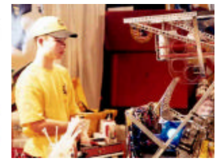
ASME International

Best Practices In **High School Engineering**



Honorable Mention

National Engineer's Week

Future Engineers Program at Upper Merion

Jeff Bugenhagen - Upper Merion Area High School

Introduction:

Each year, ninth through twelfth grade students enrolled in physics or integrated science classes participate in a full week of problem solving activities in recognition of National Engineer's Week. The week emphasizes the importance of problem solving skills in all fields through hands-on collaborative activities. Each activity highlights a specific aspect of engineering and provides students an opportunity to practice, improve, and discuss these skills. Activities and themes are summarized in the table below. Engineers from local industry are invited to support the program.

Day	Activity	Learning Objective
Day 1	Propulsion Challenge – design a propulsion system with limited materials.	Appreciate engineering as designing solutions to specific problems
Day 2	Buoyancy Challenge – design a neutrally buoyant helium balloon which will be tested in different environments.	Recognize the importance of engineering in a changing environment. Test product performance in different environments.
Day 3	Company Challenge –create a company which will successfully design, build, and inspect a product.	Participate in engineering as a process, including design, manufacturing, and quality assurance steps. Practice writing effective procedures.
Day 4	The Great Gumball Gunkulator – create a room-sized "mousetrap" machine to transport a marble through 9 areas of the room.	Demonstrate that complex systems require collaboration and effective communication skills.
Day 5	Guest Speakers Forum – meet & talk with working engineers.	Learn about the many disciplines of engineering as potential career paths.

Future Engineers Program at Upper Merion Area High School:

National Engineer's Week is recognized within our high school as an opportunity for students to practice collaborative problem solving and develop an appreciation for the field of engineering. This program is designed to make our students better problem solvers, and to help them appreciate the importance of problem solving in the world around us. Our primary focus is to make students aware of their own problem solving skills, and to provide experiences to help them improve those skills. Throughout the week, classes are grouped together across academic levels. The teachers work collaboratively to present problems, facilitate problem solving, and discuss the outcomes with students.

The success of our engineering week program depends upon planning, advertising, and community involvement. The week is publicized to increase awareness and generate enthusiasm. At the beginning of the week, students are "hired" as employees to Upper Merion Engineering Associates, and each receives a business card (or badge) with a name, division, and job title (type of engineer). The business cards are used throughout the week to organize student groups quickly and randomly.

Each activity begins with a summary of the problem, and instructions (or rules) for the solution. The activities take from 20 to 35 minutes, leaving 5-10 minutes at the end for a group discussion. The challenges become progressively more difficult. Engineers from local industry (Lockheed Martin Aerospace, Philadelphia Water Department, TiMet Corporation) are invited to participate in the challenges throughout the week. On the final day, our guest engineers share insights about their own roles as problem solvers. They easily connect the week's activities to real-world examples. Through the week, students practice problem solving and develop an appreciation for the role of engineers in industry. Each day's activity helps students appreciate a different aspect of engineering. This thematic approach has been very successful in motivating students to consider pursuing an engineering or technical degree after high school.

Day 1 - Engineers as designers

The first day's challenge allows students to create a design, manipulate materials, and test their design. The activity helps students identify the skills that an engineer (or any problem solver) uses when solving a problem. These include creativity, communication, resourcefulness, manipulation, experimentation, feedback analysis, cooperation, estimation, and prediction.

Day 2 - Engineers must consider the environment

The second challenge emphasizes the importance of feedback during the design process, and the importance of understanding the entire problem. Students become frustrated when their designs behave differently when the environment changes. This activity demonstrates how design without context can be ineffective. The best design, when used in the wrong way, may fail.

Day 3 - Engineering is a process with several important steps

By the third day, students are accustomed to the routine of the challenges. Students are enthusiastic about the company simulation because they compete as a team against the clock. In the process of designing, manufacturing, and testing a product in different locations (different classrooms) they develop an appreciation for the separation of tasks within industry, and for the communication issues which result from this separation. This activity helps students develop a direct appreciation for the importance of clear written procedures and instructions; the tendency to blame others when problems occur; the time delays in the manufacturing process; the inspection and product failure process; the time and money wasted when products fail.

Day 4 - Engineering of complex systems requires the collaboration of many sub-groups, and the use of effective communication skills.

The final challenge allows the entire group to work together as one team. Each subgroup is responsible for a part of the whole solution. Although the task seems difficult at first, students generally rise to the challenge and demonstrate outstanding teamwork and enthusiasm. The problems they encounter through this process are representative of the problems a design team would encounter when uniting the many sub-systems of a large-scale project. A single person is seldom able to be an expert on every aspect of a problem. More often, many types of engineers apply their specific skills and training to a small portion of the larger picture. This message is clear to students as a result of their success in building this complicated machine.

Day 5 - Engineers solve real-world problems.

Guest speakers from local industries add practical examples of engineering within the student's communities. Students are encouraged to think about their own futures as problem solvers and possible career opportunities in science or engineering.

Lesson Plans:

Day 1 - Propulsion Challenge - Engineering As Design

Objective:
Students will design a propulsion system to allow a toy car to move at least one meter using only the materials provided.

Materials:
Each group of students will receive 1 toy car, 1 rubber band, 1 8 ½ by 11 inch piece of paper, 1 balloon, 1 straw, 1 paper clip, 10 cm transparent tape.

Procedure/Instructions:
Student Groupings:
Let students mix together in the large group setting, but self-select partners (2-3 people per group) in the activity.

Student Instructions:
Using only the materials provided, create a propulsion system for the car that will move it at least one meter forward. Some or all of the materials can be utilized. The designers will be allowed to release the car initially, but may not interfere with its motion after release. The designers are required to remain behind the starting line. The design may be tested as often as needed, but will only have one trial on the official race course.

Teacher Notes:
The activity works best when the designated race course is open for design trials throughout the activity. This will allow students to work at their own pace. Generally, students who complete the task early will continue to work on improvements, or observe their class-mate's designs.

Outcomes:
Students will evaluate their own designs during the challenge. Individual teacher feedback will help students to identify the strengths and weaknesses of a specific design. A group review of student observations will reveal that there are often several possible solutions to a single problem; that different people will bring different skills, experiences, and ideas to the solution of a problem; and that prior knowledge and experimentation are applied to the solution of a problem.

Lesson Plans (continued):

Day 2 – Buoyancy Challenge – Engineering in the Environment

Objective:
Students will design a neutrally buoyant helium balloon, and attempt to keep the balloon suspended in the air for as long as possible.

Materials:
Helium, balloons, string, paper cups (portion control cups), string, rice, stopwatch or timer.

Procedure/Instructions:
Student Groupings:
Assign groups of 3-4 students randomly. Present the random grouping as a realistic added challenge to problem solving in a work environment.

Student Instructions:
Students will have twenty minutes to construct a helium balloon which supports a hanging cup and remains neutrally buoyant for as long as possible. During the competition, the balloon will be disqualified when the top hits the ceiling or when the bottom (lowest suspended portion) hits the floor. Students can adjust the weight of the basket with dried rice as they test their design (the rice is small and easy to clean up).

Teacher Notes:
The competition will be held in another location – a large hall or atrium is ideal. Choose a location with different temperature and air flow patterns. This will significantly affect the buoyancy of the balloon designs. Results will most likely be somewhat random.

Outcomes:
Students gain direct experience with design and feedback. Students usually experience some frustration in this activity. Their designs worked perfectly during the test phase, but behaved differently during the final test. This activity emphasizes the importance of understanding the environment in which a design will be used, and the importance of seeing the big picture in problem solving. This is related directly to design engineering, manufacturing, product sales, and customer satisfaction.

Lesson Plans (continued):

Day 3 - Company Simulation – Engineering as a Process

Objective:
Students will write effective procedures to build a small Lego™ structure. Students will simulate a company by designing, building, and testing their product according to written standards.

Materials:
Each group of 9-12 students will need two zip lock bags, two identical Lego™ structures (all built randomly from 10 pieces), a carrying tray or delivery box, a design specifications form, a product inspection form.

Procedure/Instructions:
Student Groupings:
Assign students into groups of 9-12 (this is their company), with each larger group divided into three divisions (design group, manufacturing group, quality assurance group). Split the divisions between three different areas. Different classrooms work well. One room would be the location for all the design work, another for manufacturing, and the third for quality inspections. Assign extra students or volunteers as Fed Ex employees, with the job of making deliveries between groups.

Student Instructions:
The challenge for each team: The design group will take the two Lego™ structures, and produce instructions for building the structure. Instructions can include words and pictures, but must be recorded on paper. When the designers have completed the design, they will send the assembled version to quality control for later inspection, and a disassembled version to the manufacturing department with the written instructions. The manufacturing group receives the 10 Lego™ pieces and the instructions, and builds the assembly to the best of their ability. When completed, they send the structure with the instructions to the quality control group. The quality group matches the original structure to the assembled structure. If they are identical, the product is approved. The quality group sends their inspection form with a product approval to be shipped. This is the finish line! If the assembly does not match the original, the quality group has to determine if the problem was with the original instructions, or with the interpretation of the instructions. If the instructions need to be modified, the quality group sends the materials with a product engineering change order back to the design team. If the problem was with manufacturing, then the quality group sends the materials back to manufacturing for rework. The process continues until the product is successfully shipped.

Teacher Notes:
The successful completion of the product usually takes between 10 and 20 minutes. Some groups will not complete the challenge. The Fed Ex runners are very busy, and the activity is very lively. Students often experience frustrations with others within their company, and often place blame on other divisions within their company (as often happens in a business).

Outcomes:
Students can now relate to some of the frustrations and communications that occur in a company environment. Ask the group to brainstorm about ways the company could improve its product throughput, or work together more effectively. The discussion can be directly applied to the divisions of labor in a manufacturing environment. Product design, manufacturing delays, material issues, quality control, delivery deadlines, and management of company functions can all be addressed. The need for industrial engineering and personnel also become more evident to students.

Lesson Plans (continued):

Day 4 – The Great Gumball Gunkulator – Engineers as Collaborators

Objective:
Students will develop a classroom sized "mousetrap" machine that will deliver a marble from one corner of the room, through nine marked sections, to a tin can in another corner.

Materials:
9 plastic bins, each filled with a variety of random building materials. We have been successful with wrapping paper, toilet paper, and paper towel rolls, corner molding (with edges sanded for safety), string, masking tape, pvc pipe segments, flexible tubing, lab stands, scissors,…

Procedure/Instructions:
Student Groupings:
Assign students randomly between the 9 sections of the room. They must remain in their section throughout the entire activity.

Student Instructions:
Students must remain in their own section, but must coordinate with the sections around them. They may trade materials, but can only work on the construction of the machine in their section. The marble must travel unassisted from the funnel to the tin can by the pull of gravity alone.

Teacher Notes:
It is helpful to get the students started by helping them agree on a path for the marble – what is the order of sections through which the marble will pass? It is also helpful to encourage the students to leave some time at the end for testing, as last minute adjustments will be required. Establish safety guidelines for the classroom before starting. It may seem like an impossible task, but we have observed that most groups successfully complete the challenge, and all groups come very close to completing the challenge. In a typical classroom, each group has about 1 foot of dropping distance to work with. The sections themselves come together pretty easily, but the coordination and connection between sections is the challenging part. Students are excited and engaged throughout the activity. They love it! The biggest challenge for teachers is the clean up and preparation for the next group. We have had two teachers disassembling (with the help of students) while the third teacher provides instruction to the next group in another classroom.

Outcomes:
The rewarding feeling that students have upon completing this task makes it a very worthwhile activity. It is a great activity to precede a discussion about systems engineering, division of labor, and communications between groups.

Lesson Plans (continued):

Day 5 – Guest Engineer Forum – Real Live Engineers!

Objective:
Students will discuss a variety of engineering disciplines with working engineers. Students will relate the activities of the week to real-world problem solving.

Procedure:
We have tried this a few different ways. We like to host engineers from a variety of disciplines and let the students decide which speaker they will hear. By the end of the week of activities student interest in engineering is high, and their direct experiences help them to make connections and ask appropriate questions.

Outcomes:
Students gain a good understanding of the many different skills and activities of professional engineers.

Program Summary and Assessment:

This program has been run successfully for four years. Each year students demonstrate to us that they appreciate this week as a chance to learn about the world outside of the classroom, to interact with students from other classes, to meet other teachers, to work with working professionals in the field of engineering, and to practice hands-on problem solving. We appreciate this week because it allows us to address many of the real issues of science and engineering in an engaging, fast paced, and interactive way. Student response is excellent, community participation is high, and a genuine appreciation for engineering is evident among students.

Student feedback is an important part of our program. In addition to the group discussions, we ask students to write about their experiences in their science journals. The quotations below have been taken from student journals.

> "My favorite activity was when we split up along the line of production (design, production, quality). I am a firm believer that we, as high school students, have no idea how the world works. Things don't just appear in stores. There is a process, an absolutely imperative process."
>
> - 12th grade female student who plans to pursue graphic design after high school.

> "Problem solving is not always as easy as it appears. Problem solving also requires people work together in order to complete a huge task. I demonstrated this by helping my groups to find a solution to the problems. In the final Gunkulator machine we needed to work with the groups in front and behind us, so that the entire project worked."
>
> - 11th grade female student planning to take AP physics in her senior year.

> "I really enjoyed National Engineer's Week. It was a change from the normal class and the visitors were very interesting. Nothing can beat the "Gunkulator" of course. That was probably the coolest thing I have ever done in all my classes ever. Everyone got to work together and use creativity to develop something."
>
> - 12th grade male student who plans to join the military and pursue a technical field.

Academic Standards:

The Academic Standards for Science and Technology and the National Science Education Standards identify the need for schools to address engineering principles in the high school classroom. The relevant standards are listed below. The National Engineer's Week program creates a framework to address these standards with students.

Academic Standards for Science and Technology, Pennsylvania Department of Education (July 12, 2001)

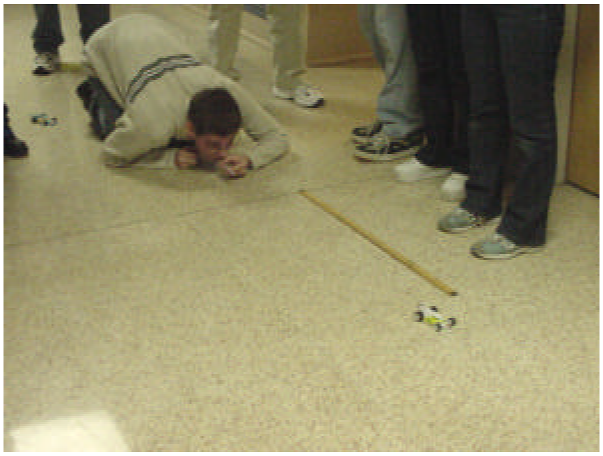
- 3.1 Unifying Themes
- 3.1.12 A - Apply concepts of systems, subsystems, feedback and control to solve complex technological problems.
- 3.2 Inquiry and Design
- 3.2.12 C - Apply the elements of scientific inquiry to solve multi-step problems.
- 3.2.12 D - Analyze and use the technological design process to solve problems; analyze problem, propose solution, implement solution, evaluate, test, and redesign.
- 3.6 Technology Education
- 3.6.10 C - Apply physical technologies of structural design, analysis, and engineering, personnel relations, financial affairs, structural production, marketing, research, design to real world problems. Apply concepts of design engineering and production engineering in the organization and application of a manufacturing activity.

National Science Education Standards (February 2001)

Science and Technology content standard E (p.192) – Abilities of technological design.

- Identify a problem or design an opportunity
- Propose designs and choose between alternative solutions
- Implement a proposed solution
- Evaluate the solution
- Communicate the problem, process, and solution

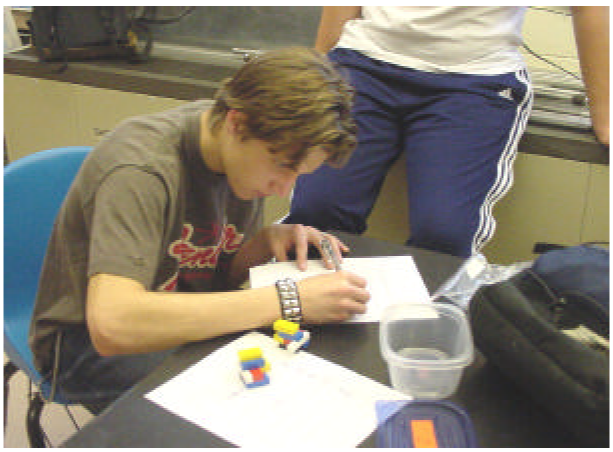
Photos:

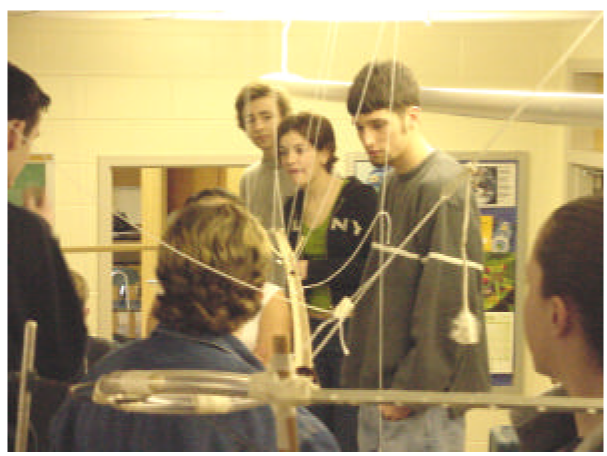
Students try out their designs during the propulsion challenge. Action and reaction forces from a deflating balloon, and wind energy are two possible solutions to the challenge.

Photos (continued):


Guest engineers from Lockheed Martin join in the buoyancy challenge.




The company activity allows students to experience the challenges of building a product.

Students construct the “Great Gumball Gunkulator,” and watch carefully as the marble travels through the machine.

Photos (continued):

Guest engineers lend a hand with Gunkulator construction. A guest speaker from a titanium metal company discusses the challenges of a manufacturing environment.

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