Standards-based Learning: An Introduction to the Engineering Design Process Using a Paper Drop Competition

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Workshop Outline

1. Design process
2. Design exercise – paper drop competition
3. Link to Illinois standards
4. Hands-on design work
5. The paper drop competition
6. Variations on the competition
7. Summary

The engineering design process follows a logical sequence of actions that can be applied to many problems, regardless of the specific engineering discipline. Whether or not a student is interested in pursuing engineering studies, understanding the engineering design process is useful in many situations that the students will encounter in their careers and lives.

This workshop presents a simple, very low-cost classroom exercise that teachers can use to introduce the basics of the engineering design process to their students. The exercise presents teams of students with a set of standard office supplies (paper, tape, paper clips, index cards, scissors), and the students use these supplies to create flying devices (actually falling devices). The devices are then judged on how long they stay in the air before reaching the ground and how close they come to a target. The exercise develops teamwork skills and allows the students to perform many of the functions found in the engineering design process, including brainstorming, examining alternative designs in terms of functionality and given constraints, prototyping, refining their designs, and evaluating their performance against given criteria and the performance of other teams. The activity for this workshop will be used to demonstrate how lessons can be aligned with standards, in that students are able to demonstrate the achievement of the skill and/or knowledge specified for a given grade level or grade level band by the standard.

After completing this exercise, students will:

- Design and construct a flying device meeting specific constraints.
- Discuss the engineering design process by describing the basic steps in engineering design.
- Describe how they evaluated design trade-offs in the creation of the device.

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Introduction to Engineering

Most people have heard of engineering, but many don't know or understand what engineering is. This chapter examines engineering, what it is, some famous engineers (and some engineers famous outside of engineering), and the problem solving process.

What is Engineering?

Engineering is the art of applying scientific and mathematical principles, experience, judgment, and common sense to make things that benefit people. Engineers design bridges and important medical equipment as well as processes for cleaning up toxic spills and systems for mass transit. In other words, engineering is the process of producing a technical product or system to meet a specific need. (Source: American Society for Engineering Education precollege web site, www.asee.org/precollege/engineering.cfm.)

Many people think of engineering and science as the same thing. There is a difference between the two, but it can be difficult to see. The general objective of science is to discover the composition and behavior of the physical world. In contract, the general objective of engineering is to design useful things. Theodore Von Karman succinctly described this difference: "Scientists discover the world that exists; engineers create the world that never was."

Since "useful things" must obey the laws of nature, engineers study science as part of their preparation to practice engineering. There is some overlap in their practice as well. Some scientists help develop instruments that will be used in scientific study, clearly an engineering role. Conversely, engineers may practice basic science as part of their engineering endeavors. Fields such as semiconductor research involve both engineers and scientists, often working on the same problems.

Engineering is a great profession. There is the fascination of watching a figment of imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it creates homes and jobs, elevates the standard of living and adds to the comforts of life. That is the engineer's high privilege. – Herbert Hoover, 31st president of the United States and mining engineer.

Some famous engineers

Many famous people have been engineers. Below is a list of a few famous engineers and their accomplishments. (Source: ASEE web site, www.asee.org/precollege/famous.cfm.)

- **Edwin Howard Armstrong –** His crowning achievement (1933) was the invention of wide-band frequency modulation, now known as FM radio. Armstrong earned a degree in electrical engineering from Columbia University in 1913.

- **Alexander Graham Bell –** inventor of the telephone. He also worked in medical research and invented techniques for teaching speech to the dear. In 1888 he founded the National Geographic Society.

- **Henry Bessemer –** English inventor and engineer who invented the first process for mass-producing steel inexpensively - essential to the development of skyscrapers.

- **Joseph Armand Bombardier –** manufacturer of the first successful snowmobile.

- **Philip Condit –** CEO, The Boeing Company, mechanical/aeronautical engineering.

- American engineer and inventor **Willis Haviland Carrier** developed the formulae and equipment that made air conditioning possible. Carrier attended Cornell University and graduated with an M.E. in 1901.

- **William D. Coolidge**'s name is inseparably linked with the X-ray tube - popularly called the 'Coolidge tube.' This invention completely revolutionized the generation of X-rays and remains to this day the model upon which all X-ray tubes for medical applications are patterned. Coolidge, born in Hudson, Mass., graduated from the Massachusetts Institute of Technology in 1896, majoring in electrical engineering. At General Electric, he invented ductile tungsten, the filament material still used in lamps, and worked on high-quality magnetic steel, improved ventilating fans and the electric blanket.

- **Seymour Cray –** After a brief service during World War II, he went to the University of Minnesota where he studied engineering. In 1951 he joined Engineering Research Associates, which was developing computers for the Navy. Later he co-founded Control Data Corporation, and in 1972 he founded CRAY Research. Seymour Cray unveiled the CRAY-1 in 1976, considered the first supercomputer.

- **George de Mestral –** attended the Ecole Polytechnique Federale de Lausanne, Switzerland where he graduated as an electrical engineer. In 1955 the "hook and loop fastener" he created was patented under the name Velcro which was derived from two French words: velour and crochet ("velvet" and "hooks").

- Though best known for his invention of the pressure-ignited heat engine that bears his name, the French-born **Rudolf Diesel** was also an eminent thermal engineer.

- **Ray Dolby –** audio system innovator and founder of Dolby Laboratories. His technical expertise has won him both an Academy Award and a Grammy!

- **Bonnie Dunbar –** NASA astronaut who earned her B.S. and M.S. degrees in ceramic engineering from the University of Washington and a doctorate in mechanical/biomedical engineering from the University of Houston. While working at Rockwell International, Dr. Dunbar helped to develop the ceramic tiles that enable space shuttles to survive re-entry. She has had an opportunity to test those tiles first hand as a four-time astronaut, including a stint on the first shuttle mission to dock with the Russian Space Station Mir.

- **Reginald A. (Aubrey) Fessenden –** Canadian-born American physicist and electrical engineer who is known for his early work in wireless communication. He began his research at the University of Pittsburgh; after designing a high-frequency alternator, he broadcast (1906) the first program of speech and music ever transmitted by radio. That same year, he established two-way transatlantic wireless telegraph communication.

Fessenden also invented the heterodyne system of radio reception, the sonic depth finder, the radio compass, submarine signaling devices, the smoke cloud (for tank warfare), and the turboelectric drive (for battleships).

- **Sir Sanford Fleming –** a civil engineer and scientist, played a key role in developing the Canadian railway system and created the worldwide system of standard time.

- **Henry Ford** held many patents on automotive mechanisms but is best remembered for helping devise the factory assembly approach to production that revolutionized the auto industry by greatly reducing the time required to assemble a car. Born in Wayne County, Mich., Ford showed an early interest in mechanics, constructing his first steam engine at the age of 15. In 1891, Ford became an engineer with the Edison Illuminating Company in Detroit. He became Chief Engineer in 1893 and this position allowed him to devote attention to his personal experiments on internal combustion engines. In 1893 he built his first internal combustion engine, a small one-cylinder gasoline model, and in 1896 he built his first automobile. In June 1903, Ford helped establish Ford Motor Company. He served as president of Ford from 1906 to 1919 and from 1943 to 1945.

- **Jay W. Forrester** was a pioneer in early digital computer development and invented random-access, coincident-current magnetic storage, which became the standard memory device for digital computers. He received a B.S. degree in Electrical Engineering in 1939 from the University of Nebraska and a M.S. degree from the Massachusetts Institute of Technology in 1945.

- **Yuan-Cheng Fung –** Fung is widely recognized as the father of biomechanics, having established the fundamentals of biomechanical properties in many of the human body's organs and tissues. He founded the bioengineering program at the University of California, San Diego. In November 2001 he became the first bioengineer to receive the President's National Medal of Science, the nation's highest scientific honor.

- **Robert Hutchings Goddard** pioneered modern rocketry and space flight and founded a whole field of science and engineering. Goddard's interest in rockets began in 1899, when he was 17. He conducted static tests with small solid-fuel rockets at Worcester Tech as early as 1908, and in 1912 he developed the detailed mathematical theory of rocket propulsion. In 1915 he proved that rocket engines could produce thrust in a vacuum and therefore make space flight possible. He succeeded in developing several types of solid-fuel rockets to be fired from handheld or tripod-mounted launching tubes, which were the basis of the bazooka and other powerful rocket weapons of World War II. At the time of his death Goddard held 214 patents in rocketry.

- **Andrew Grove –** co-founder, Intel, chemical engineer.

- **William Hewlett** and **David Packard –** co-founders of Hewlett-Packard.

- **Beulah Louise Henry** was known in the 1920s and 30s as "the lady Edison" for the many inventions she patented, including a vacuum ice cream freezer, a typewriter that made multiple copies without carbon paper, and a bobbinless lockstitch sewing machine.

Henry founded manufacturing companies to produce her creations, making a fortune in the process.

- **Grace Murray Hopper,** a computer engineer and Rear Admiral in the U.S. Navy, developed the first computer compiler in 1952 and the computer program language COBOL. Upon discovering that a moth had jammed the works of an early computer, Hopper popularized the term "bug." In 1983, by special presidential appointment, Hopper was promoted to the rank of Commodore. Two years later, she became one of the first women to be elevated to the rank of Rear Admiral. In 1986, after forty-three years of service, RADM Grace Hopper ceremoniously retired on the deck of the USS Constitution. At 80 years, she was the oldest active duty officer at that time. She spent the remainder of her life as a senior consultant to Digital Equipment Corporation. Hopper received numerous honors over the course of her lifetime. In 1969, the Data Processing Management Association awarded her the first Computer Science Man-of-the-Year Award. She became the first person from the United States and the first woman to be made a Distinguished Fellow of the British Computer Society in 1973. She also received multiple honorary doctorates from universities across the nation. The Navy christened a ship in her honor. In September 1991, she was awarded the National Medal of Technology, the nation's highest honor in engineering and technology.

- **Clarence "Kelly" Johnson –** played a leading role in the design of more than 40 aircraft and set up a Skunk Works-type operation to develop a Lockheed satellite--the Agena-D--that became the nation's workhorse in space. His achievements over almost six decades captured every major aviation design award and the highest civilian honors of the U.S. government and made him an aerospace legend. He was elected to the National Academy of Sciences in 1965, was enshrined in the National Aviation Hall of Fame in 1974, and was awarded the Medal of Freedom in 1964 by President Lyndon Johnson recognizing, his "significant contributions to the quality of American life."

- **Bill Joy –** co-founder of Sun Microsystems, electrical engineer. He received a B.S.E.E. in electrical engineering from the University of Michigan in 1975, after which he attended graduate school at U.C. Berkeley where he was the principal designer of Berkeley UNIX (BSD) and received a M.S. in electrical engineering and computer science. The Berkeley version of UNIX became the standard in education and research, garnering development support from DARPA, and was notable for introducing virtual memory and Internet working using TCP/IP to UNIX. In 1997, Joy was appointed by President Clinton as co-chairman of the Presidential Information Technology Advisory Committee.

- **Jack Kilby –** inventor of the integrated circuit. Kilby received a B.S.E.E. degree from the University of Illinois in 1947 and an M.S.E.E. from the University of Wisconsin in 1950. In 2000, he received the Nobel Prize in Physics for his work with the integrated circuit.

- **William LeMessurier –** structural designer of the Citicorp building, structural engineer.

- **Elijah McCoy** was a Black inventor who was awarded over 57 patents. The son of runaway slaves from Kentucky, he was born in Canada and lived there as a youth. Educated in Scotland as a mechanical engineer he returned to Detroit and in 1872 invented a lubricator for steam engines. His new oiling device revolutionized the industrial machine industry by allowing machines to remain in motion while being oiled. This device, although imitated by other designers, was so successful that people inspecting new equipment would ask if it contained the real McCoy.

- **Guglielmo Marconi –** The "Father of Radio" - Marconi received many honors including the Nobel Prize for Physics in 1909.

- **James Morgan –** CEO, Applied Materials, mechanical engineer. In 1996 he received the National Medal of Technology for his industry leadership and for his vision in building Applied Materials into the world's leading semiconductor equipment company, a major exporter and a global technology pioneer which helps enable the Information Age.

- **Bill Nye –** worked for Boeing before he became the "science guy", Mechanical engineering degree from Cornell University.

- **Kevin Olmstead –** world-record game show payoff winner – $2,180,000 winner, "Who Wants to be a Millionaire?" – and environmental engineer. After acquiring chemical engineering degrees from Case Western Reserve University and the Massachusetts Institute of Technology, Olmstead earned a doctorate degree in environmental engineering from the University of Michigan. He also taught civil and environmental engineering and is currently a senior project engineer with Tetra Tech MPS, an international consulting firm specializing in infrastructure and communications systems.

- **Kenneth Olsen –** inventor of magnetic core memory, co-founder, Digital Equipment Corporation. After serving in the Navy between 1944 and 1946, he attended the Massachusetts Institute of Technology, where he earned a B.S. (1950) and an M.A. (1952) in electrical engineering.

- **Arati Prabhakar –** director, National Institute of Standards and Technology (NIST), U.S. Department of Commerce. Prabhakar was appointed the 10th NIST Director in May 1993. NIST promotes U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. Previously, Prabhakar served as director of the Microelectronics Technology Office in the Defense Department's Advanced Research Projects Agency (ARPA). She holds the distinction of being the first woman with a doctorate from the California Institute of Technology, and was also the youngest director of the institute.

- **Ludwig Prandtl –** the father of fluid mechanics, mechanical engineer.

- **Edmund T. Pratt, Jr. –** former CEO of Pfizer, Inc., electrical engineer.

- **Judith Resnik –** Challenger astronaut, electrical engineer. Received a Bachelor of Science degree in electrical engineering from Carnegie-Mellon University in 1970 and a doctorate in electrical engineering from the University of Maryland in 1977.

- **Hyman G. Rickover –** the "Father of the Nuclear Navy" he led the development of the Navy nuclear submarine fleet. Masters in electrical engineering from Columbia

University. During World War II, he headed the electrical section of the Navy's Bureau of Ships, and in 1946 was enlisted into the U.S. atomic program. The next year he returned to the Navy to manage its nuclear-propulsion program. Regarded as a fanatic by his detractors, he completed the world's first nuclear submarine--the USS Nautilus--ahead of schedule in 1955. While continuing his work with the Navy, he helped build the first major civilian nuclear power plant at Shippingport, PA. Always an outspoken advocate of U.S. nuclear supremacy, he was promoted to the rank of vice admiral in 1959 and admiral in 1973. He retired from the Navy in 1982 after serving as an officer for a record 63 years. Throughout his long naval career his decorations included the Distinguished Service Medal, Legion of Merit, Navy Commendation Medal, two Congressional Gold Medals, as well as the title of Honorary Commander of the Military Division of the Most Excellent Order of the British Empire. In 1980, President Jimmy Carter presented him the Presidential Medal of Freedom, the nation's highest non-military honor.

- **Norbert Rillieux –** revolutionized in the sugar industry by inventing a refining process that reduced the time, cost, and safety risk involved in producing sugar from cane and beets. His inventions protected lives by ending the older dangerous methods of sugar production. As the son of a French planter/inventor and a slave mother, Norbert Rillieux was born in New Orleans, LA. He was educated at the L'Ecole Central in Paris, France in 1830, were he studied evaporating engineering and served as an educator.

- **Washington Roebling –** completed the Brooklyn Bridge which was started by his father, civil engineer.

- **Katherine Stinson –** the first female graduate of NC State University's College of Engineering. Initially denied admission as a freshman, Stinson went on to become one of NC State's most distinguished and active alumni. Graduating vice president of her class, she was soon hired by the Civil Aeronautics Administration as its first female engineer. Later, she served as technical assistant chief in its Engineering and Manufacturing Division until her retirement in 1973. She went on to found the Society of Women Engineers.

- **Nikola Tesla –** invented the induction motor with rotating magnetic field that made unit drives for machines feasible and made AC power transmission an economic necessity.

- **Stephen Timoshenko –** the father of engineering mechanics, engineering scientist.

- **Theodore von Karman –** Dr. von Karman was one of the world's foremost aerodynamicsts and scientists and is widely recognized as the father of modern aerospace science. He was a professor of aeronautics at the California Institute of Technology and was one of the principal founders of NASA's Jet Propulsion Laboratory, Pasadena, California.

- **George Westinghouse –** invented a system of air brakes that made travel by train safe and built one of the greatest electric manufacturing organizations in the United States. In 1886, he founded the Westinghouse Electric Company, foreseeing the possibilities of alternating current as opposed to direct current, which was limited to a radius of two or three miles. Westinghouse enlisted the services of Nikola Tesla and other inventors in the development of alternating current motors and apparatus for the transmission of high-tension current, pioneering large-scale municipal lighting.

- American inventor, pioneer, mechanical engineer, and manufacturer **Eli Whitney** is best remembered as the inventor of the cotton gin. He also affected the industrial development of the United States when, in manufacturing muskets for the government, he translated the concept of interchangeable parts into a manufacturing system, giving birth to the American mass-production concept.

- **Steve Wozniak** cofounded Apple Computer, Inc. in 1976 with the Apple I computer. Wozniak's Apple II personal computer - introduced in 1977 and featuring a central processing unit (CPU), keyboard, floppy disk drive, and a $1,300 price tag - helped launch the PC industry. In 1980, just a little more than four years after being founded, Apple went public. Wozniak left Apple in 1981 and went back to Berkeley and finished his degree in electrical engineering/computer science. Since then, he has been involved in various business and philanthropic ventures, focusing primarily on computer capabilities in schools, including an initiative in 1990 to place computers in schools in the former Soviet Union.

Some engineers famous outside of engineering

As with any college major, some people that major in engineering end up working in fields not directly related to their college majors. Below is a list of some people with engineering backgrounds that are famous for non-engineering achievements. (Source: ASEE web site, www.asee.org/precollege/famous.cfm.)

- **Yasser Arafat** - Palestinian leader and Nobel Peace Prize Laureate. Graduated as a civil engineer from the University of Cairo.

- **Neil Alden Armstrong -** became the first man to walk on the moon on July 20, 1969, at 10:56 p.m. EDT. He and "Buzz" Aldren spent about two and one-half hours walking on the moon, while pilot Michael Collins waited above in the Apollo 11 command module. Armstrong received his B.S. in aeronautical engineering from Purdue University and an M.S. in aerospace engineering from the University of Southern California.

- **Rowan Atkinson -** A British comedian, best known for his starring roles in the television series "Blackadder" and "Mr. Bean," and several films including Four Weddings and a Funeral. Atkinson attended first Manchester then Oxford University on an electrical engineering degree.

- **Leonid Brezhnev** - leader of the former Soviet Union, metallurgical engineer.

- **Alexander Calder -** a native of Pennsylvania, received his degree in mechanical engineering from Stevens Institute of Technology, Hoboken, New Jersey, and shortly thereafter moved to Paris, where he studied art and began to create his now-famous mobiles. Many of his large sculptures are on permanent outdoor display at the

Massachusetts Institute of Technology, where the first major retrospective of his work was held in 1950.

- **Frank Capra** - film director - "It Happened One Night", "Mr. Smith Goes to Washington", "It's a Wonderful Life" - college degree in chemical engineering.

- **Jimmy Carter -** 39th President of the United States. Attended Georgia Southwestern College and the Georgia Institute of Technology and received a B.S. degree from the United States Naval Academy in 1946. In the Navy he became a submariner, serving in both the Atlantic and Pacific fleets and rising to the rank of lieutenant. Chosen by Admiral Hyman Rickover for the nuclear submarine program, he was assigned to Schenectady, N.Y., where he took graduate work at Union College in reactor technology and nuclear physics and served as senior officer of the pre-commissioning crew of the Seawolf.

- **Roger Corman -**film director, industrial engineering degree from Stanford University. He started direct involvement in films in 1953 as a producer and screenwriter, making his debut as director in 1955. Between then and his official retirement in 1971 he directed dozens of films, often as many as six or seven per year, typically shot extremely quickly on leftover sets from other, larger productions. His probably unbeatable record for a professional 35mm feature film was two days and a night to shoot the original version of "The Little Shop of Horrors".

- **Leonardo Da Vinci -** Florentine artist, one of the great masters of the High Renaissance, celebrated as a painter, sculptor, architect, engineer, and scientist. His profound love of knowledge and research was the keynote of both his artistic and scientific endeavors. His innovations in the field of painting influenced the course of Italian art for more than a century after his death, and his scientific studies - particularly in the fields of anatomy, optics, and hydraulics - anticipated many of the developments of modern science.

- **Thomas Edison** - Edison patented 1,093 inventions in his lifetime, earning him the nickname "The Wizard of Menlo Park." The most famous of his inventions was an incandescent light bulb. Besides the light bulb, Edison developed the phonograph and the kinetoscope, a small box for viewing moving films. He also improved upon the original design of the stock ticker, the telegraph, and Alexander Graham Bell's telephone. Edison was quoted as saying, "Genius is one percent inspiration and 99 percent perspiration."

- **Lillian Gilbreth** - is considered a pioneer in the field of time-and-motion studies, showing companies how to increase efficiency and production through budgeting of time, energy, and money. Dr. Gilbreth received her Ph.D. in psychology from Brown University and was a professor at Purdue's School of Mechanical Engineering, Newark School of Engineering and the University of Wisconsin. She is "Member No. 1" of the Society of Women Engineers. She and her husband used their industrial engineering skills to run their household, and those efforts are the subject of the book and family film "Cheaper by the Dozen."

- **Roberto C. Goizueta** - former chairman and chief executive of Coca-Cola. Chemical engineering degree from Yale University.

- **Herbie Hancock** - jazz musician.

- **Alfred Hitchcock -** British-born American director and producer of many brilliantly contrived films, most of them psychological thrillers including "Psycho", "The Birds", "Rear Window", and "North by Northwest." He was born in London and trained there as an engineer at Saint Ignatius College. Although Hitchcock never won an Academy Award for his direction, he received the Irving Thalberg Award of the Academy of Motion Picture Arts and Sciences in 1967 and the American Film Institute's Life Achievement Award in 1979. During the final year of his life, he was knighted by Queen Elizabeth II, even though he had long been a naturalized citizen of the United States.

- **Herbert Hoover** - having graduated from Stanford University in California, Hoover was a 26 -year-old mining engineer in Tientsin, China, when the city was attacked by 5,000 Chinese troops and 25,000 members of the martial arts group known as the Boxers. (The Boxer Rebellion was a violent 1900 uprising against foreign business interests in China.) Hoover took charge of setting up barricades to protect Tientsin until its rescue after 28 days of bombardment. Thirty years later, Herbert Hoover became the 31st President of the United States; he and his wife continued to speak Chinese when they wanted privacy in the White House.

- **Lee Iacocca** - former chairman and CEO of Chrysler Corp. Iacocca graduated from Lehigh University, Bethlehem, Pa., in 1945 and received a master's degree in engineering from Princeton University in 1946. Best known for his helmsmanship at Chrysler Motors, Iacocca started out as a sales manager at the Ford Motor Co. in 1946 and by 1970 was president of the company. Joining Chrysler in 1978, Iacocca helped drag the troubled company from the brink of extinction by helping secure $1.5 billion in government loans. Iacocca's legendary status in the automobile industry is reinforced by his role in the introduction of that American icon: the Ford Mustang. He was also one of the first CEOs to proselytise his company's products on national television with the K car campaign.

- **Bill Koch** - yachtsman and winning America's Cup captain in 1992, as well as the chairman of the America3 Foundation.

- **Tom Landry -** former Dallas Cowboys coach.

- **Hedy Lamarr** - a famous 1940s actress not formally trained as an engineer, Lamarr is credited with several sophisticated inventions, among them a unique anti-jamming device for use against Nazi radar. Years after her patent had expired, Sylvania adapted the design for a device that today speeds satellite communications around the world. She is also credited with the line: "Any girl can be glamorous. All you have to do is stand still and look stupid."

- **Jair Lynch -** 1992 and 1996 Olympic gymnast. Civil Engineering degree from Stanford University.

- **Arthur Nielsen -** developer of Nielsen rating system.
- **Tom Scholtz** - leader of the rock band Boston. Master's degree from MIT in mechanical engineering.
- **John Sununu** - former White House Chief of Staff for President George Bush, former governor of New Hampshire, current CNN commentator on "**Crossfire**."
- **Boris Yeltsin -** former president of Russia.
- **John F. Welch, Jr**. - received his engineering undergraduate degree in his home-state at the University of Massachusetts. After he earned his Ph.D. in chemical engineering from the University of Illinois, he accepted a job offer from General Electric. The rest is history -- he became chairman and CEO of General Electric in 1981.
- **Montel Williams** - a highly decorated former Naval engineer and Naval Intelligence Officer, he is now an author of inspirational books and host of a popular syndicated television talk show.

Be the Engineer – Paper Drop Design

In this exercise, you will play the role of the engineer. You are given a goal and must design a solution to achieve that goal.

Learning Objectives

After completing this exercise, students will:

- Design and construct a flying device meeting specific constraints.
- Discuss the engineering design process by describing the basic steps in engineering design.
- Describe how they evaluated design trade-offs in the creation of the device.

Design Specification

Each team is required to design and construct a “flying” device. There are two design criteria for this device.

1. The device must stay in the air as long as possible.
2. The device must land as close as possible to a given target.

Each team must construct their device using any or all of the following materials.

- Three sheets of 8½" x 11" paper

- Adhesive tape
- One 3" x 5" index card
- Four paper clips
- A pair of scissors

Scoring

The competition can be held anywhere that a paper can be dropped from at least several feet in height. This could be an alcove with an opening to a lower floor or simply someone standing on a chair in a classroom. One member of each team will go to the takeoff point and launches the device toward a target on the floor. The time will be recorded from when the device is launched until it hits the ground. Then the distance will be measured from the device to the target. Each team will perform three drop runs; the times and distances will be totaled for each team.

The scoring for this competition emphasizes flight time over accuracy. The length of time before reaching the ground comprises 70% of the overall score, and the distance from the target accounts for the other 30% of the score. The scores are scaled by the slowest and fastest times or closest and farthest distances. The formula for calculating the time portion of the score, a maximum of 70 points, is as follows.

$$\text{Time score} = \frac{(\text{Your team's time - Shortest team's time})}{(\text{Longest team's time - Shortest team's time})} \times 70$$

To illustrate how this works, consider three teams with total times of 4, 8, and 11 seconds. The formula becomes

$$\text{Time score} = \frac{(\text{Your team's time - 4 seconds})}{(\text{11 seconds - 4 seconds})} \times 70$$

For the three teams, this is

$$\text{Time score} = \frac{(\text{4 seconds - 4 seconds})}{(\text{11 seconds - 4 seconds})} \times 70 = 0 \text{ points}$$

$$\text{Time score} = \frac{(\text{8 seconds - 4 seconds})}{(\text{11 seconds - 4 seconds})} \times 70 = 40 \text{ points}$$

$$\text{Time score} = \frac{(\text{11 seconds - 4 seconds})}{(\text{11 seconds - 4 seconds})} \times 70 = 70 \text{ points}$$

The longest time always earns 70 points and the shortest time receives no points. Other times earn varying numbers of points; the closer they are to the maximum time, the greater the number of points they earn.

The distance scores are calculated in a similar manner using the following formula.

$$\text{Distance score} = \frac{(\text{Longest team's distance} - \text{Your team's distance})}{(\text{Longest team's distance} - \text{Shortest team's distance})} \times 30$$

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Appendix A – Engineering Design and Problem Solving

Problem solving process

Engineers solve problems. To do this, they perform some sequence of actions collectively referred to as the *problem solving process*. The actual steps in the process may vary, depending on the problem, and two people may have different steps in their problem solving processes. Here is a general set of steps in a problem solving process that is applicable to any problem.

1. *Determine the problem to be solved.*

This isn't always as simple as it sounds. It is often difficult to distinguish between a problem and one of its symptoms. A solution that corrects the symptom, but not the underlying problem, may not be satisfactory in the long run.

2. *Determine possible solutions*

One good way to do this is called *brainstorming*. People trying to solve a problem meet and suggest possible solutions. Some solutions may be straightforward, while others are completely off-the-wall, but all solutions are recorded without criticism.

3. *Evaluate possible solutions*

Next, evaluate all possible solutions and determine one (or a few) solutions to pursue. Typically, you must consider several factors when evaluating solutions, such as cost, functions, and manufacturability. The relative importance of these factors may lead you to choose one solution over another. For example, a great product that costs too much won't succeed. Similarly, an inexpensive product that doesn't do much might not succeed either.

4. *Design the solution*

Once you've decided how to solve a problem, the next step is to design the actual solution. This might be an electric circuit, or a mechanical device, or a computer program.

5. *Test, revise, test*

After building your proposed solution, you must test it to ensure that it works properly. It may be necessary to modify your design if it does not work properly. Several revisions may be needed to achieve an acceptable design.

Case Study – Getting Kids Interested in Bowling

The bowling industry had a problem. Participation in bowling was declining nationwide, and bowling alleys were closing at an alarming rate. Just as important, children weren't interested in bowling. Their bowling balls always rolled into the gutter and they found bowling to be boring.

Children preferred other sports, and bowling was losing its next generation of participants. Children that didn't bowl would grow up to become adults that didn't bowl.

The bowling industry decided that children's lack of interest in bowling, rather than overall declining participation, was their greatest problem. Further, they determined that the boredom caused by rolling gutter balls repeatedly was a major contributor to this problem. They reasoned that getting rid of gutter balls would make bowling more interesting to children, and that they would like bowling more.

The bowling industry developed several different solutions. Lanes could be redesigned to remove gutters altogether. Gutters could be retrofitted with mechanical devices that pop up on demand to block the edges of the gutters. Here we'll examine a different solution: gutter bumpers.

Figure A.1: Gutter bumpers

As shown in Figure A.1, a gutter bumper is essentially a long, large balloon that lies in the gutter of a bowling lane. Children roll bowling balls very slowly, so slow in fact that such a ball would bounce off the gutter bumper and stay in the land, ultimately knocking down some pins. These might not work for adult bowlers, whose faster shots might roll over the gutter bumper on to the next land, but they weren't designed for adults.

Gutter bumpers offer several advantages over other designs.

- They are relatively easy to manufacture. They use materials already used for other products. The manufacturing consists of cutting the material, sealing the edges, and adding an air valve.
- They are easy to ship to bowling alleys (deflated!).
- Once at the alleys, they can be set up simply by inflating the bumpers. A standard air pump is the only "tool" needed.

- Since the bumpers are just placed in the gutters to set up the lane, the lanes do not have to be modified in any way. It is easy to convert lanes for use by children or adults.

For this problem, a relatively low-tech solution is one of the best ways to achieve the desired result.

Case Study – Wright Brothers

We look back now, and it's so obvious that December 17, 1903, was the date flight happened. It wasn't so obvious back then. The Wrights were just two people, really, among a large number of tinkerers, scientists, and adventurers around the world who were fascinated by the problem of flight. At the time, the brothers' claim that they had flown 852 feet in 59 seconds that chilly day at Kitty Hawk was merely one of many reported attempts to fly.

The fierce rivalry to be first in the air included far more prominent, better funded men than the Wright brothers, bachelors who owned a bicycle shop in Dayton, Ohio, and lived with their father. Alexander Graham Bell (not satisfied with having invented the telephone) promoted his tetrahedral-cell kites as "possessing automatic stability in the air." Newspapers followed Brazilian Alberto Santos-Dumont as he steered gas-powered airships over Paris beginning in 1898. (Source: James Tobin, *To Conquer the Air: The Wright Brothers and the Great Race for Flight.)*

One of the reasons the Wright brothers succeeded where others failed was their approach to solving the problem of achieving powered flight. Others concentrated on designing a light and powerful engine, all but ignoring the intricacies of the frame design. The Wright brothers, on the other hand, defined the problem as one of balance and steering foremost. They experimented with gliders to resolve these problems first, and then turned their attention to the engine needed to propel the airplane.

The Wright brother spent four summers in North Carolina working on their designs. Winters were spent at home in Dayton refining designs and manufacturing parts.

To get ideas for the design of their aircraft, the brothers initially spent time watching birds in flight, mainly gulls, eagles, hawks, and buzzards. They determined that it was the birds' skill, more than the shape of the wing, that enabled them to achieve prolonged flight. Nevertheless, they needed functional wings for their design.

The brothers designed several wings and tested them as kites. Testing refining, and retesting their designs, they optimized the wing designs. They then used the wings to build a glider, which they also tested as a kite.

Once satisfied with the design of their glider, they experimented with unpowered, manned flight. This led to their development of the controls needed to keep the glider level, as well as wing elevators and a movable tail. They achieved prolonged glides of over 600 feet as they validated their frame design.

Their long glides had grown out of their aptitude for learning how to do a difficult thing. It was a simple method but rare. They broke a job into its parts and proceeded one part at a time. They practiced each small task until they mastered it, then moved on. The best example was their habit of staying very close to the ground in their glides, sometimes just inches off the sand. "While the high flights were more spectacular, the low ones were fully as valuable for training purposes," Wilbur said. "Skill comes by the constant repetition of familiar feats rather *than by a few overbold attempts at feats for which the performer is yet poorly prepared." They were conservative daredevils, cautious prophets. "A thousand glides is equivalent to about four hours of steady practice," Wilbur said, "far too little to give anyone a complete mastery of the art of flying.*

The brothers next had to design their own engine and propellers. The propeller design was quite difficult, and the brothers had to develop new theories on propeller design; previous design work was geared toward the propellers used for boats. As with all their endeavors, their methodical approach and hard work led to their ultimate success.

Appendix B – Engineering Accomplishments

In February 2000, the National Academy of Engineering unveiled its list of the *20 Greatest Engineering Achievements of the 20^{th} Century*. The list was announced by astronaut/engineer Neil Armstrong at a National Press Club luncheon held during National Engineers Week. The primary selection criterion was the impact of the engineering achievement on the quality of life in the 20^{th} century. William A. Wulf, president of the National Academy of Engineering, summed it up as follows.

Engineering is all around us, so people often take it for granted, like air and water. Ask yourself, what do I touch that is not engineered? Engineering develops and delivers consumer goods, builds the networks of highways, air and rail travel, and the Internet, mass produces antibiotics, creates artificial heart valves, builds lasers, and offers such wonders an imaging technology and conveniences like microwave ovens and compact discs. In short, engineers make our quality of life possible.

Worksheet B.1 – Greatest Engineering Achievements

Below is a list of the 20 greatest engineering achievements of the 20th century; the achievements are listed alphabetically, not in rank order. Select the ten that you consider to be the greatest of the great. Do not order your selections.

1. Agricultural Mechanization
2. Air Conditioning and Refrigeration
3. Airplane
4. Automobile
5. Computers
6. Electrification
7. Electronics
8. Health Technologies
9. High Performance Materials
10. Household Appliances
11. Imaging Technologies
12. Internet
13. Interstate Highways
14. Laser and Fiber Optics
15. Nuclear Technologies
16. Petroleum and Gas Technologies
17. Radio and Television
18. Safe and Abundant Water
19. Space Exploration
20. Telephone

Worksheet B.2 – Ranked Greatest Engineering Achievements

List the top ten engineering achievements, as given by your instructor, from 1 (most important) to 10.

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____

The Complete, Ordered List

Here is the complete, ordered list of *The 20 Greatest Engineering Achievements of the 20th Century*, including brief descriptions of the achievements. (*Source: ASEE precollege web site, www.asee.org/precollege/engineering.cfm; also available at www.greatachievements.org*.)

#20 - High Performance Materials

From the building blocks of iron and steel to the latest advances in polymers, ceramics, and composites, the 20th century has seen a revolution in materials. Engineers have tailored and enhanced material properties for uses in thousands of applications.

#19 - Nuclear Technologies

The harnessing of the atom changed the nature of war forever and astounded the world with its awesome power. Nuclear technologies also gave us a new source of electric power and new capabilities in medical research and imaging.

#18 - Laser and Fiber Optics

Pulses of light from lasers are used in industrial tools, surgical devices, satellites, and other products. In communications, highly pure glass fibers now provide the infrastructure to carry information via laser-produced light, a revolutionary technical achievement. Today, a single fiber-optic cable can transmit tens of millions of phone calls, data files, and video images.

#17 - Petroleum and Gas Technologies

Petroleum has been a critical component of 20th century life, providing fuel for cars, homes, and industries. Petrochemicals are used in products ranging from aspirin to zippers. Spurred on by engineering advances in oil exploration and processing, petroleum products have had an enormous impact on world economies, people, and politics.

#16 - Health Technologies

Advances in 20th century medical technology have been astounding. Medical professionals now have an arsenal of diagnostic and treatment equipment at their disposal. Artificial organs, replacement joints, imaging technologies, and bio-materials are but a few of the engineered products that improve the quality of life for millions.

#15 - Household Appliances

Engineering innovation produced a wide variety of devices, including electric ranges, vacuum cleaners, dishwashers, and dryers. These and other products give us more free time, enable more people to work outside the home, and contribute significantly to our economy.

#14 - Imaging Technologies

From tiny atoms to distant galaxies, imaging technologies have expanded the reach of our vision. Probing the human body, mapping ocean floors, tracking weather patterns, all are the result of engineering advances in imaging technologies.

#13 - Internet

The Internet is changing business practices, educational pursuits, and personal communications. By providing global access to news, commerce, and vast stores of information, the Internet brings people together globally while adding convenience and efficiency to our lives.

#12 - Space Exploration

From early test rockets to sophisticated satellites, the human expansion into space is perhaps the most amazing engineering feat of the 20th century. The development of spacecraft has thrilled the world, expanded our knowledge base, and improved our capabilities. Thousands of useful products and services have resulted from the space program, including medical devices, improved weather forecasting, and wireless communications.

#11 - Interstate Highways

Highways provide one of our most cherished assets - the freedom of personal mobility. Thousands of engineers built the roads, bridges, and tunnels that connect our communities, enable goods and services to reach remote areas, encourage growth, and facilitate commerce.

#10 - Air Conditioning and Refrigeration

Air conditioning and refrigeration changed life immensely in the 20th century. Dozens of engineering innovations made it possible to transport and store fresh foods, for people to live and work comfortably in sweltering climates, and to create stable environments for the sensitive components that underlie today's information-technology economy.

#9 - Telephone

The telephone is a cornerstone of modern life. Nearly instant connections - between friends, families, businesses, and nations - enable communications that enhance our lives, industries, and economies. With remarkable innovations, engineers have brought us from copper wire to fiber optics, from switchboards to satellites, and from party lines to the Internet.

#8 - Computers

The computer has transformed businesses and lives around the world by increasing productivity and opening access to vast amounts of knowledge. Computers have relieved the drudgery of routine daily tasks, and brought new ways to handle complex ones. Engineering ingenuity fueled this revolution, and continues to make computers faster, more powerful, and more affordable.

#7 - Agricultural Mechanization

The machinery of farms - tractors, cultivators, combines, and hundreds of others - dramatically increased farm efficiency and productivity in the 20th century. At the start of the century, four U.S. farmers could feed about ten people. By the end, with the help of engineering innovation, a single farmer could feed more than 100 people.

#6 - Radio and Television

Radio and television were major agents of social change in the 20th century, opening windows to other lives, to remote areas of the world, and to history in the making. From wireless telegraph to today's advanced satellite systems, engineers have developed remarkable technologies that inform and entertain millions every day.

#5 - Electronics

Electronics provide the basis for countless innovations - CD players, TVs, and computers, to name a few. From vacuum tubes to transistors, to integrated circuits, engineers have made electronics smaller, more powerful, and more efficient, paving the way for products that have improved the quality and convenience of modern life.

#4 - Safe and Abundant Water

The availability of safe and abundant water literally changed the way Americans lived and died during the last century. In the early 1900s, waterborne diseases like typhoid fever and cholera killed tens-of-thousands of people annually, and dysentery and diarrhea, the most common waterborne diseases, were the third largest cause of death. By the 1940s, however, water treatment and distribution systems devised by engineers had almost totally eliminated these diseases in American and other developed nations. They also brought water to vast tracts of land that would otherwise have been uninhabitable.

#3 - Airplane

Modern air travel transports goods and people quickly around the globe, facilitating our personal, cultural, and commercial interaction. Engineering innovation - from the Wright brothers' airplane to today's supersonic jets - has made it all possible.

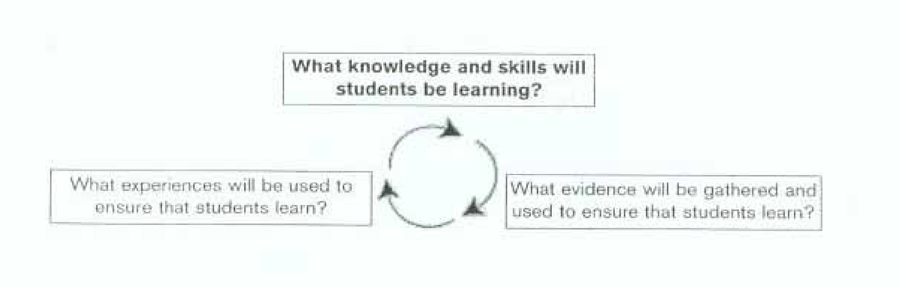
#2 - Automobile

The automobile may be the ultimate symbol of personal freedom. It's also the world's major transporter of people and goods, and a strong source of economic growth and stability. From early Tin Lizzies to today's sleek sedans, the automobile is a showcase of 20th century engineering ingenuity, with countless innovations made in design, production, and safety.

#1 - Electrification

Electrification powers almost every pursuit and enterprise in modern society. It has literally lighted the world and impacted countless areas of daily life, including food production and processing, air conditioning and heating, refrigeration, entertainment, transportation, communication, health care, and computers. Thousands of engineers made it happen, with innovative work in fuel sources, power generating techniques, and transmission grids.

Appendix C – Alignment with Illinois Content Standards



This activity can be linked to Illinois science standard 11.B. The alignment is defined by student learning objectives for the appropriate grade levels, as follows:

EARLY ELEMENTARY: 11.B.1b. Design a device that will be useful in solving the problem.
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.

LATE ELEMENTARY: 11.B.2b. Develop a plan, design and procedure to address the problem identifying constraints (e.g., time, materials, technology).
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.
2. After completing this exercise, students will discuss the engineering design process by describing the basic steps in engineering design for this device.

MIDDLE/JUNIOR HIGH SCHOOL: 11.B.3b. Sketch, propose and compare design solutions to the problem considering available materials, tools, cost effectiveness and safety.
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.
2. After completing this exercise, students will discuss the engineering design process by describing the basic steps in engineering design for this device.

EARLY HIGH SCHOOL: 11.B.4b. Propose and compare different solution designs to the design problem based upon given constraints including available tools, materials and time.
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.
2. After completing this exercise, students will discuss the engineering design process by describing the basic steps in engineering design for this device.
3. After completing this exercise, students will describe how he/she/they evaluated design trade-offs in the creation of the device.

LATE HIGH SCHOOL: 11.B.5b. Select criteria for a successful design solution to the identified problem.
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.
2. After completing this exercise, students will discuss the engineering design process by describing the basic steps in engineering design for this device.
3. After completing this exercise, students will describe how he/she/they evaluated design trade-offs in the creation of the device.

STUDENT PERFORMANCE DESCRIPTORS

Statements of Assessment that show whether the students have achieved the skills and knowledge defined by the Learning Objectives and the grade appropriate Standard(s).

Learning Objective
1. After completing this exercise, students will design and construct a flying device meeting specific constraints.

Assessment Statements
Students will sketch the flying device, meeting the specified constraints.

Students will construct their flying device from the sketch and make modifications to achieve the requirements that it stays in the air as long as possible and lands as close to a given target as possible.

Learning Objective
2. After completing this exercise, students will discuss the engineering design process by describing the basic steps in engineering design for this device.

Assessment Statement
Students will write a report (and/or make an oral presentation) describing the steps of the engineering design process that were followed in the construction of the flying device.

Learning Objective
3. After completing this exercise, students will describe how he/she/they evaluated design trade-offs in the creation of the device.

Assessment Statements
Students will report on the modifications made in the design of their flying device to assure achievement that it stays in the air as long as possible and lands as close to a given target as possible. They will also write on their design the reasons for the modification and the result of the modification.