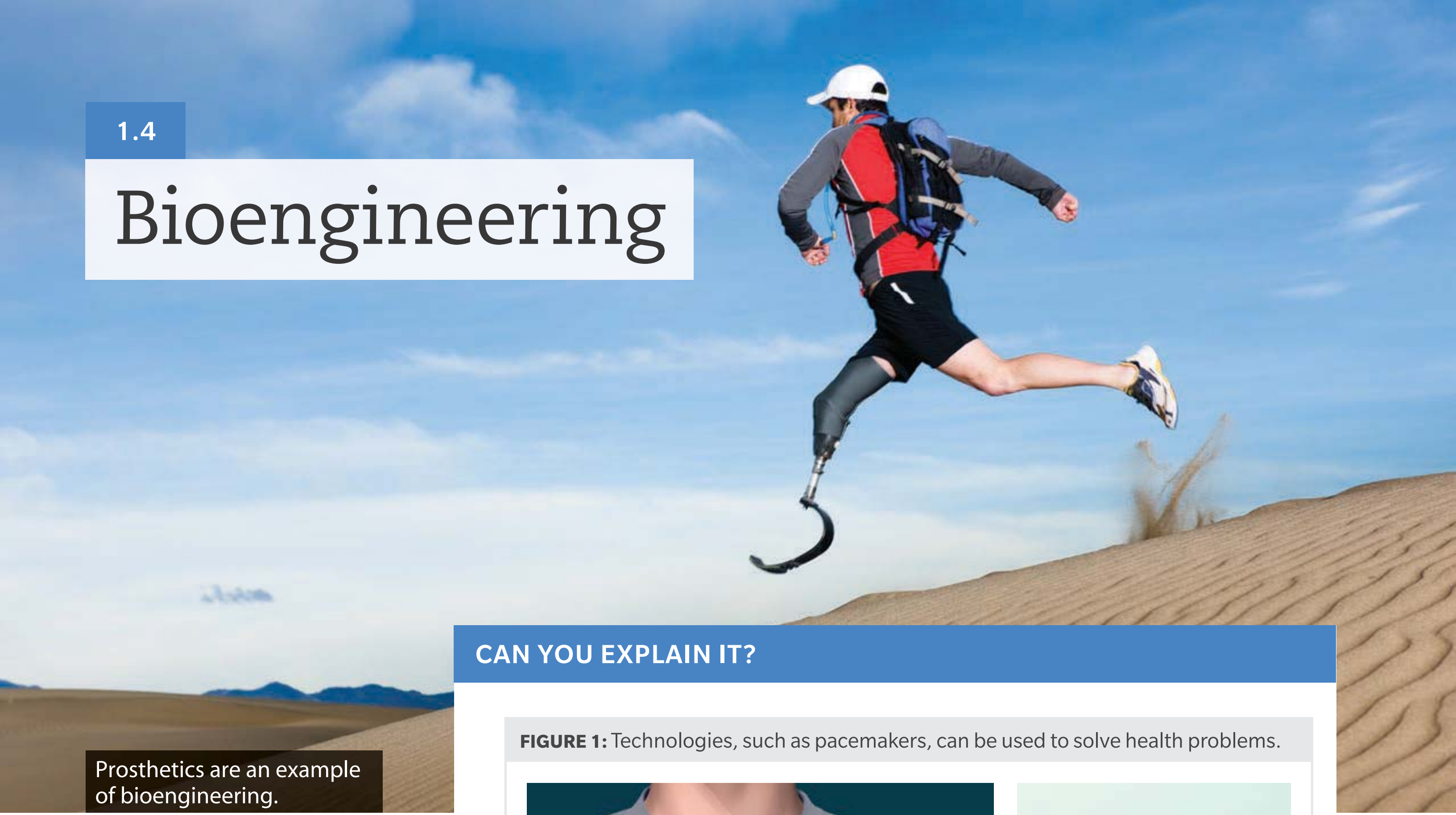
1.4

Bioengineering

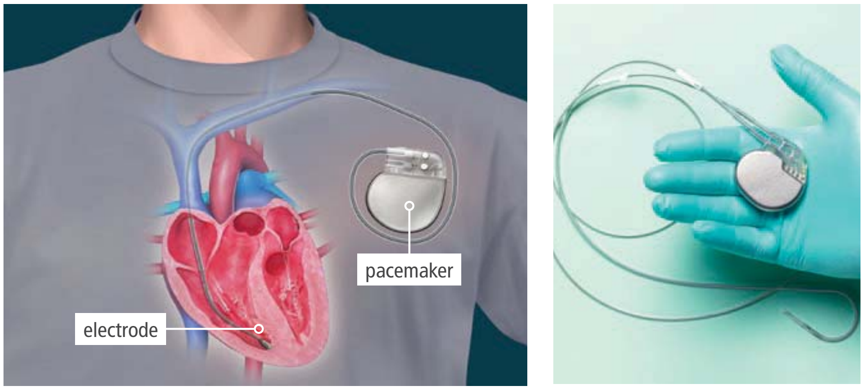


Prosthetics are an example of bioengineering.

Gather Evidence As you explore the lesson, gather evidence to explain how a nonliving system can be designed to work together with a living system.

CAN YOU EXPLAIN IT?

FIGURE 1: Technologies, such as pacemakers, can be used to solve health problems.



In a healthy heart, the rhythmic beating is the result of carefully timed nerve signals that spread throughout the cardiac muscle. These signals cause the muscle to contract in a specific sequence that forces blood to travel through the atria and ventricles of the heart. When these signals fail to fire correctly, the heart may beat slowly or erratically, or one or more chambers may not contract properly. If this occurs, a medical professional may fit a patient with a pacemaker.

Pacemakers are designed to take over or assist the nerve signals that occur naturally in the heart. The first battery-operated, portable pacemakers were developed in the 1950s. A modern pacemaker, shown in Figure 1, consists of a battery and computer in the casing with electrodes entering the heart. The electrodes and computer work together to monitor the heart's activity and send electric impulses when the heart's rhythm is abnormal. The battery provides the power for the electrodes to stimulate the cardiac muscle.

Predict The batteries in pacemakers do not last forever and eventually need to be recharged or replaced. What types of features would you need to consider when designing a better battery for a pacemaker?

Image Credits: (t) ©MichaelSvoboda/E+/Getty Images; (br) ©Photographer's Choice/Peter Dazeley/Getty Images

Technology and Living Systems

When you think about the term *technology*, you probably think of a cell phone or a tablet computer. Technology is the application of scientific knowledge for practical purposes. Technology does include advanced machines, such as computers and robotic equipment. It also includes simpler items you may not have thought of, such as sunglasses, scissors, and pencils.

Collaborate Discuss with a partner three technologies that you used as you prepared for school today.

Technology and the Human Body

Over the course of human history, advancements in science and technology arose through the process of engineering. Bioengineering applies the concepts of engineering to living things. Through bioengineering and scientific advancements, biotechnology has developed that allows people to live longer, healthier lives.

Analyzing Benefits, Risks, and Costs

Every new technology has benefits, risks, and costs. Bioengineers must analyze these tradeoffs when considering how new or improved technologies can impact living systems. Decisions must be made about whether a new technology's benefits outweigh the associated costs and risks. Benefits are the favorable effects of the solution, while the costs and risks are the unfavorable effects. A cost might include the impact on the environment. A risk could be the side effects from using a medical device. Engineers must balance the benefits, risks, and costs of each design solution.

FIGURE 2: A cochlear implant sends audio signals to the brain.

For example, cochlear implants increase the hearing ability for people with damaged inner ears. In a normal ear, the pinna (the ear's outer portion) funnels sound waves into the auditory canal. The sound waves then hit the eardrum, causing it to vibrate. These vibrations are then applified by the middle ear. Hair cells in the cochlea convert the waves into impulses that are transmitted to the brain by the auditory nerve.

A cochlear implant, shown in Figure 2, has a microphone and speech processor, which pick up sounds from the environment. A transmitter and stimulator convert signals from the processor into electrical signals. An electrode array implanted into the cochlea collects the electrical signals and sends them to the auditory nerve.

Analyze How does a cochlear implant's process of transmitting sound to the brain mimic the process used by the ear?

Scientists and engineers continue to modify technology to meet the needs and demands of society. This often involves increasing the benefits of technology while reducing the costs and risks. For the cochlear implant, engineers could increase the benefits by improving the speech recognition ability. They also may work with scientists to decrease the likelihood of infection, reducing the risk. Engineers may find new materials that reduce the cost on the environment and reduce the cost of the implant. A replacement for precious metals in computers could reduce the environmental impact from mining and make an implant less expensive.

Research and Development

Scientists ask questions to learn more about a phenomenon, and engineers design solutions to problems related to that phenomenon. This back-and-forth between scientists and engineers is part of a process known as research and development. The studies and testing performed during this process often lead to the development and improvement of technologies.

Explain How are technology and life sciences related in the field of bioengineering?

In the case of the cochlear implant, scientists asked questions to learn more about the phenomena of hearing. Scientists might have asked, "How do the ear and brain interact to detect sound?" or "Which structures are affected in patients with hearing loss?" Engineers designed the cochlear implant using information on the mechanics of hearing that arose from scientific research.

Technology and Society

Technology has greatly influenced society, and society has influenced progress in technology. New technologies change our lifestyles, diets, and living spaces. Likewise, as social trends, economic forces, and cultural values change, new technologies emerge that support these changes. These new technologies also may propel society toward new changes in culture, health, and the environment.

Consider the advances in emergency medical treatment and technology. Prior to the 1950s, many ambulances were simply a way to deliver a patient to the hospital. Ambulances only had enough room for a patient in the back, so no medical care could be given during transport. Changes in societal expectations led to vehicles with enough room for emergency responders to work on patients, as well as new technologies to save lives. Modern ambulances continue to undergo design changes as new medical needs arise.

FIGURE 3: With technological improvements, emergency response time is faster.

Science as a Human Endeavor How have improvements in emergency medical technology changed our society?

All new technologies come with risks and costs to people and society, no matter how great the benefits. For example, many vaccines are refrigerated, allowing them to remain effective for longer periods of time. Refrigeration is rare in some parts of the world, though, making it difficult for people to access these vaccines. Refrigerants also add to the greenhouse gas effect. In response, some researchers are turning their attention to producing vaccines that do not require refrigeration.

Engineering

Clean Drinking Water

FIGURE 4: Societies around the world gain access to clean drinking water through new engineering designs, such as improved devices to transport water and new wells.

Many people in the world do not have access to clean drinking water. They must walk miles to and from wells to bring water to their homes. Once they carry the water home, it often needs to be filtered to avoid water-borne diseases, such as cholera. In response, bioengineers developed better water filtration systems in wells, making the water cleaner and safer. Engineers also developed devices to make it easier to transport water over long distances, as shown in the left image in Figure 4. Getting water can be a full day's work and is often the job of women and young girls. By decreasing the time spent focusing on water, women and girls have more time to devote to other tasks, such as education.

Collaborate If you were asked to design a device to transport water, such as the rollers shown in Figure 4, what societal, cultural, and environmental impacts would you need to consider?

In some cases, by solving one problem, advances in technology can cause new social and economic problems. Medical technology has enabled many humans to live longer lives. In some countries, longer life spans mean that the proportion of older individuals continues to grow, and more resources are needed to support these people.

The environment also is a concern when it comes to new technologies. Disposable medical supplies make it possible to use sterile equipment on each new patient. Once used, though, the material needs to be disposed of properly to prevent biohazardous waste from potentially affecting others.

Explain During the next 50 years, what biotechnology would you like to see developed or improved? Describe the potential benefits, risks, and costs of the technology and how it would impact society.

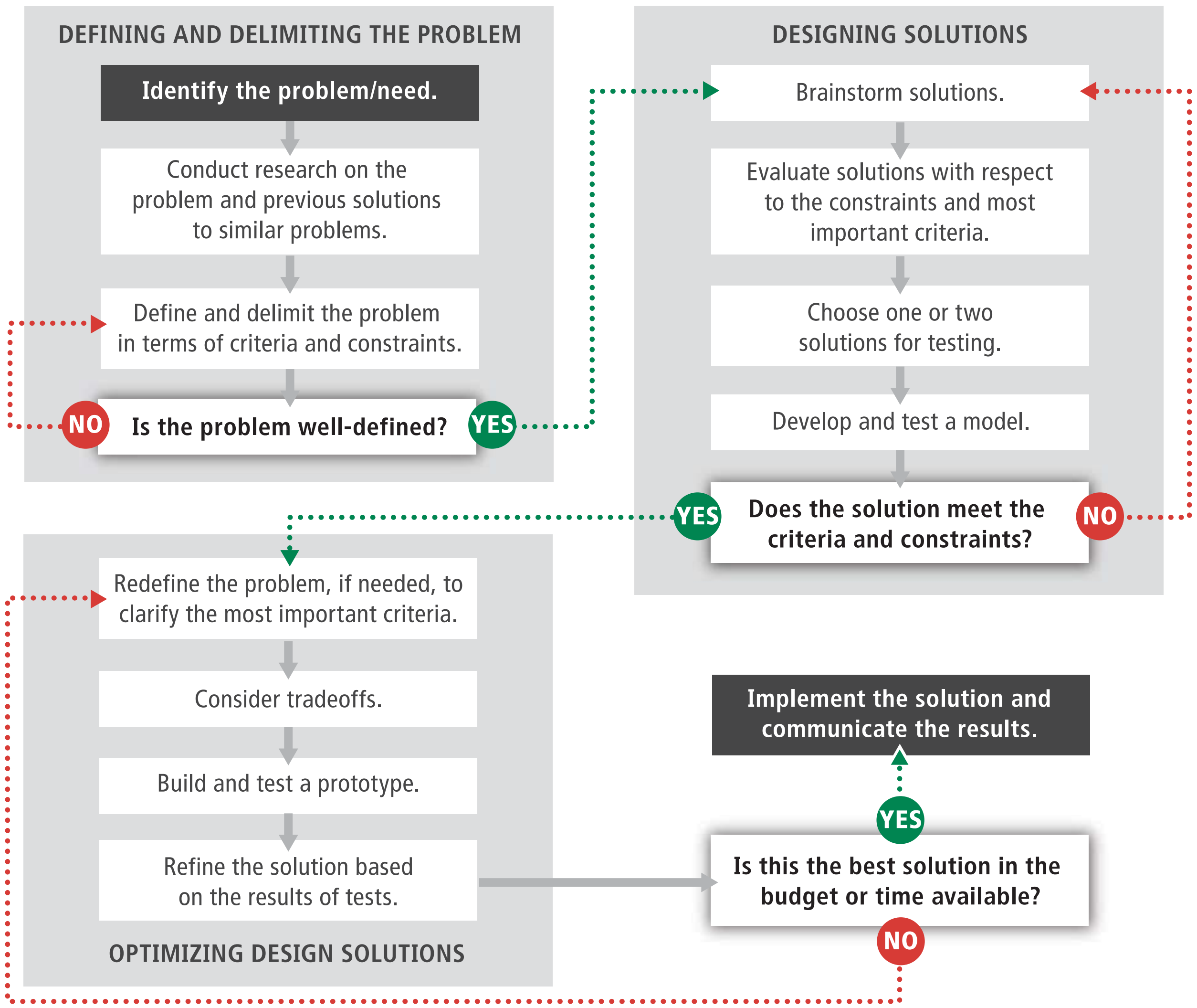
Engineering in Life Science

Engineering and scientific inquiry both involve a set of principles and a general sequence of events. Scientific investigations often include steps such as asking questions, making predictions, and investigating the effects of changing variables. The engineering design process includes steps, such as defining a problem, developing possible solutions, and optimizing a solution.

The Engineering Design Process

The engineering design process is a method used to develop or improve technology. The process is iterative, meaning it uses repeating steps. Engineers do not always apply these steps in the same order. They may skip some on occasion or perform other steps more than once.

FIGURE 5: The engineering design process is a set of steps that lead to designing or improving a solution to a problem.



Following a well-defined set of steps ensures that engineers take a thoughtful and complete approach when designing a solution to a problem. In this process, engineers must first identify and define the problem or need. In doing so, they may need to perform research or analyze data to learn more about the problem. They must identify aspects that are desired in a final solution as well as the limits on the solution. Next, engineers will begin to design solutions. During this stage, they will evaluate several different solutions and choose only one or two options to begin testing. In the testing, or optimizing, stage, designs are tested using computer simulations and prototypes. Based on the results of these tests, the designs may be accepted or refined. The engineers may even decide to choose a different solution and start the process over.

Imagine that bioengineers are designing a new type of artificial hip. They will need to research how a normal hip functions and what types of materials are safe to use. The client that hired the engineers may ask the team to consider using 3D printing to custom fit the product to each patient. They may also say the design can cost no more than $10,000. The engineers will come up with many different design solutions, but only those that cost less than $10,000 will be considered. The final design may not be 3D printed, but it may have other aspects that make it better. Engineers must consider these types of tradeoffs before presenting their final design.

Collaborate With a partner, discuss why it is necessary for scientific and engineering processes to be iterative, instead of following a fixed sequence of steps.

Defining and Delimiting the Problem

The first step in the engineering design process is to ask questions that help specifically define the problem. These questions help an engineer understand the criteria for the design. Criteria make clear what a successful solution must accomplish and how efficient and economical that solution should be. These are the "wants" for the solution. Criteria can include many different aspects of a design, but often cost, safety, reliability, and aesthetics are considered.

Then, engineers delimit the problem. Delimiting is the process of defining the limitations, or constraints, of the solution. Constraints are the limitations of a design and are usually given by the client. These constraints can include things like cost, weight, dimensions, available resources, and time. Any solution that does not meet the constraints of the design is not considered.

Engineers often must balance criteria and constraints. They may accept some risks in tradeoffs, or compromises, for greater benefits. Engineers also may give up one benefit in favor of another to avoid a potential risk. Consider the artificial hip example again. Any design that exceeds the $10,000 constraint is not approved. The manufacturer may consider a design using more typical materials if that reduces a risk or increases a benefit over using different materials. The benefit of the tradeoff will depend on the problem defined by the engineer.

Analyze A company is designing an electric wheelchair and hires you as the engineer. They tell you the wheelchair must not cost more than $5,000. The design must be usable by people with limited hand movement and should not require a battery replacement very often. In your Evidence Notebook, define the problem and then list criteria and constraints for possible solutions.

Explore Online

Hands-On Lab

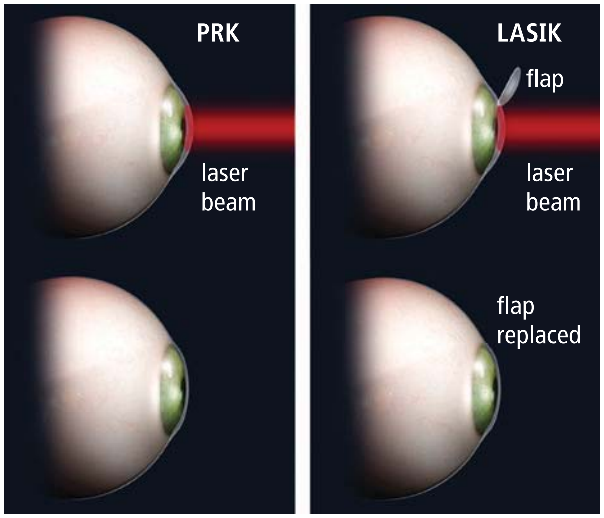
Modeling Joint Movement

Use the engineering design process to develop models of the joints in the skeletal system and test their ranges of motion.

Engineering

Vision Correction Technology

FIGURE 6: PRK and LASIK both correct a person's vision using a laser, but the technique used will depend on the needs of the patient.



Vision correction has undergone many changes since glasses were first developed in Italy in the 13th century. In addition to modern glasses, people with impaired vision also can buy contact lenses or undergo surgery to fix their eyesight. LASIK and PRK are two of the more recognizable technologies developed to address vision problems. In LASIK surgery, a blade or laser forms a flap on the outer surface of the cornea. Then, another laser reshapes the cornea. In PRK, the surface layer of the cornea is removed and the corneal bed is reshaped. Doctors and patients must weigh the criteria and constraints before choosing a solution. Figure 7 lists several of the criteria for each of these vision correction technologies.

Analyze Analyze the tradeoffs between each of the engineering solutions for vision correction technologies in Figure 7. How would a doctor explain the tradeoffs of each choice to a patient? What questions might a doctor ask to help a patient pick the technology that best addresses their needs and wants?

FIGURE 7: Vision correction technologies have tradeoffs including safety, reliability, cost, and aesthetics.

Technology	Eyeglasses	Contact Lenses	LASIK	PRK
Safety	Provides sun protection and physical protection for the eyes.	Provides sun protection but not physical protection. Infections are possible if lenses are not cleaned often.	Cannot provide sun or physical protection. Procedure is generally safe. Relatively short recovery time.	Cannot provide sun or physical protection. Procedure is generally safe. Longer recovery time.
Reliability	Can be lost or broken. Lenses or frames can be replaced as needed.	Can be lost or torn. Can be replaced as needed.	Results are relatively permanent. Glasses may become necessary.	Results are relatively permanent. Glasses may become necessary.
Cost	Prices range from tens to hundreds of dollars.	Prices range from tens to hundreds of dollars.	Prices are typically in the thousands of dollars.	Prices are typically in the thousands of dollars.
Aesthetics	Come in many colors and shapes. May obscure some facial features.	Come in many colors. Do not obscure facial features.	Does not obscure facial features. Eye color cannot be altered.	Does not obscure facial features. Eye color cannot be altered.

Engineers prioritize criteria by deciding which ones are most important for a given problem. They make tradeoffs between them to begin brainstorming solutions to the problem. Engineers may even redefine the problem to clarify the most important criteria before beginning to design and test a solution. Remember, if a proposed solution does not meet the constraints of the problem, it will not move forward in the engineering design process.

Designing Solutions

After engineers have identified the constraints and criteria for solving a problem, the next step is to brainstorm design ideas for a solution. Usually, engineers and other specialists work in teams when brainstorming. The group leader presents the problem to be solved and encourages all ideas to be suggested, even if they seem outrageous.

Once the team has brainstormed several ideas, they may use a decision matrix, or Pugh chart, to evaluate each solution against the criteria of the problem. In a decision matrix, each criteria is given a number, or weight, based on how important that criteria is. The more important the criteria, the greater the weight assigned to it. Then, each design is rated based on how well it meets those criteria. The scores for each design are multiplied by their respective weights, and the products are totaled so engineers can determine how well the design is meeting the criteria. They may choose to take the design with the highest score to the next phase, or they may choose to brainstorm new ideas if no designs meet the requirements.

FIGURE 8: An example decision matrix for three water filtration system designs, weighted on a scale from 0 to 5

Design Criteria	Weight	Design 1	Design 2	Design 3
Safety	5	4	1	5
Reliability	4	2	3	4
Cost	2	1	2	1
Aesthetics	1	1	1	0
Total Points		31	22	43

Figure 8 shows how a decision matrix can be filled out for three designs. In this example, each column represents a different design for a new water filtration system people can use in their homes. Safety is weighted a 5, meaning it is extremely important. Aesthetics, though, are weighted very low, meaning they are not as important. To determine how to weight each design, engineers may choose to make a model or run computer simulations to see how each design would work in a typical situation.

A bioengineer may use a decision matrix to evaluate a technology, such as a new design for a Continuous Positive Airway Pressure (CPAP) machine. These machines are worn by people who suffer from sleep apnea, a condition where breathing starts and stops during sleep. CPAP machines are worn while a person is sleeping and supply a constant source of pressure to help keep their airways open. The criteria for a machine like this would likely include safety and reliability but also may include comfort, ease of use, and noise level.

FIGURE 9: Examples of different CPAP designs

Engineering Make a decision matrix for the three CPAP machines shown in Figure 9. What criteria do you think are important for this machine? How would you weight them?

Once a number of solutions are proposed, they are evaluated against the criteria and constraints set out for the desired solution. Solutions that do not meet the constraints must be redesigned if they are to be considered. In general, one or two ideas that best meet the criteria and all constraints are selected, and these ideas enter the optimization phase of the design process.

Optimizing Design Solutions

When one or two solutions have been chosen, engineers may build a prototype of the technology to further test the capabilities and effectiveness of the design. A prototype is the first build of a design and may not be built to scale or with the final materials. Since the results from testing the prototype may result in design changes, prototypes are often built with cheaper materials than the final version. This way, engineers can run many tests and build many versions of their designs. As the design becomes more refined and finalized, engineers may begin to use the final materials to ensure the solution will work as expected.

Analyze What types of information can be gained from building a prototype that is not an exact model of the final product?

Engineering

Optimizing Prosthetics

One of the biggest challenges often facing designers is the need to think creatively and to seriously consider new designs. While not traditional, these new designs may be what are required to solve a problem or improve an existing product. Van Phillips engineered the "blade" prosthetic leg/foot now preferred by runners. His design abandoned the traditional clunky prosthetic, favoring lightweight materials tailored to athletes, as shown in Figure 10.

FIGURE 10: Prosthetic leg designs have changed over time. As new materials are developed, new ideas are generated.

Collaborate Discuss this question with a partner: How have advances in the different fields of science and engineering influenced prosthetic limb technology?

Testing is an important part of the engineering design process, allowing engineers to get feedback on the design. Data collected from tests will tell engineers if their design is working as expected. The data also may show design problems that were not seen in early stages of the process. Engineers will review these issues and determine which ones need to be fixed. Considering tradeoffs is an important part of the optimization process. Issues that do not seriously impact important criteria or constraints may not be corrected if the tradeoff is undesirable, such as increasing the cost of the design. However, if the problem is important enough, engineers may need to change the design or brainstorm new designs to address the concern.

FIGURE 11: Engineers may return to a design or a prototype during the optimization process.

Life cycle analyses are another way to evaluate a design. A life cycle analysis attempts to evaluate the real cost of a new technology or design. It takes into account the materials and energy used to manufacture, transport, use, and dispose of a product. Perhaps one design has several benefits over another. If the design is much more expensive to produce, manufacturers might abandon it in favor of another, less expensive design. If it wears out quickly and needs to be replaced often, the design might be abandoned in favor of a more durable alternative.

Life cycle analysis also considers the environmental impact of the materials and wastes from producing the design. Engineers might consider an alternative if manufacturing a design produces pollution. If the product cannot be thrown away safely, a biodegradable or recyclable option may be considered.

Engineers may also run a cost-benefit analysis to further evaluate their design solution. A cost-benefit analysis is a method of identifying the strengths and weakness of a design. The cost could be the monetary cost to produce the design. If the device costs too much to make and the benefits are not great enough, the design solution may be disregarded in favor of a less expensive design. A cost also could be related to environmental factors. If a design uses a very rare metal and will result in large-scale mining, the environmental impact may outweigh the benefits, especially if a different material could be used.

When a final design has been chosen and fully tested, engineers will communicate their results. This may just involve presenting the final solution to the client to begin production. If the design is new or groundbreaking or has important implications, the engineering team may publish a journal article detailing the design to the scientific community.

Language Arts Connection

Research the life cycle of different cell phones. How long are they built to last? What are the energy requirements to manufacture a phone? Develop your own life cycle analysis of a phone to determine the true cost of the technology.

Explain How do you think the engineering design process differs for biotechnologies, like pacemakers, used in the medical field compared with that used in other fields of technology, like in developing a cell phone?

Careers in Science

Careers in Bioengineering

Bioengineering includes a variety of fields, such as biomedical engineering, cellular engineering, molecular engineering, and others. Bioengineers use engineering methods and biological science to design and manufacture equipment, computer systems, and new materials used in the field of biology.

Biomedical Engineering

Devices made by biomedical engineers include artificial joints and organs, prosthetics, corrective lenses, and dental implants. Biomedical engineers still use the engineering design process to help them develop and optimize medical technologies. In this field, engineers must always consider how a design will interact with the different systems of the human body.

FIGURE 12: Biomedical engineers design devices, such as prosthetic limbs. This prosthetic limb is designed to interpret messages from the user's nervous system.

A bionic hand, as shown in Figure 12, might interact with the nervous system to interpret signals to grasp an item. However, implanting such a device could cause a stress on the immune system, causing the body to reject the device. Biomedical engineers must consider all potential health risks when designing solutions.

Imagine that a company wants to develop prosthetics for competitive swimmers who have had one of their legs amputated at the knee. The company needs a working design within six months and wants each prosthetic to cost less than $30,000. The prosthetic must last a swimmer at least five years before any parts need to be replaced. How would an engineering team solve this problem?

First, the engineering team must define and delimit the problem. The constraints were given by the company: The design must cost less than $30,000; it needs to be completed in half a year; and all components need to last at least five years. The criteria for this problem may include weight, hydrodynamics in the water, and safety of use.

Once the problem is defined, engineers will begin brainstorming possible designs. Each proposed design will be evaluated, and the solutions that meet all constraints and the most important criteria will be chosen for testing. When developing prosthetics, engineers may run computer simulations and use other types of models to help evaluate each solution. The team may realize that traditional prosthetic materials are too heavy to be used for an aquatic prosthetic. Instead, they may research more lightweight materials.

The engineering team will then begin testing and optimizing their designs. They will build prototypes and may even fit their prototype to swimmers to get feedback and data on the design. At this stage, engineers may realize their design generates too much drag in the water and needs to be redesigned to be more streamlined.

Even when the client approves a solution, engineering teams may continue to review designs and make improvements. As technology changes, there are new opportunities for improved design concepts.

Working with a team, develop your own design of an aquatic prosthetic leg. Imagine you are working with the same constraints outlined in this example. With your group:

Define and delimit the problem In your group, outline the criteria and constraints and then clearly define the problem.

Design a solution Each individual in your group should propose a potential solution. Assign weights to the criteria your group outlined, and make a decision matrix to evaluate each design. Choose the highest-rated design, or brainstorm additional ideas until you find a solution that solves the problem your group outlined. Remember, you may need to redefine the problem if the design solutions do not meet the criteria or constraints. When your final design has been chosen, make a model, such as a drawing, of that design and have your teacher approve it before moving to the next stage of the process.

Develop a prototype Using common household and classroom items, develop a prototype of your approved design. You may use items such as paper towel rolls, PVC tubing, cardboard, tape, and any other items you may need. Remember, a prototype does not need to be a replica of the final product. Your prototype may not be made to scale or it may not be waterproof. The prototype should be able to demonstrate how the design will work, but it does not need to function completely.

Optimize the design After building your prototype, review your design and identify areas where the design could be improved. Review the criteria and constraints again to ensure your design is solving the problem. If you feel your design did not work, brainstorm new designs or ways to change aspects of your designs. You may wish to build an additional prototype to test your modifications.

Language Arts Connection With your group, research other designs for prosthetics that help people swim. Then, make a presentation to share with the class. In your presentation:

- Include a summary of your research and the prosthetic designs you discovered.
- Present a diagram of your final design to the class.
- Explain the most important criteria considered in designing your solution.
- Finally, present your prototype and explain how your design will solve the problem.

Cellular Engineering

Cellular engineering is a field of bioengineering that combines an understanding of cellular functions, biological systems, and engineering practices to develop technologies that help improve people's lives. For example, cellular engineers may study ways that stem cells can be used to improve the lives of people with medical conditions, such as Parkinson's disease or diabetes.

Tissue engineering uses aspects of cellular engineering to develop biological tissues. Whole tissues or portions of tissues can be made from cells and then used to repair damaged areas of the body. Scientists in this field are even trying to make entire organs using their understanding of cellular function, engineering, and biological systems.

FIGURE 13: Bioengineers develop technologies, like MRI machines, to help scientists learn more about living systems.

Molecular Engineering

Molecular engineering is a highly integrated field of study combining knowledge from biology, chemistry, mechanics, and materials science. Molecular engineers study ways to build better materials and systems by studying the molecular properties of those materials.

In the field of biology, molecular engineers are studying immunotherapy. Immunotherapy is the treatment of disease by amplifying or minimizing the body's immune response. Molecular engineers are developing vaccines to increase patients' immune responses.

Molecular engineers also are researching ways to edit and manipulate an organism's genetic material. This may allow them to treat or cure genetic disorders, modify metabolic rates, and modify the structure of proteins to make new functions. To make changes to the genetic material of an organism, molecular engineers are developing new technologies to help further their research.

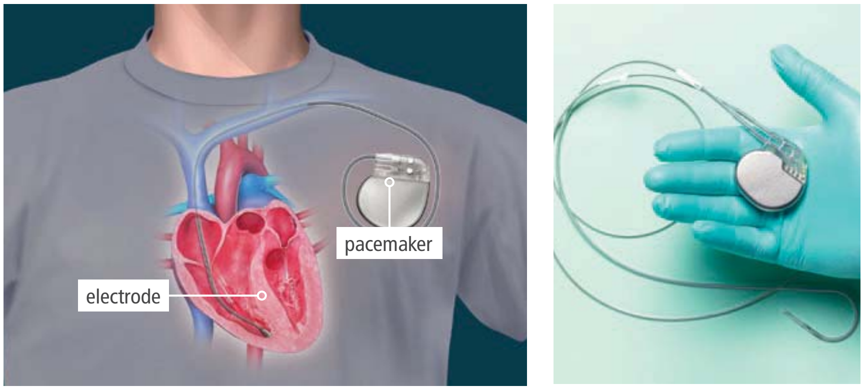
Language Arts Connection Write a short newspaper-style article comparing and contrasting the different fields of bioengineering.

3D BIOPRINTING | NANOTECHNOLOGY | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 14: A pacemaker is a nonliving system that functions inside a living system, the human heart.



Pacemakers generate electrical signals that stimulate the heart when cardiac activity is abnormal. The pacemaker has gone through many design changes based on improved technology and medical knowledge since its initial conception. As technologies improved, designs became smaller. As scientific understanding of anatomy, heart conditions, and biological systems progressed, so did the efficiency of pacemakers. Scientists and engineers continually work together to improve upon this design and many others in the medical field.

Explain The batteries in pacemakers eventually need to be recharged or replaced. What types of features would you consider when designing a better battery for a pacemaker?

When designing a new component for a device, engineers will still use the engineering design process. The process is iterative, so the steps may not be applied in the same order. For example, when designing a new battery for a pacemaker, engineers may start by testing pacemakers and existing batteries. The data gathered in these tests may help them brainstorm new ideas for how to improve the previous design.

The engineering team also will have different constraints when improving a design than when creating a new design. For example, engineers will only be able to develop batteries that fit inside the existing pacemaker and work with the components already in the design. They also may be working within a shorter timeframe and a smaller budget than if they were developing a new pacemaker design.

By working with patients, doctors, and manufacturers, engineers can identify the most important criteria to incorporate into their design. Perhaps patients would rather have a battery that is easier to recharge than one that lasts a few years longer and needs to be replaced. Once engineers understand the limitations in the current design, the constraints, and the important criteria, they can begin developing new designs.

CHECKPOINTS

Check Your Understanding

1. Imagine that you are an engineer who designed a prototype for a client. After testing the prototype, you discover it does not address the client's needs. What might be a possible next step in the process?

2. You and a partner have brainstormed a design for an implanted device to help keep insulin levels in check for a person who is diabetic. What should be the next step in the design process?
   a. test on a patient
   b. build a prototype
   c. revise the design
   d. evaluate the design

3. Which of the following technologies would likely involve a bioengineer to design and build? Select all correct answers.
   a. artificial heart valve
   b. tablet computer
   c. artificial hip joint
   d. global positioning system
   e. automobile engine
   f. surgical robot

4. A biomedical engineer is developing a portable medical imaging machine designed to be used in remote areas or in situations where a natural disaster has made access to local imaging facilities difficult. She made a list of criteria and constraints for the new device. Which of these should be classified as criteria? Select all correct answers.
   a. transmits information wirelessly to base medical facility
   b. one person can carry it without assistance
   c. uses a rechargeable battery
   d. case made of high-impact plastic
   e. generates high-definition CT scans
   f. completes scans rapidly

5. One of the ways in which society impacts technology is through government regulation. Describe how government regulation can have both positive and negative impacts on technology.

6. Make a decision matrix to compare three models of a device, perhaps personal tablet devices or phones. Use the following questions to build the matrix and evaluate the results:
   a. What design criteria are most important?
   b. How would you weight these criteria?
   c. How would the competing designs score on each criterion?
   d. Which design(s) should move to the next stage of the process and why?

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Bioengineering is the application of engineering processes and practices to living things.

Engineering develops and modifies technological solutions for the needs of society.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how bioengineering solutions influence the environment while addressing the wants of society.