2 Me, an Engineer?

INVESTIGATION

AN ENGINEER IS any person who designs, builds, or maintains engines, machines, structures, or processes to solve practical problems. A **biomedical engineer** is a specific kind of engineer who uses technology, mathematics, and knowledge of biological systems to solve biological or medical problems. Biomedical engineers often design, build, and test devices or procedures to help people. Examples of products that biomedical engineers have developed include artificial joints, pacemakers, and magnetic resonance imaging (MRI) scanners, which take pictures of the soft tissue in the body.

Although you may have never thought of yourself as an engineer, you have probably created solutions to problems that you have encountered. In this activity, you will simulate being both a patient with a broken arm and an engineer who is discovering ways to perform various tasks with one arm.

Ouch!

Arti broke her arm when she accidently fell off her bike. Her arm was put in a cast from the middle of her upper arm to the first joint of her fingers and then put in a sling. To make matters worse, she can't move her hand in the cast, and it is the hand Arti normally writes with! Her injury gave her a fresh perspective on her daily routine because she found it challenging to complete everyday tasks with one arm.

This X-ray shows breaks in the radius and the ulna bones located in the forearm.

GUIDING QUESTION

What tools and strategies can you design to deal with a broken arm?

MATERIALS

For each group of four students

- 1 ball of string
- 1 roll of masking tape
- 2 sheets of card stock
- 1 pair of scissors

For each pair of students

- 1 triangular sling
- 1 safety pin

For each student

- 1 Student Sheet 2.1, "Recording Solutions"

PROCEDURE

1. With your partner, decide who will wear the sling first. After visiting the stations, you will switch roles and the other partner will try the stations while using the sling.
2. Have the first person simulate a broken arm by putting their dominant arm (the one usually used for writing) in a sling. Look at the illustrations below to find out how to make a sling.

Tying a Sling
a. Lay the triangular bandage under arm with the point toward the elbow.
b. Bring the bottom corner up and around the back of the neck.
c. Tie the ends behind the neck.

3. Go to each station as directed by your teacher and try to perform the task described on the Station Card. With your partner, devise a solution to the problem. Although the partner with the sling cannot have physical help to solve the problem, work together to find a way to accomplish the task. You may develop a strategy or use the supplies provided to make a simple tool. Try to invent a solution that would allow someone to independently carry out this daily activity.

4. As you complete each task, have your partner record your solution on Student Sheet 2.1, "Recording Solutions." Identify the tools and strategies you use.

5. Think about your solution from the previous step and try to **optimize** it, meaning make it as good as you can given the constraints. You might improve your solution to the task by combining solutions or reducing steps. Your goal is to creatively come up with a more efficient solution. Record your improved solution on Student Sheet 2.1.

6. After you have visited the first half of the stations, have your partner wear the sling and repeat Steps 3–5 for the second half of the stations.

7. With your partner, review the stations and identify any questions you asked that helped form solutions.

ANALYSIS

1. What was the best solution you came up with during the activity? Explain what made it better than other solutions.

2. Describe the most challenging problem you think you would face in everyday life if you broke your arm.

   a. What questions do you have about this problem?

   b. Explain how you would solve this problem with a tool and/or a process.

3. What were the strengths and weaknesses of the model of putting your arm in a sling to see what it would really be like to break your arm?

   Hint: You may want to interview some people who have dealt with real injuries before answering this question.

4. Imagine a cast used for a broken arm. The cast has a structure. **Structure** is the way something is formed, built, or organized. Explain how its structure contributes to its function. **Function** is a purpose for which a particular thing is used.

5. Identify an everyday problem you would like to solve. Describe the problem and clarify what is and is not part of the problem.

   a. What individual or groups need this problem to be solved?

   b. What needs will be met by solving the problem?

   c. What scientific ideas or information are relevant to the problem?

   d. What are the potential societal and environmental impacts of a solution?

   e. How important is it to solve this problem?

   f. What is one solution or tool you would like to invent to solve this problem?

EXTENSION

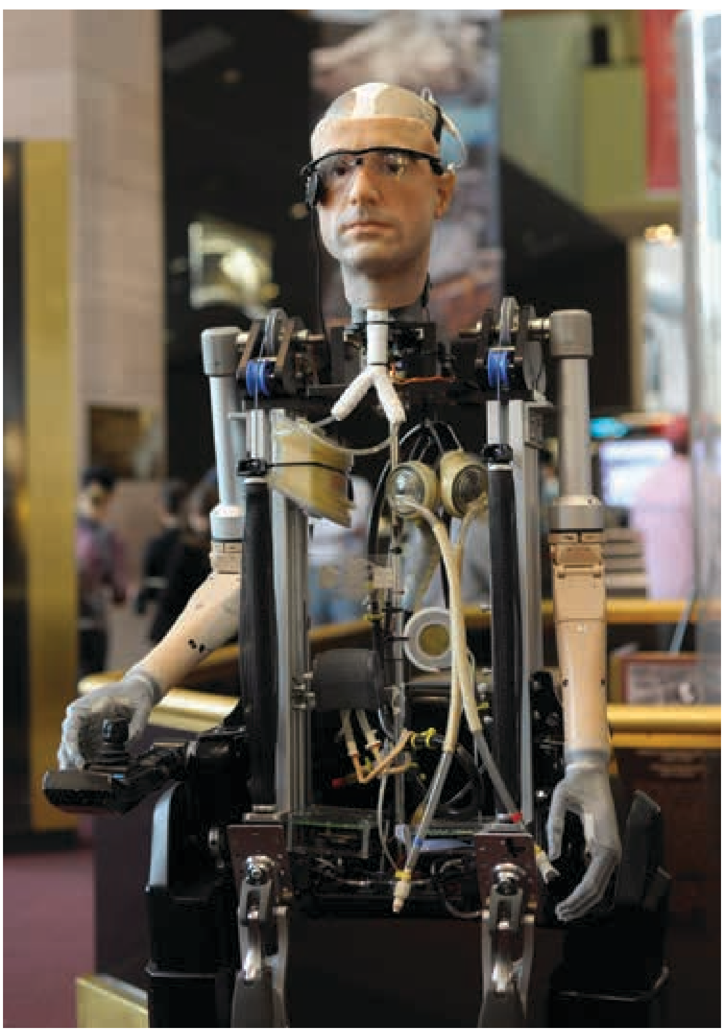
Interview a person with a disability from your community; ask them about some of the tools and strategies they use in daily life and how they benefit from available biomedical technologies.

A blind student reads braille created on a braille writer.

3 Bionic Bodies

READING

IN THE LAST activity, you developed tools and strategies to solve problems you would face if you couldn't use one of your arms. People invent strategies or tools to solve many kinds of problems. For example, memorizing paces is a strategy blind people use to navigate a familiar environment. Eyeglasses are a tool people with vision problems use to see better. In some cases, tools are designed to aid existing body structures, such as with eyeglasses. In other cases, tools are used to replace body parts altogether, such as with an artificial hip. In this activity, you will read about some individuals who have been affected by advances in biomedical devices.



The Incredible Bionic Man project combined all the prosthetic parts currently available to build a single functioning "body." It is made entirely of technologies used in real people. The face is modeled after Bertolt Meyer, a Swiss professor and life-long prothesis user.

GUIDING QUESTION

How has the development of artificial body parts changed lives?

MATERIALS

For each student

1 Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies"

READING

Use Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies," to guide you as you complete the following reading.

Case Study 1

Aimee Mullins is a successful model and actress. She has worked as a fashion model, been in over a dozen films or TV shows, and been featured in over 40 books or magazines. Aimee has even spoken about the topics of body image, identity, design, and innovation at a well-known conference.

Kelly Cartwright of Australia leaps to a gold medal in the long jump at the 2012 Paralympic Games in London, England.

But Aimee Mullins is not like most people. She was born without the fibulas in both of her legs. The fibula is one of the two long bones in the lower leg. When Aimee was a baby, her parents made the difficult choice to have her legs amputated just below the knees. This would give her the possibility of learning to walk with artificial legs. By the age of two, she had learned to walk with prostheses (praws-THEE-sees), which were, typical of that time, heavy and wooden. Despite this, she danced, played soccer, skied, and biked. In college, she became the first amputee to compete in the NCAA Division I track and field events. She went on to the Paralympics where she competed in the 100-m sprint and the long jump. She was the first person in the world to use flex-foot "cheetah" running blades, a carbon-fiber structure designed for running.

Now Aimee has over a dozen pairs of prosthetic legs, including designs that are suited for sports, some for everyday use, and a cosmetic pair that look and feel like real legs.

Without the new technologies of the past 40 years, Aimee would not be able to have such useful prosthetic legs. Over time, leg prostheses have been improved by creative engineers who carefully analyzed normal body structure and function. Then they used specialized materials and structures to imitate the same functions. Today, the most innovative designers are developing a prosthesis that connects directly to the wearer's nerves. This device enhances abilities by directly sending information to the central nervous system.

Case Study 2

Brendan Monson is a high school student who was diagnosed with Type 1 Diabetes (T1D) when he was 5 years old. His body does not produce insulin. Insulin is a hormone made by the pancreas. The body needs insulin to absorb simple sugars from the bloodstream into the cells of the body. Brandon has to monitor his sugar levels constantly and inject himself with insulin to maintain the right amount of sugar in his blood. Balancing sugar levels, food, exercise, and other variables to choose his insulin dose involves constant monitoring and calculations.

Controlling the disease when he was younger meant giving up flexibility and caused the whole family to adjust their routines. For example, he had to get up early every day so that he would receive his insulin at the same time every morning. His parents developed a chronic sleep problem from getting up every few hours at night to check his blood sugar level while he slept. Now as a teenager, he is taking responsibility for his own insulin monitoring. Brendan has had conflicts with his parents about managing his insulin on his own. On one hand, he is gaining independence from them as he grows, but even a little neglect can result in a life-threatening situation. Additionally, physical changes as a teenager can make controlling Brendan's blood sugar even more complicated.

Some people control their T1D with a biomedical device called an *insulin pump*. An insulin pump delivers insulin through a thin flexible plastic tube that connects to a needle inserted through the skin. Although they still have to monitor sugar levels, many people prefer this continuous system of insulin delivery over injections.

An emerging device available to T1D patients is a “closed-loop” system. This device uses a blood sugar sensor to monitor the patient’s sugar level and then it automatically delivers insulin when needed. Unlike a traditional insulin pump, it maintains acceptable sugar levels with minimal effort from the patient. It does not cure the disease but may make it easier and safer to live with T1D. There have been trials of the newest devices in controlled settings, including with teenagers like Brandan who want to control their disease without supervision. In one of the trials, teenagers reported that the device safely provides a quality of life improvement for overnight use. The system was tested in a long-term clinical trial of patients in their everyday environments. The results were compared with use of a previous generation insulin pump. The trial’s success met the requirements needed for government approval for adults and teens ages 14 and up with T1D.

The hybrid closed-loop system continuously monitors glucose levels of the wearer and automatically delivers insulin. The device pictured is the MiniMed® 670G system made by Medtronic.

Participating in a clinical trial, like the one using the hybrid closed loop system, is different from having regular care from your own doctor. The main purpose of a clinical trial is to study therapies that are promising but need evidence that they are safe and effective to be used by many people. The treatment is considered experimental during the clinical study. However, some patients are willing to accept this risk in exchange for the chance to use a promising new treatment that will hopefully be approved after the trial. Brendan Monson is glad that the clinical trial of the new insulin monitoring and delivery system was successful so that he can use this new technology to better manage his diabetes.

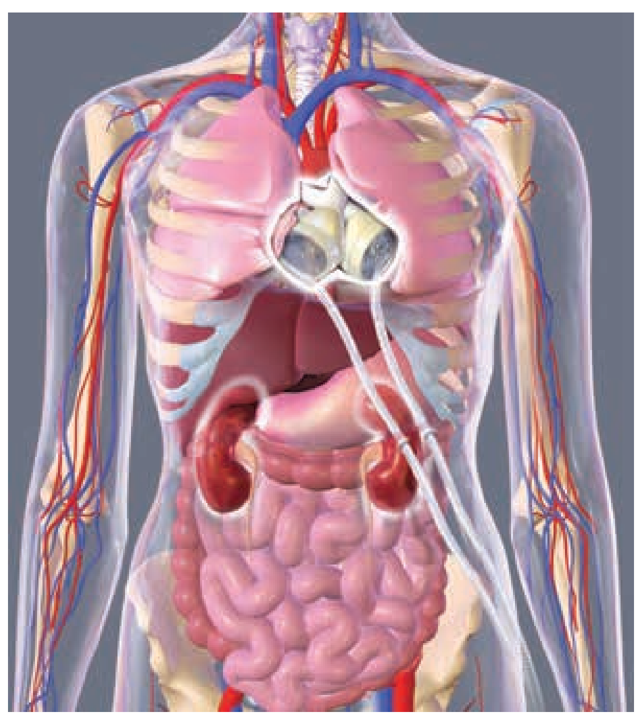
Case Study 3

In 1982, Dr. Barney Clark was critically ill and hospitalized. The 62-year-old dentist was dying of multiple organ failure, and he had reached the point where there were no medical options for him. Barney had congestive heart failure, which means his heart wasn't pumping blood as it should. The heart was working, but the body's need for blood and oxygen wasn't being met.

Barney knew he did not have long to live but agreed to undergo surgery to replace his failing heart with an artificial one, named the Jarvik 7 (after its inventor, Robert Jarvik). The Jarvik 7 was made up of replacement ventricles that went into Barney's chest cavity and was attached to a "power console" the size of a small refrigerator. It provided electricity and compressed air to run the heart.

Barney agreed to the surgery not so much to increase his survival but in the interest of advancing science. In fact, he told doctors before the operation that he did not expect to live more than a few days, but the successful heart led him to live for 112 days. Although the heart was a medical success, Barney suffered greatly before his death. His ordeal was highly publicized by the media around the world. A permanent heart solution has great appeal because the need for heart transplants far exceeds the supply and because few heart transplant patients survive very long.

The artificial heart temporarily replaces the ventricles and valves with a man-made device that circulates blood around the body. It is powered by a pump carried externally in a pack. Courtesy of Syncardia.com



From a scientific perspective, the performance of the Jarvik 7 exceeded expectations. However, Barney's experience left many feeling as though the permanent artificial heart was unethical. In the following decades, engineers focused on developing devices that assisted hearts instead of permanently replacing them. Since then, reliable artificial hearts have been developed for use during surgery or to bridge the time between heart failure and implantation of a transplant heart. Many of these devices and implants have been improving as battery technology has improved, resulting in batteries that weigh less and last longer.

Designing for Success

New tools and procedures in the field of medicine are helping people live longer, healthier lives. From eyeglasses and artificial legs to modern surgical techniques, technology is helping more and more people improve the quality of their lives. The process of design, testing in artificial settings, and clinical trials in patients has led to many successes.

In all of these case studies, the development of the medical devices began with an understanding of scientific ideas, including the normal structure and function to be copied. Based on the problem to be solved, biomedical engineers identify criteria and constraints for their designs. A **criterion** (plural **criteria)** is a minimum requirement for how the design must function. A criterion for the artificial pancreas design is that it must accurately calculate the insulin dose to maintain blood sugar levels. A **constraint** is something that limits or restricts the design, such as the availability of a particular material or part needed or limits on the size or final cost of the design. A constraint for an artificial pancreas is that the device must run on batteries. These and other basic criteria and constraints from the case studies are shown in the table below.

	CRITERIA	CONSTRAINT
Case Study 1: Leg prosthesis	Movable joints, allows natural stride, durable materials	Cannot be too heavy to wear, must fit in clothing
Case Study 2: Insulin system	Reliable, accurately calculates insulin dose	Must run on replaceable or rechargeable batteries, device must be portable
Case Study 3: Artificial heart	Reliable operation, successfully moves blood through the body	Must fit inside chest cavity, must run on replaceable or rechargeable batteries

A successful solution to problems like the ones described in this activity depended on the ability of the biomedical engineers to more precisely identify the problems' criteria and constraints. They also needed to know the relevant scientific principles and understand how their solutions could be limited by how they might potentially impact people and the environment.

Potential Environmental Impacts

The impact of a medical device includes the positive effects on the patient as well as the negative effects on the patient or the environment. One example of innovation that has led to both positive and negative effects is the use of plastics in biomedical devices. Plastics are ideal for single-use disposable devices, such as syringes, IV bags, and tubing, because they are low in cost, require little energy to produce, and are lightweight. However, using a lot of plastic creates a disposal problem because they are not typically biodegradable, and recycling plastic is problematic. For example, IV bags and tubing make up 25% of all hospital trash. Although plastics in medical devices take up a small percentage of all plastic waste (the biggest portion going to all forms of packaging), the negative impact of plastics on the environment should be considered. Like all human activities, engineering draws on natural resources that have short- and long-term consequences. Although reducing environmental impact can limit current design options, future design is driven by the findings of research, the needs of people, and a desire to reduce negative effects.

Hospital use IV bags, tubing, and syringes that are typically made of plastic, like the ones shown here.

ANALYSIS

1. Describe at least three examples not found in the reading of ways in which technology helps people overcome physical limitations.
2. For each case study, explain how the person did or did not benefit from biomedical engineering.
3. For the case of designing prostheses for Aimee Mullens, what are some of the
   a. criteria of the design?
   b. constraints of the design?
   c. scientific principles involved?
   d. impact of the design on others?
   e. impact of the design on the natural environment?
4. What problems in medicine still need better solutions? Provide an example and explain why you think there is a big need in our society to solve it.
5. Consider a biomedical device of your choosing that is not yet invented. Describe the device and then explain
   a. the design criteria for the device.
   b. the science relevant to the design.
   c. the potential positive and negative impacts on people.
   d. things that limit possible designs.
6. **Reflection**: Would you ever participate in a clinical trial? Why or why not?

EXTENSION

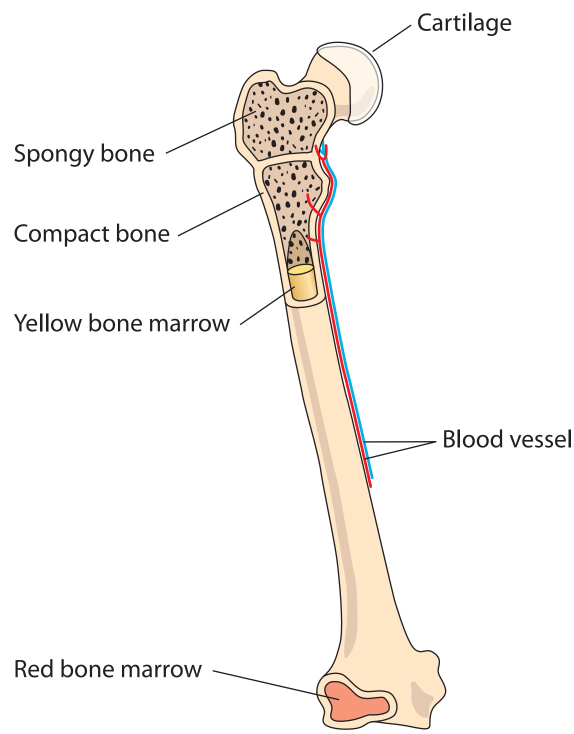
Visit the *SEPUP Third Edition Biomedical Engineering* page of the SEPUP website at www.sepuplhs.org/middle/third-edition to learn more about artificial organs and the Bionic Man.

4 Artificial Bone Model

DESIGN

ENGINEERS DESIGN MANY artificial body parts, including bones. Designing replacement bones for the human body requires understanding the important structure and function of bones. Bones must be strong enough to support muscles and tissues at rest and during exercise. Natural bone weighs surprisingly little, especially in animals that fly. They are also slightly flexible so that under normal stress, they bend a little rather than break—the way tree branches do. To be useful in a prosthetic arm or leg, artificial bones must also be strong, flexible, and lightweight.

In this activity, you will model an artificial bone. A **model** is any representation of a system or its components used to help one understand and communicate how the system works. It could be a diagram, a computer program, or a scaled-down device. The artificial bone model you build in this activity will be a prototype. A **prototype** is an early sample of a product that provides information about how the device or system works. A prototype might use substitute materials for convenience, such as building a frame out of metal pieces instead of molded plastic. A prototype provides a way for new ideas to be tested, evaluated, and then used to improve a design.



Human bone is made up of a dense and hard outer layer and a spongy honeycomb like inner structure.

GUIDING QUESTION

How can you design a prototype of an artificial bone that is strong yet light?

MATERIALS

For each group of four students

1 wooden dowel
4 pieces of printer paper
12 strips of paper, approximately 2 in x 11 in
1 metric ruler
1 towel
50 pennies (1 roll)
1 scale
transparent tape
polyester filling
cylindrical container with string hanger

For each student

1 Student Sheet 4.1, "Initial Bone Prototypes"

PROCEDURE

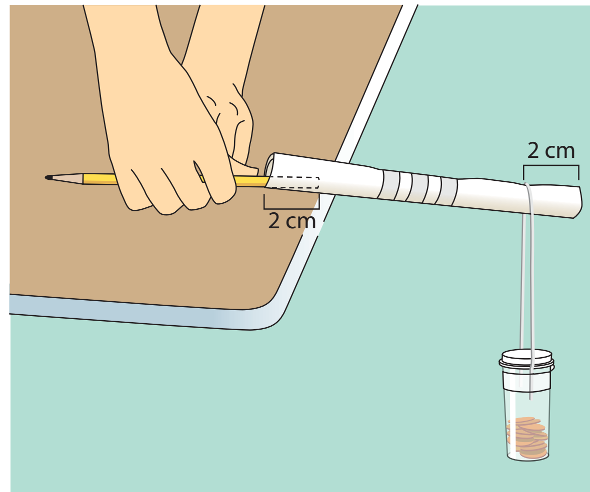
Part A: Define the Problem

1. Watch your teacher's demonstration of how to test your artificial bone prototype for strength in this activity. The strength will be determined by filling the container with mass until failure occurs. Your prototype fails when the mass slides off the end.
2. Read the following design criteria and constraints for the artificial bone prototype. As a class, clarify or add any relevant criteria or constraints to the design challenge.

Design Criteria

The design must

- be at least 21 cm long.
- be able to support the hanging cylindrical container without the container sliding off.
- not include any lip or obstruction that could prevent the mass from sliding off.
- have a minimum strength-to-mass ratio of 14:1.



Design Constraints

The design is limited by

- using a paper cylinder as the base of the artificial bone.
- using only the materials provided.
- being held together with tape.

3. As a class, make a table like the one below and estimate the mass of the materials.

Mass of Materials

Material	*Mass*
Piece of paper	
Paper strip	
Filling (per volume)	
Tape (per area)	

Part B: Brainstorm Prototypes

4. Discuss different ways you could strengthen the base of your artificial bone with filling or by adding paper while still maintaining a low weight. Come up with as many ideas as possible on how to design the artificial bone, and make a list of the ideas. With your group, choose the four best ideas from the list.

5. On Student Sheet 4.1, "Initial Bone Prototypes," draw and label diagrams of your bone prototypes. At this point, you should estimate the amount of each material that you will need in your designs.

Part C: Construct Your Design

6. Each person in the group should make one of the four initial prototypes selected by your group.

7. Create the paper cylinder by rolling the paper around a marker, taping the paper to itself, and then removing that marker from the paper cylinder.

8. On Student Sheet 4.1, measure and record the mass of your prototype.
9. Have all group members share the initial drawings and prototypes within your group.

Part D: Test and Evaluate

10. Make a mark on each bone 2 cm from one end and another mark 2 cm from the other end.
11. Use the procedure demonstrated by your teacher and illustrated in Part A to test your group's initial prototypes' ability to support a weight. Add weight incrementally to the prototype being tested until the cylindrical container slides off. Record the amount of mass your prototype was able to support on Student Sheet 4.1.
12. Use your results to evaluate which one of the four designs should be modified for the next round of testing. Do this by calculating the strength-to-mass ratio of each of your designs on Student Sheet 4.1 and identifying which prototype had the best strength-to-mass ratio.
13. Decide if any parts of the four designs can be combined to create a solution that is better than any of the four previous prototypes. Also, identify new ideas that may create a better design.
14. Redesign your prototype by changing only one variable you identified in the previous step. A **variable** is a changing factor. In an experiment, the variable is what is studied.

Part E: Redesign and Optimize

15. Build a new prototype that optimizes the design by providing the highest possible strength-to-mass ratio. Record your design in your science notebook.
16. Retest and re-evaluate your prototype as you did in Step 12.

Part F: Share Designs

The white spaces on this X-ray show an artificial hip that consists of a metal stem, ball joint, and socket cup.

17. As directed by your teacher, present your development process to the class. Include
    - a description of your procedure for constructing your prototypes.
    - the data you collected.
    - ways you optimized your design.
    - any conclusions you can draw based on the data you collected.
18. With your class, determine if a better design could be made from combining characteristics of the solutions presented.

ANALYSIS

1. Which of your prototypes

   a. was strongest?

   b. was lightest?

   c. had the highest strength-to-mass ratio?
2. Describe any trade-offs you made in your final design. A **trade-off** is an exchange of one outcome for another—giving up something that is a benefit or advantage in exchange for something that may be more desirable.
3. Describe the similarities and differences of features in your prototypes.
4. How would your design have differed if you needed only to meet a criterion of having high strength? Explain which of your initial four prototypes you would have tried to optimize.
5. If you had more time and could use any materials, what would your next design look like? Sketch and label it to show what changes you would make.
6. Which of the class's artificial bone prototypes looks most promising for future development? Explain.
7. How might a light but strong tube be used other than to replace bones? List at least three ideas.