstration or class project.
   - Associated costs for producing the organization system.

7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs – 8th grade only. Using the tests in the previous section, students

should describe what they have learned about their solution. Encourage them to explain their reasoning for choosing a particular solution. Specifically, they should discuss how well the solution met the criteria and stayed within the constraints. They should discuss the trade-offs they made between the various criteria and how they thought about the design priorities.

8. Identify possible design improvements. 8th-grade students should describe how their solution could be improved and encouraged to consider a redesign. If they could do it all over again, would they build it the same way? Remind students that design improvements can be anything. They can increase the functionality, improve the ease of use and/or lower the cost.

What the Students Should Learn About the Process

The most basic level of the engineering design process, a level that all middle school students should be comfortable doing, is to define a problem that addresses a human need. They should all understand constraints involved and connect the concepts to relevant scientific principles and knowledge. Middle school student should build models when possible and in all cases evaluate their proposed solutions. The table below addresses what the students will learn about the engineering design process at each grade level.

Students use the Engineering Design process to enhance the learning of science when they define problems and design solutions. Engineering design isn't a stand-alone component of the Oregon science standard. It should be used as a way to motivate, deepen students' interest in science content and also practice math and communication skills.

On the OPAS website, there are two activities that have been compiled to assist using the Engineering Design Process to teach Physical Science and Earth and Space Science in middle school. Each activity provides an intriguing scenario, teaching guide, student handouts, and vocabulary alerts. The activities are each aligned to the Engineering Design portion of the Oregon State Standards to facilitate easy adoption into the classroom.

Connecting the Engineering Design Process

Connecting Engineering Design to Learning Earth and Space Science

In this lesson, students play the role of environmental engineers who have been hired by the city's Bureau of Environmental Services (BES) to design curbside bioswales that clean stormwater runoff before it soaks into the ground or enters the city's drain system.

The lesson is divided into three parts.

1. A reading activity that introduces the concept of bioswales to students.
2. Students then experiment with different filter materials to better understand their properties and abilities. Students will be able to describe and measure water solutions in terms of pH and turbidity.
3. Students use the Engineering Design process to research and design their own filters. They will determine the best combination and amounts of materials for a bioswale.

Tying it all together

Following is a table of how the ***Water Filtration*** lesson relates to the Engineering Design Process, the Oregon Engineering Design Standards, and the Earth and Space Science Standards. The steps exemplify how scientific inquiry and the engineering design process overlap to create meaningful lessons for students. This table is only a general guide – you may find more correlations and connections as you move through the lesson.

Connecting the Engineering Design Process

Steps of the EDP	**Engineering Design Standard Correlation**	**Earth and Space Science Standard Correlation**	**Water Filtration Correlations** *See the "Water Filter Design Activity" student handout*
1. Define a problem that addresses a need	6.4D.1 Define a problem that addresses a need. 7.4D.1 Define a problem that addresses a need. 8.4D.1 Define a problem that addresses a need.	6.2E.1 Explain the water cycle and the relationship to landforms and weather. 7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	Pollutants from the environment such as oil, fertilizer, pesticides, soap, and animal waste are polluting creeks, lakes, rivers, ponds, streams and wetlands. In addition, some of this polluted water is entering aquifers and tainting water that is used in many households for watering vegetables, cooking, and bathing.
2. Identify criteria, constraints and priorities	7.4D.1 Identify constraints. 8.4D.1 Specify criteria, constraints, and priorities.	N/A	Criteria examples: Filter should lower turbidity, change pH and/or take a specific length of time. Priorities: Cleaning the water is the top priority. Constraints: Supplies available
3. Describe relevant scientific principles and knowledge	6.4D.1 Identify science principles that may be related to possible solutions. 7.4D.3 Explain how new scientific knowledge can be used to develop new technologies. 8.4D.1 Use relevant science principles.	6.2E.1 Explain the water cycle and the relationship to landforms and weather. 7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	Oil, fertilizer, pesticides, soap, and animal waste are pollutants that can cause illness.
4. Investigate possible solutions	Grade 6 – N/A Grade 7 – N/A 8.4D.1 Investigate possible solutions.	6.2E.1 Explain the water cycle and the relationship to landforms and weather. 7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	Brainstorm two different design ideas.
5. Design and construct a proposed solution	7.4D.2 Design, construct, and test a possible solution using appropriate tools and materials. 8.4D.2 Design, construct, and test a proposed solution.	N/A	Build one of the designs.
6. Test a proposed solution and collect relevant data	Grade 6 – N/A Grade 7 – N/A 8.4D.2 Design, construct, and test a proposed solution and collect relevant data. 6.2E.1 Explain the water cycle and the relationship to landforms and weather.	7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	Test the design.

Connecting the Engineering Design Process

Steps of the EDP	Engineering Design Standard Correlation	Earth and Space Science Standard Correlation	Water Filtration Correlations *See the "Water Filter Design Activity" student handout*
7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs	6.4D.2 Evaluate proposed engineering design solutions to the defined problem. 7.4D.2 Evaluate proposed solutions to identify how design constraints are addressed. 8.4D.2 Evaluate a proposed solution in terms of design and performance criteria, constraints, priorities, and trade-offs.	6.2E.1 Explain the water cycle and the relationship to landforms and weather. 7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	Evaluate: How well did the filter work?
8. Identify possible design improvements	Grade 6 – N/A Grade 7 – N/A 8.4D.2 Identify possible design improvements.	6.2E.1 Explain the water cycle and the relationship to landforms and weather. 7.2E.3 Evaluate natural processes and human activities that affect global environmental change and suggest and evaluate possible solutions to problems.	How could it be better? Either redesign the filter based on the results and observations or build and test another design.

Connecting Engineering Design to Learning Physical Science

In this engineering challenge lesson, students will design and build prototype coaster cars. Their ultimate goal is to build the fastest model car possible. At the completion of the lesson, there is a simulated race where teams compete for the title of "Ultimate Racer".

The lesson is divided into three parts.

1. Part one is a background reading activity that familiarizes students with the history of soapbox racing in America and also provides a basic explanation of the physics of the cars.
2. In part two, students will experiment with materials to better understand the relationship between force, friction, speed and acceleration in coaster cars.
3. In part three, using the data they collect from their experiments, students will design, build, test and evaluate their own creations.

Tying it all together

Following is a table of how the ***Coaster Cars*** lesson relates to the Engineering Design process, the Oregon Engineering Design Standards, and the Physical Science Standards. The steps exemplify how scientific inquiry and the engineering design process overlap to create meaningful lessons for students. This table is only a general guide – you may find more correlations and connections as you move through the lesson.

Connecting the Engineering Design Process

Steps of the EDP	**Engineering Design Standard Correlation**	**Physical Science Standard Correlation**	**Coaster Car Correlations** *See the "Ultimate Speed Challenge Design Activity" student handout*
1. Define a problem that addresses a need	6.4D.1 Define a problem that addresses a need. 7.4D.1 Define a problem that addresses a need. 8.4D.1 Define a problem that addresses a need.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	You are entering the annual soapbox derby Ultimate Racer competition. If you want to win, you will need to design and build a car that is faster than last year's winner.
2. Identify criteria, constraints and priorities	7.4D.1 Identify constraints. 8.4D.1 Specify criteria, constraints, and priorities.	N/A	Criteria: The car must go fast and straight. Other possible criteria: How much should the car to weigh, and/or how long should it take to construct? Priorities: Rank your criteria from most to least important. Constraints: What things will limit your ability to build the fastest car that goes straight?
3. Describe relevant scientific principles and knowledge	6.4D.1 Identify science principles that may be related to possible solutions. 7.4D.3 Explain how new scientific knowledge can be used to develop new technologies. 8.4D.1 Use relevant science principles.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	Gravity can be used as a source of potential energy. Friction will slow down the car. Mass will affect the acceleration and velocity. Shape and surface area will affect the air resistance.
4. Investigate possible solutions	Grade 6 – N/A Grade 7 – N/A 8.4D.1 Investigate possible solutions.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	Brainstorm different design ideas.
5. Design and construct a proposed solution	6.4D.2 Design, and construct a possible solution. 7.4D.2 Design, construct, and test a possible solution using appropriate tools and materials. 8.4D.2 Design, construct, and test a proposed solution.	N/A	Build one of the designs.
6. Test a proposed solution and collect relevant data	Grade 6 – N/A Grade 7 – N/A 8.4D.2 Design, construct, and test a proposed solution and collect relevant data.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	Test the design
7. Evaluate the proposed solution in terms of design and performance criteria, constraints, priorities and trade-offs	6.4D.2 Evaluate proposed engineering design solutions to the defined problem. 7.4D.2 Evaluate proposed solutions to identify how design constraints are addressed. 8.4D.2 Evaluate a proposed solution in terms of design and performance criteria, constraints, priorities, and trade-offs.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	Evaluate: How well did the car do?
8. Identify possible design improvements	Grade 6 – N/A Grade 7 – N/A 8.4D.2 Identify possible design improvements.	7.2P.1 Identify and describe types of motion and forces and relate forces qualitatively to the laws of motion and gravitation.	How could it be better? Either redesign the filter based on the results and observations or build and test another design.

Conclusion

What now, next steps

The next step is to participate in a training conducted by a facilitator who will provide activities that can be taken back to the classroom, as well as sample work samples, engineering design charts and references, templates and checklists. In late 2012 the Oregon University System offered school districts a competitive grant opportunity that provides winning school districts and schools small incentive grants to assist them in offering these workshops to their teachers. Similar grant opportunities may be offered in the future and some schools and school districts may decide to offer the workshops on their own. For information on this possibility, please contact XXXX@ous.edu. Teachers who attend a workshop will be given the opportunity to think about how they teach, draw upon the collective wisdom of their colleagues, participate in hands-on activities and walk away with Engineering Design Process lessons to be used in their school with their materials.

If you cannot attend a workshop or you want to get started immediately, the next steps are considering how to adapt what you have learned from this primer to existing and new science lessons. Get together with your colleagues to brainstorm. Use the Engineering Design process to develop a method for deploying engineering design in the classroom.

The Engineering Design Process	Possibilities
1. Define the problem or need	Adapting what you have learned from this primer
2. Identify the criteria, constraints and priorities	Criteria: using the engineering design process to teach science Constraints: materials, time, collaboration Priorities: Students use the process to learn science concepts
3. Describe relevant scientific principles and knowledge	Use what you know about science instruction to adapt the lessons
4. Investigate possible solutions	Research on the Internet to see what others are doing or collaborate with a colleague.
5. Design and construct a proposed solution	Modify the lesson.
6. Test a proposed solution and collect relevant data	Give it a try and see if it works.
7. Evaluate solutions	Evaluate how it went.
8. Identify possible design improvements	Redesign the lesson to make it better.

Key Terms

Constraints — Limits on possible solutions. When we solve a practical problem we usually have limits on how big the solution can be, how much it can cost, how easy it is to use, etc.

Criteria — The things your solution should do or be (i.e. cheap to manufacture locally). Engineering problems are usually described in terms of a set of goals that become the criteria against which we judge possible solutions.

Design (noun) – A plan for a product, process, or system created to solve a problem.

Design (verb) — The process of modifying or inventing a product, process, or system to solve a problem, including the look, feel, features and performance.

Innovation – A new or improved means to solve a problem.

Invention – The first occurrence of a new technology designed to solve a problem or meet a need. Invention is closely related to innovation. An invention often indicates an intent to market the product or to protect the intellectual property with a patent or other process.

Knowledge — When a practical problem is being solved, we need to consider which scientific facts about the problem and possible solutions to the problem might be needed to solve the problem. In many cases we need to gather more scientific information to come up with a good solution.

Model – In relation to using the engineering design process, a model is something that represents a design. It may function like the design or represent the size and shape of the designed object, or be a graphical representation (e.g. a scale drawing) of an object or a process.

Modifications – Changes to a design that are intended to improve performance. Making modifications to a design is a normal step in the design process since the first design is almost never perfect.

Need — The reason why we want to solve a problem. Most engineering problems relate to a need that relates to people, society or the world around us.

Optimization – The process of considering and making design tradeoffs in order to maximize performance with respect to a criterion or prioritized list of criteria.

Practical – The characteristic that a problem or solution has a real-world application.

Priorities – A ranking of criteria in their order of importance.

Priority — The relative importance of the criteria and constraints. Usually some criteria are more important than others. Likewise for constraints.

Key Terms

Principles — Most engineering design solutions use scientific principles to meet the goals of the project. One example would be various types of energy can be transformed into thermal energy or heat. Engineers know that energy cannot be created or destroyed so therefore, designing something that uses a light bulb to illuminate a space will also create some heat in the space.

Problem — Something that needs to be solved and usually the goal of an engineering design project. Most engineering projects relate to a practical problem that provides a benefit to people or improves upon an existing solution.

Prototype – A not yet final working model of a design that is usually constructed to test performance or other criteria.

Simulation — A representation of a model or solution, tested under various conditions or changes in input, that exhibits at least some of the aspects of the real situation or solution so that it can be studied and improved. Simulations can be physical representations or implemented on a computer.

Solution — In relation to using the engineering design process, a solution is a possible way of solving a practical problem.

Trade-off — Practical problems almost always have many solutions. When we compare one solution to another, doing a better job of achieving one criterion often means doing less well on another criterion. In other words, we are forced to trade-off one criterion for another.

Additional Resources

Methods and tools to produce work samples

- Oregon Middle School Engineering Design Scoring Guides and notebook templates
  Web reference: www.ode.state.or.us/search/page/?id=32 or tinyurl.com/l8prupx

- Engineering Design Work Sample Justification Sheet for scoring student work
  Web reference: http://tinyurl.com/cqof2dy

- Grades 6-8 - 2011-12 Scientific Inquiry and Engineering Design Scoring Guide
  Web reference: http://tinyurl.com/cohkh5u

- Secondary Sample Student Language Engineering Design Scoring Template. This document represents one good approach for assisting students in developing a work sample using engineering design. Many other approaches are also possible. This template has been successfully used by several teachers in Oregon to help students produce Engineering Design Work Samples.
  Web reference: tinyurl.com/ctkoxmz

- Secondary Sample Student Language Engineering Design Scoring Template
  Web reference: http://tinyurl.com/bnbwpk3

- Oregon Middle School Engineering Design Notebook template that can be found on the web at http://www.ode.state.or.us/search/page/?id=32

Additional Resources

Web Resources

- Middle School sample activities: http://opas.ous.edu/EDOSC/Materials.php
- Request for application http://www.oregonetic.org/grant-info/
- Engineering Design Core and Content Standards for all bands available on: Pages 25 and 26 of http://bit.ly/V0nf7C
- Next Generation Science Standards www.nextgenscience.org
- *Scientific and Engineering Practices in K-12 Classrooms: Understanding a Framework for K-12 Science Education* by Rodger W. Bybee: http://bit.ly/UDeO6G

Pre-Engineering Curriculum and Projects

- Engineering is Elementary - This project develops curricular materials in engineering and technology education for children in grades K-5 (www.mos.org).
- Project Lead the Way - Project Lead the Way (PLTW) is a non-profit organization that promotes engineering courses for middle (Gateway to Technology) and high school (Pathway to Engineering) students. (www.pltw.org)
- Materials World Modules - Materials World Modules focus on materials engineering – books, kits and training for middle and high school students. (www.materialsworldmodules.org)
- Salvadori Center - The Salvadori Center focuses on improving children's content understanding and problem-solving skills by using project-based learning that focuses on the built environment. (www.salvadori.org)
- Stuff That Works - Stuff That Works is technology curriculum for the elementary grades. (citytechnology.ccny.cuny.edu)
- Children Designing and Engineering - Produced by the College of New Jersey, Children Designing and Engineering are teacher instructional guides that describe how to adapt activities for different populations, and provide hints for managing design-based learning (www.childrendesigning.org).
- Teachengineering.org - Funded as part of the NSF-supported National Science Digital Library (NSDL) to provide educational resources for STEM (science, technology, engineering and mathematics) education. TeachEngineering.org is a searchable, web-based digital library collection populated with standards-based engineering curricula for use by K-12 teachers and engineering faculty. (www.teachengineering.org)
- Design Squad - Design Squad is a reality-based competition show aimed at kids and people of all ages. Its goal is to get viewers excited about engineering and the design process. The series has free engineering resources you can use in classrooms, after-school programs, and event settings to get middle school kids excited about engineering. (www.designsquad.org)