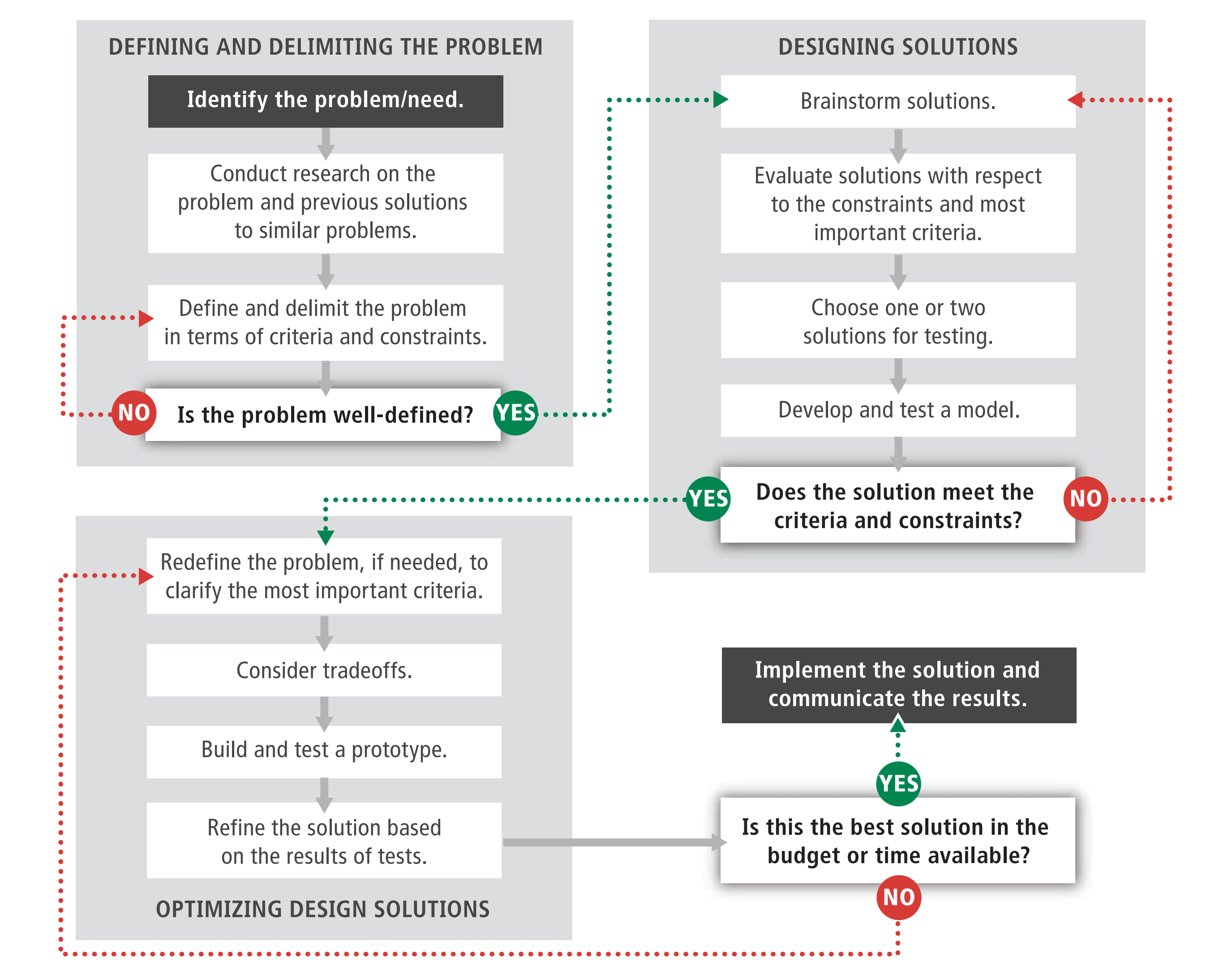
Engineering in Life Science

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.

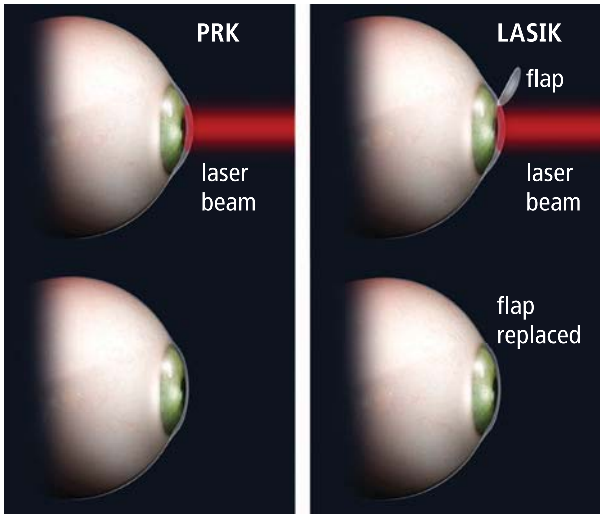
Explore Online

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.

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.

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.

FIGURE 9: Examples of different CPAP designs

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.

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

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

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?