Welcome to Engineering the Future: Science, Technology, and the Design Process

Engineering the Future is a full-year course designed to introduce students to the world of technology and engineering, as a first step in becoming technologically literate citizens. Additionally, the course will help beginning high school students answer the question, “Why should I study math, science, and engineering if I don’t plan on a technical career?” Through this course’s practical real-world connections, students have an opportunity to see how science, mathematics, and engineering are part of their everyday world, and why it is important for every citizen to be technologically and scientifically literate.

Engineering the Future maps directly to the Standards for Technological Literacy (ITEA 2000), Benchmarks for Science Literacy (AAAS 1993), and National Science Education Standards (NRC, 1996), as well as many state science frameworks. Major goals of the course, which reflect these standards, are as follows:

Goal 1. Students will develop a deep and rich understanding of the term “technology.” Students learn that the technologies we take for granted—TVs and DVDs, refrigerators and furnaces, the food on our dinner plates, cars and power plants—were created by people through “the engineering design process.”

Goal 2. Students develop their abilities to use the engineering design process. Students take on the role of engineers and apply the engineering design process to define and solve problems by inventing and improving products, processes, and systems.

Goal 3. Students will understand the complementary relationships between science, mathematics, technology, and engineering. By learning about the work of practicing engineers, students get an “insider’s view” of how engineers apply mathematical skills and scientific knowledge to solve problems and meet human needs and desires.

Goal 4. Students will understand how advances in technology affect human society, and how human society determines which new technologies will be developed. Students learn through a variety of examples how everyone is affected by changes in technology and how people influence future technological development by the choices they make as workers, consumers, and citizens.
Goal 5. Students will be able to apply fundamental concepts about energy to a wide variety of problems. The concept of energy is fundamental to all of the sciences, but it is also challenging to learn. So, as to build a useful mental model of energy, students will learn to apply the same energy principles to thermal, fluid, and electrical systems.

In brief, the course is intended to help today’s high school students understand the ways in which they will engineer the world of the future—whether or not they choose to pursue technical careers.

Instructional materials for Engineering the Future include an Engineer’s Notebook and textbook for each student, and this Teacher Guide.

The Engineer’s Notebook guides students in their day-to-day activities. It provides detailed instructions and datasheets for design challenges and supporting activities, as well as rubrics so that students will understand how their work will be evaluated. The Notebook is divided into four booklets for the four major projects of the course. Each booklet is hole-punched so it can be inserted into a 3-ring binder, and pages are perforated so that a task can be torn out neatly, stapled, and given to the teacher for assessment.

The textbook is written from the viewpoint of practicing engineers. Men and women from various ethnic and cultural backgrounds tell what it’s like to practice their profession, and how they came to do what they do. Through these first-person stories, students learn important concepts that relate to their own design projects.

Assessment Tools for this course include:

1) In-class assessments. The task guidelines suggest ways to lead discussion and observe student work, which will help you determine how well students are learning and make appropriate course corrections.

2) Project rubrics. Rubrics for assessing individual and team performance on creative engineering design tasks are included in the Engineer’s Notebook so that students can see how their work will be evaluated.

3) End-of-unit tests. This Teacher Guide includes four project tests, which you can administer to your students after each quarter of the course.

The most important element of the course is you, the teacher. Your understanding of the content, your enthusiasm for the subject, and your ability to engage your students in creative and analytic thinking are by far the most important resources at your command.
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The idea that all students should learn about technology and engineering is relatively new on the educational landscape. The high school curriculum we take for granted today was largely shaped by the Committee of Ten, chaired by Harvard President Charles W. Eliot. More than a century ago, the Committee published a definitive report about what all students should learn (Eliot, 1893).

The Committee’s report called for high school students to study English and mathematics, modern languages, history and geography, and the sciences—physics, astronomy, chemistry, and natural history, which we now call biology. Except for dropping the requirement that all students should study ancient Latin and Greek, the Committee of Ten’s report still describes the high school curriculum of today.

Now, after more than a century, an educational revolution is gaining momentum. National leaders in government, industry, and education have realized that in order to maintain our strength among industrialized nations, we must build a technologically literate citizenry. A major step in accomplishing this goal was taken in 2000 by the International Technology Education Association with the publication of standards that describe what everyone should know and be able to do in the areas of technology and engineering (ITEA, 2000). In 2001, the Commonwealth of Massachusetts followed suit with the first state-level curriculum framework that mandates technology and engineering be taught to all students at all levels K–12 (Massachusetts, 2001). A recent state-by-state analysis (Koehler et. al, 2007) found that nearly all state frameworks call for some technology and engineering education with an emphasis on technology and society issues, while a number of states—New York, Pennsylvania, Vermont, and Delaware—call for the kind of in-depth learning about the engineering design process found in the Massachusetts framework.

In 2002, the National Academy of Engineering published an influential report that presents a compelling case for making technology an integral part of everyone’s education. According to the report, entitled Technically Speaking: Why All Americans Need to Learn More About Technology:

As far into the future as our imaginations can take us, we will face challenges that depend on the development and application of technology. Better health, more abundant food, more humane living and working conditions, cleaner air and water, more effective education, and scores of other improvements in the human condition are within our grasp. But none of these improvements is guaranteed, and many problems will arise that we cannot predict. To take full advantage of the bene
and to recognize, address, or even avoid the pitfalls of technology, Americans must become better stewards of technological change. Present circumstances suggest that we are ill prepared to meet that goal. This report represents a mandate—an urgent call—for technological literacy in the United States. (Pearson, 2001)

Nonetheless, there is still widespread misunderstanding about the curriculum needed to support technological literacy. National leaders speak of the need for education in science, technology, engineering, and mathematics (STEM), but they often emphasize only science and mathematics to the exclusion of technology and engineering. *Engineering the Future* is aimed at bridging the gap between the abstract knowledge of science and mathematics and the critical problems we face today, and that our students will encounter in the world of tomorrow.

**Why engineering?**

Engineering and technology are two sides of the same coin. *Technologies* are the processes and products that people have developed to solve problems or meet human needs and desires. *Engineering* is the practice of modifying or creating new technologies. The term “engineering” has been selected for the title of this course, rather than “technology,” for the following reasons (Wicklein, 2003):

- A focus on engineering helps to clarify that this course is about technology education (the designed world) rather than educational technology (use of computers in teaching).
- The term “engineering” is better understood and valued than “technology” by the general public, although misconceptions about both terms are common.
- The fundamental principles of engineering (especially the design process and using systems) provide a solid framework to design and organize a curriculum.
- Engineering provides an ideal platform for integrating mathematics, science, and technology.

Just as science education is associated with professional scientists, engineering education is associated with professional engineers. Both engineers and scientists are well-compensated and highly respected career pathways, and it’s important that all students learn about these professions before they make choices in their school careers that would rule either of them out.
Where does this course fit in the high school curriculum?

*Engineering the Future* is not intended to provide training in specific vocations. It is meant to help all students—whether they eventually choose to attend a university, another tertiary education institution, or enter the world of work—better understand the designed world and the wide variety of career paths a person might take in designing, manufacturing, maintaining, or using technologies.

For some students, the course will open career interests that would otherwise have lain dormant, until it is too late for them to enroll in elective science and math courses, and gain entry to technical studies at a college or university. Consequently, the intended placement of this course is in the first year of a high school student’s career.

Alternatively, *Engineering the Future* can serve as a capstone course for high school juniors or seniors, so that students can apply to practical situations all that they learned in high school, ranging from science and math to history, social studies, communication—even art and music. You may also use this course to provide an excellent introduction to the field of engineering for students who are considering technical careers.

Who should teach this course?

The most important qualification for teaching *Engineering the Future* is a desire to foster students’ creative talents and analytical skills. Other valuable qualifications include the ability to lead discussions that encourage students to question their assumptions and consider new ideas as well as to help students work effectively in teams to brainstorm ideas, make decisions, and to build and test prototypes.

Regarding educational background and professional licensure, teachers who have a state license to teach technology/engineering in grades 6–12 are already fully qualified (under No Child Left Behind legislation) to teach this course. However, we envision that licensed physics and mathematics teachers will not find it difficult to learn the additional skills they will need to teach this course. The Museum of Science has created and is testing an online program to enable teachers to gain the additional knowledge and skills they need to teach this course, and to receive graduate credit toward further certification and licensure. For more information on how to enroll in this course, check out our web site at www.mos.org/etf.
Which department should be responsible for this course?

*Engineering the Future* is designed for all students, not just those in an accelerated program to become engineers, or for students in vocational tracks. Because it has a strong science laboratory component, most schools include it in their science department, along with chemistry, physics, and biology. However, it could also be included in the technology department. Some schools have even changed the name of their science departments to “Science and Technology” to recognize the value of integrating these two fields. While any of these solutions is feasible, it will be important to choose the solution that best supports acceptance of the new course by students, parents, and guidance counselors and that best demonstrates the integration in math, science, technology, and engineering.

Whatever home department is chosen for *Engineering the Future*, the course should not stand alone but be one step in a sequence of courses that students take as they progress through high school. When students complete this course, they will have a broader understanding of the wide variety of technical careers that are open to them. Some students may wish to take more courses in science or math, or more specialized courses in technical fields. However, not all students will wish to become involved in science and technology as careers. By providing alternative sequences, students will have opportunities to choose pathways that are consistent with their current interests and desires while keeping their options for the future open.

What are the goals of this course?

*Engineering the Future* was designed with a “backward design process,” as described in the book *Understanding by Design* (Wiggins and McTigh, 1998). When using this approach, you should be explicit about the evidence that we would expect students have attained in the goals of the course. We have operationally defined the five course goals as follows:

**Goal 1. Students will develop a deep and rich understanding of the term “technology.”** As evidence of this understanding, students will:

- Describe at least ten different technologies—objects and processes that have been modified to suit human needs and wants.
- Explain that technologies are modified or invented through the engineering design process, which consists of several steps: defining the problem, conducting research, generating possible solutions, selecting and refining one solution, constructing a prototype, testing and evaluating the prototype, communicating the solution, and redesigning.
- Give examples of how three different kinds of professional engineers bring creative ideas to life.

**Goal 2. Students develop their abilities to use the engineering design process.**

- Demonstrate the ability to use the engineering design process to solve a problem or meet a challenge.
- Give an example showing that the steps of the engineering design process can be immensely fruitful, but need not be followed slavishly.
- Describe two different contexts—such as a city, the human body, or an automobile—in which systems analysis can help to solve problems.
Goal 3. Students will understand the complementary relationships among science, technology and engineering. As evidence of this understanding, students will:

- Demonstrate the ability to apply energy concepts to solving engineering design problems.
- Explain how advances in technology have made new discoveries in science possible.
- Give examples of how mathematics can help engineers solve problems.
- Describe the relationship between science and engineering.

This diagram illustrates the relationship between science and technology, and how these fields are related to human society:

- A scientist’s goal is to investigate the natural world. An arrow leads to the results of inquiry—scientific knowledge. The ever-changing body of scientific knowledge informs engineers as they create and improve upon the designed world.
- Continuing the circle, engineers produce various technologies, including products and processes designed to solve problems and meet human needs.
- The final arrow, completing the circle, represents the idea that a variety of technologies help scientists conduct their investigations of the natural world.
Goal 4. Students will understand how advances in technology affect human society, and how human society determines which new technologies will be developed. As evidence of this understanding, students will:

- Describe at least six differences in prevailing technologies that make the life of today’s teens different from the teens of 100 years ago.
- Explain how society determines which new technologies are brought to market. Illustrate at least two examples.
- Give at least two examples of new technologies that have unintended effects, and tell why these effects are positive, negative, or both.
- Give at least two examples in which the negative environmental impacts of past technologies are being reduced by the development of new technologies.
- Summarize two different scenarios of a future world—one in which citizens thoughtfully choose which technologies should be developed, and one in which there is no careful planning for technological change.

Goal 5. Students will be able to apply fundamental concepts about energy to a wide variety of problems. As evidence of this understanding, students will:

- Describe situations in which a difference in temperature, pressure, or electrical potential drives the flow of energy through a system.
- Explain why energy input is required to produce and maintain a difference in temperature, pressure, or electrical potential.
- Describe the sources of resistance to energy flow in thermal, fluid, and electrical systems.
- Give examples to illustrate that the rate of energy flow is directly proportional to a difference in temperature, pressure, or electrical potential, and inversely proportional to the resistance in these systems.

Why focus on safety?

A safety briefing is an important part of any class in which students are constructing projects. There are several areas where safety needs to be highlighted: using power tools; large machine tools; smaller tools such as utility knives or hot glue guns; and preventing skin contact and inhalation of adhesives, paints, and fine particles. Students should also be aware of the emergency equipment around the room such as fire extinguishers, exits and evacuation maps, eyewashes, and communication procedures in the event of an emergency. Some teachers have students and their parents sign a safety contract that lists the tools the students will be using, the safety rules, why it’s important for students to act responsibly.

What do students need to know about energy?

Energy concepts are difficult to learn; yet understanding energy is essential for virtually all fields of science and engineering. In biology it’s important to understand how organisms obtain and transform energy for life processes, and how energy flows through ecosystems and food webs. In earth and space science, students learn that energy from the sun drives wind and ocean currents, and that thermal energy inside the earth moves continents and causes volcanic eruptions and earthquakes. In physics, the law of energy conservation is one of the most important ideas that
students are expected to learn and apply in solving problems. And our daily use of electricity and fuel keeps hundreds of thousands of engineers employed designing more efficient ways to generate energy and reduce our impact on the environment.

In this course, we have decided to focus on energy for several reasons:

- Energy offers a useful set of ideas for understanding the world around us.
- Energy is a foundation concept in all fields of science and engineering.
- Energy concepts are difficult for students to learn, and misconceptions about it are widespread.

There are many reasons why students so often have misconceptions about energy. In everyday life we use the term “energy” loosely to describe how we feel, or how hard we work. In science the term is more precisely defined, but sometimes the definitions are confusing. In physics, for example, energy is usually defined as “the capacity to do work.” However, students also learn that in energy transformations some energy is always lost to the environment in the form of heat that cannot do work. In chemistry and biology, students learn about energy in different contexts and only rarely see the similarity of energy concepts across disciplines. In this course, we avoid these problems by focusing instead on the following energy principles:

1) Energy is like a substance in that it can flow from one place to another—but it is not a substance.

2) The rate at which energy flows is directly proportional to a difference in temperature, pressure, or electrical potential. In other words, “difference drives change.”

3) Energy input is required to maintain a difference in temperature, pressure, or electrical potential. This idea is summarized as “It takes a difference to make a difference.”

4) The rate at which energy flows is inversely proportional to resistance.

If students are to benefit from learning about energy early in their high school experience, they need to learn it in such a way that they can apply it readily in new situations. This is the idea of transfer of learning. Educational research strongly indicates that transfer will occur more readily if the concept to be taught is presented in different contexts, and if students are guided in recognizing how the abstract concept can be applied in those different contexts (Bransford, Brown, and Cocking, 1999). Those abstract concepts are the energy principles listed above, which students apply in three different contexts.

**Temperature differences drive change.** In Project 2.0 students are asked to design an energy-efficient building. An important consideration in doing so is to minimize the loss of thermal (heat) energy through walls by increasing the resistance using insulation. However, no matter how well it is insulated, maintaining a difference between indoor and outdoor temperatures requires the input of energy using a furnace or air conditioner.

**Pressure differences drive change.** In Project 3.0 students use inquiry to figure out how an engine transfers energy, and how energy is transferred through pneumatic and hydraulic systems. They also explore how pipes of various sizes and shapes resist the flow of energy through pipes.

**Electric potential differences drive change.** In Project 4.0 students are guided in designing circuits, and measuring current, voltage, and resistance. Through activities they see that the flow of electrical energy increases if there is a greater electrical potential difference (measured in volts) and decreases if there is a greater resistance (measured in ohms).
By emphasizing the use of energy concepts in these three different contexts, you can help your students develop a more flexible, useful, and transferable concept of energy that will serve them well in later years, both in school and in life.

Why is teamwork important?

Our extensive interviews with engineers have confirmed that good engineering requires a team effort. Therefore, students must learn how to work effectively in teams. There is some tension between the encouragement of teamwork and independent work, given the need for teachers to assign individual grades for students. The tension is considerably reduced if expectations are clearly presented to the students for each activity. Suggestions for how to do this will be offered at various points in the Teacher Guide and built into the Engineer’s Notebook.

What math and science will students learn?

In this course, the students do more than read about engineering. They also take on the role of engineers themselves. Like engineers, they are asked to undertake projects to meet certain human needs. Unlike much of schoolwork that has right and wrong answers, the projects can be completed successfully in a variety of ways.

The course is divided into four sections, called projects, each of which takes about eight weeks to complete. The primary purpose of Project 1.0 is to engage students in using the engineering design process to meet human needs. The students are encouraged to be creative while meeting the criteria and constraints of the problem.

Engineering is characterized by the application of math and science to ensure that designs are not only pleasing to the eye, but they also function as intended. Students practice fundamental mathematical skills and the engineering design process in all four projects, and apply science concepts and processes in Projects 2.0, 3.0, and 4.0.

On the following pages is a brief summary of the four projects, including the design work guided by the Engineer’s Notebook, the related chapters in the text, and learning objectives.
Project 1.0: Design the Best Organizer in the World

Project 1.0 begins with a video of an industrial design team at work. Then students undertake their first project—to design a better cell phone holder. They also learn how to make engineering drawings, a skill that they will use throughout the course. During the next design challenge, which is the major project of the first unit, the students work in teams to conduct marketing surveys to find out what kinds of organizers people would like to purchase. The concept of an “organizer” also helps students recognize the vast array of technologies that exist in the world around them. Student teams design, draw, and construct models of their organizer concepts, then redesign their organizers for manufacturing. Finally, they build a prototype for testing with the intended audience.

Readings—Manufacturing and Design

As students work through the activities in the Engineer’s Notebook, they come across assignments in the textbook that relate to their class activities. The chapters in Unit 1 of the text, which correspond to Project 1.0 of the Engineer’s Notebook, are as follows.

Chapter 1: Amy Smith, an engineering instructor at MIT, explains how she works with her students to design tools that improve lives half a world away.

Chapter 2: Inventor Shawn Frayne shares the design process—an approach to solving engineering problems—and explains why it’s more of a guideline than a rule.

Chapter 3: Jamy Drouillard (pictured at right) is an aeronautical engineering student with high-tech dreams. In this chapter he describes his own design process, which includes analyzing toy technology and developing computer simulations.

Chapter 4: Lam Loc, a Computer-Aided Design (CAD) technician, explores engineering drawing techniques and explains why a picture is worth more than a thousand words to engineers.

Chapter 5: Robert Hartmann, an electrical engineer at an industrial design firm, explores how companies use the design process to develop products for the market.

Chapter 6: Araceli Ortiz, a former manufacturing engineer at Ford, tells the story of the automobile’s rise to fame and explores how companies decide what to mass-produce.

Chapter 7: Dudley Green, a process engineer at Teradyne Corporation, shows that every product and every technology is a part of an interconnected system that is, itself, designed.

Chapter 8: Christine Epplett, a developer at New Balance Athletic Shoe, takes students through the process of designing and mass-producing popular footwear.

Chapter 9: Inventor Saul Griffith illustrates why nature knows best when it comes to building better manufacturing systems.
### Science and Mathematics Content

#### Skills and Concepts from the Notebook

**Engineering Skills and Concepts**
- Engineering design process (define the problem, research the problem, develop possible solutions, choose the best solution, create a prototype, test and evaluate the prototype, communicate the solution in drawings and words, redesign)
- Criteria and constraints
- Trade-offs
- The importance of teamwork
- Optimization
- Markets (niche markets, mass markets)
- Cost-benefit analysis
- Life cycle analysis

**Mathematics Skills and Concepts**
- Length measurements
- Area and volume calculations
- Mass measurements and density calculations
- Engineering drawing techniques: orthographic, isometric, oblique, and perspective

**Manufacturing Concepts**
- Manufacturing technologies (molding, casting, separating, forming, assembling, finishing)

#### Concepts from the Text

**Engineering Concepts**
- Engineering design process (define the problem, research the problem, develop possible solutions, choose the best solution, create a prototype, test and evaluate the prototype, communicate the solution in drawings and words, redesign)
- Criteria and constraints
- Trade-offs
- The Importance of teamwork
- Engineers and engineering
- Appropriate technologies
- Microenterprise
- Markets (niche and mass markets)
- Manufacturing technologies (molding, casting, separating, forming, assembling, finishing)
- Assembly line vs. batch production
- Systems
- Universal systems design
- Optimization
- Inventory
- Life cycle analysis

**Mathematics Concepts**
- Engineering drawing (orthographic, isometric, oblique, perspective)
- Computer-Aided Design (CAD)
Project 2.0: Design a Building of the Future

Project 2.0 introduces students to the problems of urban sprawl. To address these problems, the students learn about the “new urbanism” movement in which city planners, architects, and engineers work together to design structures that serve a variety of functions. Students are challenged to work in teams to design a structure for housing and at least one other function, such as office space, retail shops, or manufacturing facilities. But first they need to determine how to design structures that will bear heavy loads, how to test materials that have the properties needed in different parts of the structure, and how to design a building that minimizes the amount of energy needed to maintain a comfortable temperature. Finally, they apply the concepts and tools of science to design a building that is structurally sound, thermally efficient, and promises to help solve the problems of urban sprawl.

Readings—Sustainable Cities

By reading the text, students learn how designers draw on mathematics and science to design structures and systems that will stand the test of time, promote the health and well-being of residents, and preserve more of the natural world.

Chapter 10: Peter Park, an urban planner in Denver, describes the key elements of the world’s greatest cities as well as a new and improved design for his own.

Chapter 11: Field engineer Kirk Elwell explores the various forces and loads that a structure must be designed to withstand as he describes the design and construction of a major Boston bridge.

Chapter 12: Structural engineer Bill Baker explains how he’s engineering the world’s tallest structure to withstand sky-high forces.

Chapter 13: Prity Rungta, a construction manager in Toronto, Canada, describes the complexity of building a house on time and on budget.

Chapter 14: Geotechnical engineer Cathy Bazán-Arias explains why engineers need to understand the land they are building on.

Chapter 15: “Green” architect Chris Benedict explains why conventional heating systems can be bad for the environment, and how to design a building that conserves energy while keeping its inhabitants warm.

Chapter 16: Lauren Stencel (pictured at left), a college student, describes how she’s helping to build a home that uses the sun for its energy needs.
### Science and Mathematics Content

#### Skills and Concepts from the Notebook

**Mathematics Skills and Concepts**
- Measurement of population density
- Scale, ratio, proportions
- Algebraic reasoning
- Creating, reading, and interpreting graphs

**Mechanics and Construction Skills**
- Failure mechanisms: compression, tension, bending, torsion, and shear
- Measure tensile and compressive strength; graph results
- Interpret stress and strain
- Measurement of mechanical properties: elasticity, plasticity, elongation
- Calculation of live loads and dead loads
- Calculation of mechanical advantage
- Analysis of beams and trusses
- Green building design

**Energy Concepts**
- Conductors and insulators
- Difference drives change
- Heat and temperature
- Flow of thermal energy $Q = \Delta T / R$, where $\Delta T = \text{temperature difference}$, $R = \text{R-Value}$
- R-values used to rate thermal conductors
- Convection, conduction, radiation

#### Concepts from the Text

**Mechanics and Construction Concepts**
- Geotechnical engineering
- Construction engineering
- Cities and towns are designed systems
- Properties of different materials
- Materials testing methods
- Interpreting stress and strain curves
- Dead loads and live loads
- Trusses and load distribution
- Compression, tension, and shear forces
- Failure mechanisms: compression, tension, bending, torsion, and shear
- Foundations
- Properties of construction materials
- Project management
- Green architecture
- Urban Sprawl
- Multi-use buildings

**Energy Concepts**
- Difference drives change
- Energy transfer and storage
- Heat and temperature
- Insulators and conductors
- Thermal resistance
Project 3.0: Improve a Patented Boat Design

Project 3.0 invites students to build a “putt-putt boat” that is powered by a thermal/fluid engine. The challenge is to apply fundamental concepts of energy to understand how the boat works, and then redesign it. Lab teams work together in a series of activities to learn how energy is transferred through the boat system, from a candle that provides energy input, to the jets of water that propel the boat forward. These experiments involve the behavior of compressible gases and noncompressible fluids, conduction of thermal energy, and the concept of resistance to fluid flow in pipes. As students build knowledge of the science behind the putt-putt boat, they take on the role of working engineers and produce a patent to communicate their ideas.

Readings—Unit 3 Going with the Flow

What do a rocket engine and a sewer system have in common? Some of the concepts that explain how liquids flow through pipes can also be used to understand how moving fluids make engines run—including those that power cars, boats, and planes.

Chapter 17: Bob Brown, design engineer at Woods Hole Oceanographic Institute, describes how he’s overhauling the deepest-diving manned submersible in the country.

Chapter 18: Astronautical engineer April Ericsson shares how she’s designing a spacecraft that will bring Martian material back to Earth.

Chapter 19: Activist Josh Tickell tells the story of how he reworked his diesel van to run on leftover cooking fuel.

Chapter 20: Chris Langenfeld, design engineer at DEKA Research, explains why it’s sometimes better to look to history when designing low-emission engines.

Chapter 21: Professor of thermodynamics Ron DiPippo describes how geothermal wells might provide a solution to some of the problems associated with burning fossil fuels for energy.

Chapter 22: Rebecca Steinman (shown left), a nuclear engineer, explains how a nuclear reactor is designed to provide electric power safely without creating air pollution.

Chapter 23: Environmental engineer Lisa Bina leads a tour of a major city’s sewage system and explains how it has been redesigned to protect residents and wildlife.
## Science and Mathematics Content

### Skills and Concepts from the Notebook

#### Hydraulics & Pneumatics
- Compressibility of gases
- Incompressibility of liquids
- Open and closed pneumatic systems
- Open and closed hydraulic systems
- Pneumatic pump
- Hydraulic press
- Fluid resistance

#### Thermodynamics Concepts
- Boyle’s Law: \( P/V = \text{Constant} \)
- Charles’ Law: \( V/T = \text{Constant} \)
- Gay-Lussac’s Law: \( P/T = \text{Constant} \)
- Pascal’s Law
- Carnot engine
- Engine efficiency
- Convection, conduction, radiation

#### Manufacturing
- Contents and purpose of patents
- Die and mold design and manufacturing
- Brake-forming manufacturing process
- Die-press manufacturing process
- Quality control
- Prototype testing
- Patent process

### Concepts from the Text

#### Hydraulics & Pneumatics
- Properties of fluids
- Compressible and noncompressible fluids
- Pressure
- Pressure at depth
- Open and closed systems
- Working fluid

#### Thermodynamics Concepts
- Relationship between temperature, pressure, and volume
- Thermal expansion
- Work as a form of energy
- Engine (internal and external combustion)
- Efficiency
- Stirling engine
- Fluid resistance

#### Fluid-Thermal Systems for Electrical Power
- Geothermal energy
- Nuclear energy
- Power plant design
- Steam turbine design
- Renewable and nonrenewable resources
- Pollution and nuclear waste
Project 4.0: Electricity and Communication Systems

To spark students’ interest, Project 4.0 begins with a communications activity in which the students build a circuit to control a scoreboard numeral and create a binary code for each numeral. They then conduct a variety of activities to learn about the basics of circuit electricity using fun Snap Circuits™. With a strong foundation in electricity, students then explore various communications systems using microphones, speakers, laser diodes, and fiber optics. Students also learn about electrical power systems and why some systems work better than others for different applications. Throughout the unit the students design and test circuits to solve specific problems, from detecting rodents in the basement to controlling two fans so they run at variable speeds.

Readings—Power to Communicate

In this unit, students find out how electricity is generated and distributed to millions of people daily. They also explore how electrical systems are integral to communication technologies such as telephones, internet, cell phones, and satellite systems.

Chapter 24: Computer scientist Dave Clark describes the digital world of computers and explains his role in designing the Internet.

Chapter 25: Sol Lerner, a computer programmer, develops systems that can “understand” human speech.

Chapter 26: Nanette Halliburton, a test engineer at Cisco Systems, Inc., explains how information can travel encoded as light through fiber-optic cables.

Chapter 27: Carnegie Mellon communications engineer Alex Hills describes how he developed satellite communication systems in rural Alaska.

Chapter 28: Museum of Science curriculum developer Joel Rosenberg shares a model for electricity that he found while designing this course.

Chapter 29: Chemical engineer Soung-Sik Kim (pictured at left) explores how electricity can be generated more efficiently with less environmental impact.

Chapter 30: Electrician Ken McAuliffe explains the complex process of wiring a large building for electricity.

Chapter 31: Christine Bordonaro, a materials engineer at Evergreen Solar, explains how engineers have harnessed the energy of the sun to generate electricity.

Chapter 32: Entrepreneur Jim Gordon describes how developing a wind farm off Cape Cod illustrates the controversy that surrounds energy technologies.
## Science and Mathematics Content

### Skills and Concepts from Notebook

#### Electricity and Electrical Systems
- Electrical components: batteries, bulbs, wires, sockets, resistors, variable resistors, LEDs, photoresistors, switches, capacitors, etc.
- Parallel and series circuits
- Schematic diagrams
- Electrical conductors and insulators
- Function and use of ammeters
- Function and use of voltmeters
- Ohm’s Law \( \Delta V = I \times R \)
- Control systems
- Multimeter functions (zero adjust, ranges)
- Calculating energy and power in circuits
- Photovoltaic circuits
- Relation between motors and generators

#### Electronics Concepts
- Building an amplifier and numeric display
- Digital and analog signals
- Storage and retrieval of data
- Speakers and microphones

#### Optics & Communications Concepts
- Exploring infrared remote-control devices
- Total internal reflection
- Electromagnetic spectrum
- Encoding and decoding messages
- AM and FM signals
- Fiber optics

### Concepts from the Text

#### Electricity and Electrical Systems
- Charge
- Circuit
- Current and voltage
- Alternating Current (AC)/Direct Current (DC)
- Electrical conductors and insulators
- Electrical load
- Electrical resistance
- Electrical power
- Electrical distribution grid
- Ohm’s Law
- Generators and motors

#### Electronics Concepts
- Encoding and decoding signals
- Transmitters and receivers
- Cell phones and satellites
- Wireless networks
- Binary code
- Digital and analog signals
- Internet

#### Optics & Communications Concepts
- Reflection and refraction
- Total internal reflection
- Fiber optics
- Electromagnetic radiation
- Electromagnetic spectrum
- Waves and frequencies
What facilities and equipment are required?

*Engineering the Future* is a laboratory course in which students will be expected to design, build, and test prototypes. While students will learn a great deal from their textbooks and discussion sessions, they will not be able to understand what engineering is all about unless they have opportunities to actually do it themselves. The list of laboratory facilities, equipment, and consumable materials you will need to teach the course is included in this guide. These materials have been kept to a minimum to keep costs as low as possible.

Projects 1.0 and 2.0, which comprise the first semester, require materials such as cardboard, tape, glue, graph paper, and tools such as scissors, utility knives, and so on. These materials are widely available and best purchased locally. Projects 3.0 and 4.0, the second semester of the course, involve more specialized materials: syringes and tubes for hydraulic and pneumatic activities, Snap Circuit™ electricity kits, and so on, which must be purchased from a limited number of suppliers. Details for purchasing kits for these materials are included in the “Materials” section of this Teacher Guide.

Regarding facilities, some sort of shop or laboratory where students can fabricate their inventions with cardboard, glue, wood, and nails, and conduct experiments involving water and electricity would be ideal. However, a wood shop is not absolutely essential for teaching the course. Teachers can modify the requirements for constructing scale models and prototypes based on the facilities available and their own expertise in teaching students how to use various tools. Also, you will need space to store student projects between classes.

Moveable tables and chairs will enable students to interact in small teams as they work on their projects, and still allow them to assemble for large-group discussions.

What teaching methods are used in this course?

A variety of teaching methods are used in this course, including textbook reading, small-group and large-class discussions, and both individual and team design challenges. These different methods are suggested with the understanding that not all students learn the same way. Some have a greater need to explore and invent on their own, while others need more structure. There is a guiding philosophy to this course.

First, we recognize the importance of the ideas and skills that students bring to the learning situation. Students are therefore encouraged to share their initial ideas and approaches to problems and to consider these initial ideas in light of new information and insights provided by the teacher, the course material, and other students. That is why small- and large-group discussions are essential.
Second, we recognize that conceptual change is not always easy or immediate. Sometimes students need to struggle with conflicting ideas so that they may construct a more meaningful and consistent understanding of the content. For example, students often struggle to understand that engineers do not consider the “failure” of a model design to be a bad thing. Failures help engineers find weaknesses, so that their next design will provide a better solution to the problem.

Third, it is simply not possible for students to learn the engineering design process from the textbook alone. The activities are absolutely essential. In many cases, high school students have no previous experience solving problems that require them to think “outside the box,” while at the same time subjecting their designs to specific criteria and constraints. Finding an elegant solution to a problem can be immensely satisfying to your students, but it can also be very frustrating. That is why they are called “design challenges.”

Fourth, the engineering design process is at the heart of what engineers do. Even though most engineers do not follow this cyclical process step-by-step, it nonetheless provides a pathway for thinking, just as the inquiry method does for scientists.

Finally, there is no substitute for a teacher who is sensitive to the various learning styles of his or her students and capable of modifying a lesson on the spot or taking advantage of a “teachable moment” to help students raise their understanding to a higher level.

The following chart illustrates that scientific inquiry and engineering design are parallel processes with many similarities:

<table>
<thead>
<tr>
<th>Scientific Inquiry</th>
<th>Engineering Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulate a question.</td>
<td>Define a problem.</td>
</tr>
<tr>
<td>Research how others have answered it.</td>
<td>Research how others have solved it.</td>
</tr>
<tr>
<td>Brainstorm hypotheses and choose one.</td>
<td>Brainstorm solutions and select one.</td>
</tr>
<tr>
<td>Conduct an experiment to test the hypothesis.</td>
<td>Create and test a prototype.</td>
</tr>
<tr>
<td>Modify hypothesis based on results.</td>
<td>Redesign solution based on test results.</td>
</tr>
<tr>
<td>Draw conclusions and write paper.</td>
<td>Finalize design and make drawings.</td>
</tr>
<tr>
<td>Communicate findings orally and in writing.</td>
<td>Communicate design in words and drawings.</td>
</tr>
<tr>
<td>Investigate new questions.</td>
<td>Define new problems.</td>
</tr>
</tbody>
</table>

Although engineering design is emphasized in most of the projects, there is a very strong emphasis on scientific inquiry in Project 3.0, in which students need to figure out how their putt-putt boat works in order to improve on the design. Engaging in this process is very important for the students to learn how energy flows in thermal and fluid systems, which leads to an understanding of the physical principles that underlie the operation of engines.
There is one more notable difference between teaching the mathematics of science versus the mathematics of engineering. Science is a global enterprise, so the metric system is uniformly used in scientific laboratories and classrooms worldwide. Engineers, however, must work with the materials and equipment provided by their culture, and for students in the U.S. that is the English system of units. It’s not possible to go to a lumberyard in the U.S. and order wood by the meter, or to inspect a bill from the electric utility to find the cost of electricity in joules rather than kilowatt-hours. So, in this course we use the system of units that will be easiest for students to apply in the world around them.

**How do the tasks incorporate the “Five Es”?**

Each task of a project in ETF addresses at least one of the “Five Es”: Engage, Explore, Explain, Elaborate, or Evaluate (Bybee, 1966). Demonstrations, quick-builds, or focus questions motivate engagement. Students do hands-on explorations that lead to discovery. Once students have explored the concepts, questions naturally arise, so they are ready for the teacher’s (or another student’s) explanation. Activities that involve the students in applying what they just learned give them opportunities to elaborate and extend their understanding. Finally, benchmark questions and rubrics help the students evaluate their own work with input from the teacher. When teaching, you may want to modify the balance of the Five Es to provide purposeful reinforcement or emphasis to meet your own students’ needs.

**Why are readings and discussions important?**

The textbook chapters provide information and encourage thinking that would not be possible with hands-on projects alone. Citizens are rarely asked to vote on whether or not they would like to see a new technology developed and introduced. Nonetheless, as workers and consumers in modern society, we collectively make those decisions every day. All new technologies that enter the mainstream—such as automobiles, telephones, and, more recently, cell phones—result from the collective actions of millions of individuals. These technologies, in turn, have a profound effect on human societies. The readings and questions encourage students to think about the effects of technological revolutions of the past and recognize how their own actions will affect the world of the future. Class discussions about the readings are a very important means of helping your students fully grasp these important ideas.

**Why is the course organized around projects?**

Student learning is often measured by “on demand” tests. However, a person’s performance in the world of work is rarely measured in that way. Instead, employees at all levels are evaluated based on their productivity and their ability to work well with others. Projects are an excellent way to encourage teamwork and individual contributions to the efforts of a group. Projects are also an engaging vehicle for communicating key concepts and providing opportunities for students to develop skills related to technology and engineering. Consequently, instead of using the term “unit” to name the major divisions of the activities in the course, we refer to these as “projects.” While in common language the term “project” means any planned undertaking, engineers use the term to mean a major piece of work with a clear goal, process, and endpoint. Engineering projects almost always involve teams of people with complementary skills who apply their knowledge and creativity to reach the overall goal.
What are the tasks?

Each project is further broken down into “tasks.” Each task is an essential learning experience, which ranges in length from one to ten class sessions. Tasks begin with focus questions to orient students to the central ideas, and a set of objectives to guide the teacher in ensuring that the students are moving toward specific understandings and skills. Breaking large projects into small tasks can be very helpful to students who may at first be overwhelmed by a major project.

Why should you collaborate with other teachers?

As a teaching method, collaboration with other teachers at the school site can make it possible for students to see the connections among various school subjects. Connections with science and math are obvious, but there are often good connections with art and graphic design teachers, as well as English and social studies teachers. For example, if you are aware that your students are studying American history, you might want to add a reading on Benjamin Franklin’s role in understanding the nature of electricity while they learn about his role as a diplomat and statesman in their history class.

How can you best communicate with your school community?

Parent’s Night or Open House is an obvious way to get feedback from parents. You might also want to send a note home on occasion asking parents to share what they have heard from their students about the class and to offer any suggestions they might have. Parents and others in the school community often have great connections to local industries that are willing to contribute materials to schools. As well, identifying engineers and technicians that are in contact with the students, such as friends and relatives, and inviting them to come speak to the class is a great motivator for learning. Finally, to build interest and enthusiasm for engineering in your school, you may want to communicate with the rest of the faculty and student body about what your students are doing. Arranging for displays of student projects is an excellent way to share your students’ work with the school, and the video about Engineering the Future we provide on the DVD in this Teacher Guide is another way of communicating what this course is all about.

How can you learn more about ETF?

Teaching this course for the first time may be challenging for many teachers. Science teachers might be unused to supervising students in the safe use of tools, or the logistics involved in building projects, especially if there is no shop space available. Technology teachers may be unfamiliar with the energy concepts, or techniques for engaging students in the inquiry process. To help teachers meet these challenges, the developers of Engineering the Future have also created professional development programs and materials.

Professional development materials include a DVD with an overview of the course, and Teacher Tips, which are short video clips about key concepts in the unit. Other programs include presentations at teachers’ conferences; multi-day teacher institutes; an online professional development course, which can be taken for graduate credit; as well as an online discussion forum. To learn about programs currently available, check the web site at the Museum of Science in Boston www.mos.org/etf or Key Curriculum Press www.keypress.com/etf.
We invite your feedback

The remainder of this Teacher Guide provides detailed suggestions for presenting the four projects and each task of the course. In order to improve these materials, your input is absolutely essential. As you complete each project, please take notes, and then write to tell us what you and your students have done, what worked, what didn’t work, and what we can do to improve the course. Send your suggestions to editorial@keypress.com.

Thank you, and welcome to the community of people who teach Engineering the Future.

References


