2 *Me, an Engineer?*

INVESTIGATION

1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students are challenged to design tools and strategies to solve the practical problem of using one arm to complete daily tasks. Within the criteria and constraints of the problems, students navigate the environment and use iterative testing to solve the problem. Students are introduced to the crosscutting concept of structure and function and explore the interdependence and influence of science, engineering, and technology on society and the natural world. The activity concludes with an opportunity for students to define and analyze a design problem in their everyday lives.

NGSS CORRELATION

Performance Expectation

Working towards MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Working towards MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Working towards MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Disciplinary Core Ideas

MS-ETS1.A Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

MS-ETS1.C Optimizing the Design Solution: The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.

*MS-ETS1.B Developing Possible Solution*s: Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Science and Engineering Practices

Asking Questions and Defining Problems: Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

Crosscutting Concepts

Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.

Influence of Science, Engineering, and Technology on Society and the Natural World: All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.

WHAT STUDENTS DO

By simulating an injury to the dominant arm, students use their ingenuity and some simple supplies to invent solutions to problems they encounter in everyday tasks. Students are led to the discovery that engineers can develop either tools or strategies and that both are influenced by the ideas of an individual or group. Through the experience, students consider the practical impacts and needs of people with disabilities and the possibilities of biomedical engineering.

MATERIALS AND ADVANCE PREPARATION

- *For the class*

  4 Station Cards
  4 stations, as described below

  Stations 1 and 2: Get Dressed
  * 2 sweaters and/or button-up shirts
  * 1 pair of large lace-up shoes

  Stations 3 and 4: Hair Care
  * 10 ponytail holders
  * 2–4 long-haired dolls

  Stations 5 and 6: School Work
  * 4 sheets of construction paper
  * 4 pairs of scissors
  * 4 metric rulers
  * crayons

  Stations 7 and 8: Wrap a Package
  * 4 small boxes
  * 4 pairs of scissors
  * paper for wrapping
  * 1 roll of string or ribbon
  * transparent tape

- *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"
  * 1 clipboard (optional)

**Not supplied in kit*

Assemble the equipment that is not provided in the kit. Set up four stations around the classroom. At each station, provide two or more sets of the equipment so that more than one group can work at each station. Place each Station Card at the appropriate station.

Have a tray available to each group of four students with string, masking tape, card stock, scissors, safety pins, and triangular slings. You may wish to loosely tie the slings ahead of time so that students can slip them over their heads.

TEACHING SUMMARY

GET STARTED

1. Students share stories about temporary physical disabilities, such as a broken arm.
   a. Introduce the scenario by asking students to share their experiences.
   b. Introduce the field of biomedical engineering.

DO THE ACTIVITY

2. If you have not previously done so, introduce the SEPUP model for collaborative work.
   a. Introduce SEPUP's 4–2–1 model.
   b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.
   c. Introduce strategies for effective group interaction.
   d. Explain how you will distribute materials.
3. Students work at the stations with the materials.
   a. Instruct students on how to circulate among the stations.
   b. Encourage ingenuity in solving the problems.
4. Introduce crosscutting concepts.
   a. Explain that crosscutting concepts bridge disciplines in science and engineering.
   b. Give an example that makes sense for students.
   c. Introduce the crosscutting concept of structure and function.
   d. Relate structure and function to this activity.

BUILD UNDERSTANDING

5. Students share problems and solutions.
   a. Discuss the tools and strategies students considered while constructing solutions.
   b. Ask students to discuss how they optimized their solutions.
   c. Introduce the use of criteria and constraints to define a problem.
   d. Invite students to define a design problem beyond the classroom activity.

TEACHING STEPS

GET STARTED

1. Students share stories about temporary physical disabilities, such as a broken arm.
   a. Introduce the scenario by asking students to share their experiences.

      After students read the scenario in the introduction, ask them if any of them have broken an arm or other body part that has involved wearing a cast or brace. Encourage those who have to describe to the class how they broke it and what difficulties they experienced as a result. Ask students to reserve their ideas for strategies they used for coping until after all students have tried the activities.

      Teacher's note: You may have students with disabilities in your class or students who have siblings or friends with disabilities. Students may be uncomfortable discussing this topic, but most will be curious and interested to learn more. It is extremely important in these activities that students are respectful of one another and of all people who may be different from them.

   b. Introduce the field of biomedical engineering.

      Although the purpose of this activity is to have students explore tools and strategies for dealing with a broken arm, it serves as an introduction to biomedical engineering. Review the definition of a biomedical engineer provided in the Student Book. Let students know that in this activity, they will be playing the part of an engineer and a patient with a broken arm.

DO THE ACTIVITY

2. If you have not previously done so, introduce the SEPUP model for collaborative work.

   a. Introduce SEPUP's 4–2–1 model.

   Explain to students that many of the activities in this unit use the SEPUP 4–2–1 cooperative learning model. Students work in groups of four or in pairs to share, discuss, compare, and revise their ideas and to conduct investigations and activities. In all cases, each individual student is responsible for contributing ideas, listening to others, recording and analyzing their results, and monitoring their own learning.

   b. Clarify which situations are appropriate for collaboration and which are appropriate for working independently.

   In science, collaboration is essential to the development of new ideas and a better understanding of scientific concepts. However, scientists should publish only their own work and must give others credit when they build on their ideas.

   c. Introduce strategies for effective group interaction.

   As with the previous activity, explain or model what productive group interactions (both agreement and constructive disagreement) look like and sound like. For more information about group work, including two optional Student Sheets to help support students' interactions, see the Facilitating Group Interaction section of Teacher Resources II, "Diverse Learners."

   d. Explain how you will distribute materials.

   The materials management reflects the 4–2–1 structure of the classroom activities. The equipment kit typically contains materials in either sets of 16 (for each pair of students in a class of 32 students) or 8 (to be shared among groups of four), depending on how the activity is organized. In this activity, students will have a sling for each pair of students while the other materials are shared among groups of four.

   You might wish to establish numbered containers for materials distribution. This will allow you to quickly check the contents of the containers and hold groups accountable for ensuring their materials are returned in good shape.

3. Students work at the stations with the materials.

   a. Instruct students on how to circulate among the stations.

      Show students where the stations are set up, and explain to them that the Station Cards have instructions about each task. At each station, students should record notes on Student Sheet 2.1, "Recording Solutions." Describe to students how they will move around the room as groups of four but will trade off completing the tasks in pairs.

   b. Encourage ingenuity in solving the problems.

      Encourage students to use the tape, string, and card stock to produce tool-based solutions or at least models of ideas for such solutions. Encourage creativity in dealing with each task by suggesting that students come up with possible ideas before settling on one best way. It may be helpful to remind students that the goal is for them to invent solutions for independent living. Focus their attention on the structure and function of the tools they devise.

4. Introduce crosscutting concepts.

   a. Explain that crosscutting concepts bridge disciplines in science and engineering.

      They can be a lens or touchstone through which students make sense of phenomena and deepen their understanding of disciplinary core ideas. Refer students to the chart in Student Book Appendix G, "Crosscutting Concepts," and point out the symbols and definitions provided.

   b. Give an example that makes sense for students.

      For example, students have almost certainly noticed patterns, such as the predictable pattern of the seasons every year. Earth scientists might study patterns in rock layers, physical scientists might study patterns in the behavior of chemicals, and life scientists might study patterns in the kinds of trees in different climates. Observing, questioning, and trying to explain patterns are things all scientists do. This is why patterns are considered a crosscutting concept.

   c. Introduce the crosscutting concept of structure and function.

      This crosscutting concept relates to the close relationship between the structure of an object or system and what it does or how it behaves. Review the symbol used for Structure and Function in Appendix G, "Crosscutting Concepts. Structure and function applies from the atomic scale to the astronomical scale. A simple example of the crosscutting concept of structure and function is teeth and how the sharp front teeth are better at biting off pieces of an object while the flatter back teeth are better at chewing. Use this or other accessible examples to clarify this crosscutting concept for students. Scientists look at relationships between structure and function to figure out how things work. This idea is explored further in Analysis item 4.

d. Relate structure and function to this activity.

Support how students think about structure and function by discussing how the tools they made in this and the previous activity have a shape that serves a particular function. For example, if they used an object to hold down the paper to wrap a package in this activity, they were more likely to have success with a heavy book than a paper clip. In contrast, the paper clip may have made the perfect tool to rescue Fred in the previous activity.

BUILD UNDERSTANDING

5. Students share problems and solutions.

a. Discuss the tools and strategies students considered while constructing solutions.

Have students share some of their inventions (both tools and strategies) for solving some of the most difficult problems from the activity. If time allows, ask a few students to demonstrate their inventions. Suggest that both tools and strategies can be considered inventions and can be used to solve everyday problems.

b. Ask students to discuss how they optimized their solutions.

Have students share how they tested their solutions and then revised them based on what they learned. Emphasize that this iterative testing leads to a better, or optimized, solution. If using the term iterative, explain that an iterative process is a way to accomplish a desired result by repeating rounds of analysis or a cycle of operations. The objective is to bring the desired decision or result closer to discovery with each repetition (iteration).

c. Introduce the use of criteria and constraints to define a problem.

Tell students that, in addition to optimizing performance, an important way to improve the success of a design is to define the problem precisely. Informally introduce *criteria* and *constraint*s as the requirements and limits of a solution to a problem. In this activity, the criterion was the task at hand, such as wrapping a present, and the main constraint was the limitation of using only one hand. In the next activity, students will be formally introduced to the definitions of criteria and constraints.

d. Invite students to define a design problem beyond the classroom activity.

Have students generate problems they know well or have had at home that they have solved by developing a tool, process, or system. It may help to consider other everyday activities that generally require two hands. Discuss what knowledge they needed to know to solve the problem and what limits they faced. Brainstorm examples of common household problems students may have solved, or may have had help in solving, regardless of whether they have a disability. Many schools have Maker Faires or design contests, so this conversation is a great "seed" for having kids have a cross-disciplinary approach to these other activities.

SAMPLE RESPONSES TO ANALYSIS

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

   Student responses may vary depending on their procedure. One sample response is shown here:

   Our best solution to the Doing Homework problem was to tape the paper to the table. This made it possible to write without the paper moving around.

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

   Student responses may vary. One sample response is shown here:

   I think cooking at home would be the hardest because I make macaroni and cheese for my little brother sometimes. It would be hard to open the package and also to clean up the dishes.

   a. What questions do you have about this problem?

      I wonder if I can stir the pot with one hand or if that would make it slide around dangerously.

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

      I think that I would open the package by putting it between my knees and using scissors. I am not sure how to secure the pot on the stove, though. I might use a big heavy pot that would be hard to move by stirring it.

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.

   Strengths of the activity include the fact that you could identify some of the difficulties of having a broken arm or disability. The simulation also allowed us to create tools and/or strategies to address these difficulties. One weakness was that our model did not show how our solutions would work for someone who had pain of an injury or with a disability.

4. Imagine a cast used for a broken arm. The cast has a structure, or 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.

   Student responses may vary. One sample response is shown here:

   The function of the cast is to keep the arm in the same place so it can heal so the cast I imagine would have a very hard outside shell so that it could not be moved. Although the outside would have to be rigid, the inside could be soft so that it is more comfortable for the person wearing it.

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

   Student responses may vary depending on their procedure. One sample response is shown here:

   I would like to help my cousin who has cerebral palsy and can't use his right hand well. He walks around fine and his other arm is really strong, but the problem is spasms in his right arm and hand. It would be good for him to use his right hand so he can pick up things that take two hands.

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

      There are about half a million kids with cerebral palsy, and many of them are facing this problem. Grownups with cerebral palsy and others with similar problems are also in need.

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

      The need of people with all kinds of limited movement to live more independently and be physically stronger.

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

Scientific knowledge that is relevant to the problem includes understanding how nerve and muscles work in a normal person and why they don't work with people who have a disability like cerebral palsy.

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

The impact could be huge if a group of people were able to move in a way they once were not able to move. The solution maybe wouldn't have much environmental impact except for the materials used.

e. How important is it to solve this problem?

It is important for those who have an arm and hand problem and also could lead to more discoveries about how to overcome other kinds of paralysis.

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

I think one solution is to build a glove that can move the fingers and wrist as an exoskeleton.

EXTENSION

You may wish to invite a person from your community who has a disability to come to your class to discuss with students some of the tools and strategies they use in their daily life. For example, a blind person might discuss the use of Braille for reading and writing, or the use of a code they invented to identify cans in the cupboard. Perhaps invite an occupational therapist to join the class and discuss how they help people use tools and strategies to become more independent.

REVISIT THE GUIDING QUESTION

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

The tools and strategies students developed in this activity include the use of devices to secure and move things, such as using string and tape to connect objects. Strategies include sequencing movements to increase success or creating a work-around to achieve a goal. There is more than one way to solve everyday problems that someone with a broken arm may face.

ACTIVITY RESOURCES

KEY VOCABULARY

biomedical engineer

engineer

function

optimize

scientist

structure

BACKGROUND INFORMATION

ARM INJURIES

Lower arm injuries resulting from falling when participating in sports are common in early adolescents. These injuries often involve the dominant arm because people instinctively use it to break a fall. Many arm and wrist injuries can be prevented by wearing wrist guards. Young people are more likely to crack a bone than break it, but a forceful fall can break the bone. Treatment for a complete break involves setting the bone and splinting the arm for 4 to 6 weeks (the older the patient, the longer healing takes). At first, swelling may make it painful or difficult to use the fingers. As the break starts to heal and swelling goes down, patients are encouraged to exercise their fingers to maintain range of motion and also to promote bone growth. Once pain is reduced and hand mobility increases, it becomes easier to use the fingers of the injured arm and to accomplish activities with less modification.

Name____ Date__________

STUDENT SHEET 2.1

RECORDING SOLUTIONS

Station	Your solution	Tool, strategy, or both?	Your optimized solution
Get dressed			
Hair care			
School work			
Wrap a package			

Name *Sample student response* Date____________

STUDENT SHEET 2.1

RECORDING SOLUTIONS

Station	Your solution	Tool, strategy, or both?	Your optimized solution
Get dressed	*Wear big clothes that are easy to put on, put elbow in first, use shoe grabber*	*Strategy, tool*	*Fling the sweater across shoulders*
Hair care	*Use a hair clip: double hair tie over hand first, make a bun, use teeth to help stretch hair tie*	*Strategy, tool*	*Made a side ponytail; it was easier than a centered ponytail*
School work	*Use opposite hand, use computer voice-recognition software*	*Strategy, tool*	*Google talk, autocorrect*
Wrap a package	*Use a book or heavy object to hold down folded ends while tape is put on, use injured arm/hand to brace package, use knee or other body part to hold package*	*Strategy*	*Put package on a flat surface; used more paper than needed and just folded the paper instead of cutting to the right size of paper*

3 Bionic Bodies

READING

1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students explore the application of biomedical engineering through the case studies of three individuals. These cases show that individual needs, desires, and values help drive the technologies and the limitations of their use. Students read about the role of criteria and constraints in the design process. In the case studies, successful solutions to the problems depended on the ability of the biomedical engineers to precisely identify the problems' criteria and constraints, know the relevant scientific principles, and understand the potential impact on people and the environment that can limit solutions. Students choose a medical issue and define an engineering problem related to it that could be solved through the development of a device. Students are formally assessed on Performance Expectation MS-ETS1-1.

NGSS CORRELATION

Performance Expectation

MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

Disciplinary Core Ideas

MS-ETS1.A Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

Science and Engineering Practices

Asking Questions and Defining Problems: Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

Crosscutting Concepts

Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.

Influence of Science, Engineering, and Technology on Society and the Natural World: All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment.

The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.

Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Common Core State Standards—ELA/Literacy

RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.

RST.6-8.9: Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic.

RST.6-8.2: Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions.

WHAT STUDENTS DO

Students read three case studies that explore how the subjects' lives are affected by advances in biomedical devices. The cases focus on who can benefit from biomedical engineering and explores a bit about the process of bringing a device to market. In one case, there are ethical and social choices presented during the course of clinical trials. Finally, students read about the role of criteria and constraints in engineering.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  1 Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies"
  1 Scoring Guide: CONSTRUCTING EXPLANATIONS (EXP)

- *For each student*
  1 Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies"
  1 Scoring Guide: CONSTRUCTING EXPLANATIONS (EXP) (optional)

TEACHING SUMMARY

GET STARTED

1. Students consider how they solve problems.
   a. Ask students, "What are some medical devices you can think of?"
   b. Relate the crosscutting concept of structure and function to this activity.
   c. Ask students, "Would you be willing to try a new but untested device that might help you?"

DO THE ACTIVITY

2. (LITERACY) Support reading comprehension with a Three-level Reading Guide.
   a. Pass out Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies."
   b. Have students complete the Student Sheet after they complete the reading.
3. Encourage students to think about how each person in the case study does or does not benefit from technology.
   a. For each case study, discuss who benefits.
   b. Discuss where in the engineering development process each device is when encountered by the people in the reading.
   c. Ask students, "What are the environmental consequences to developing these devices?"
4. Students consider how criteria and constraints affect the development of biomedical devices.
   a. Introduce the concepts of criteria and constraints.
   b. Ask students, "How have the criteria and constraints for the artificial heart changed since the Jarvik 7 was developed?"
   c. Discuss the role of usability and ergonomics.

BUILD UNDERSTANDING

5. (EXP ASSESSMENT) If you have not previously done so, introduce the SEPUP Assessment System.

   a. Provide an overview of the Scoring Guides.

   b. Explain the expectations for student growth over time.

6. Students define an engineering problem of their choosing.

   Discuss student responses to Analysis item 4.

TEACHING STEPS

GET STARTED

1. Students consider how they solve problems.

   a. Ask students, "What are some medical devices you can think of?"

      Have students brainstorm a list of familiar medical devices. Begin with ideas that came up in the last activity. List their ideas on the board or on an overhead projector. Expect students to respond with devices such as pacemakers, artificial joints, and hearing aids. Identify those devices that would stay in a person for the remainder of their lives, such as dental fillings, surgical screws and plates, and stints. Let students know that they will read about some individuals who were, or hope to be, the recipients of new technology that could be used for a lifetime.

   b. Relate the cross cutting concept of structure and function to this activity.

      Ask students to identify how the materials in the devices they suggested are shaped and used to serve particular functions. For example the shape of a hearing aid is designed to funnel sound into the ear.

   c. Ask students, "Would you be willing to try a new but untested device that might help you?"

      Students are likely to respond that it depends on the circumstances and how promising the technology is. Also, they should consider what the negative consequences might be if they tried it and it didn't work. For example, if you were testing a new type of walking assistance device, the consequences of it failing are smaller than if you were testing a new medication that you needed for survival.

DO THE ACTIVITY

2. (LITERACY) Support reading comprehension with a Three-level Reading Guide.

   a. Pass out Student Sheet 3.1, "Three-level Reading Guide: Bionic Bodies."

      You might wish to review each of the statements and clarify them as needed. The Reading Guide presents students with statements that require three levels of understanding: literal, interpretive, and applied. Students are asked to determine which statements are supported by the text. Explain that the statements under number 3 (applied) do not always have a single correct response. Students may interpret information differently and agree or disagree with each statement. Regardless of their perspectives, it is important for students to be able to explain and support their positions.

   b. Have students complete the Student Sheet after they complete the reading.

      Possible responses to the Reading Guide are shown at the end of this activity. Clarifying notes are provided for the statements that do not accurately represent the content in the reading. Note that this strategy is not asking students to discern which of the statements are true or false, as many of them are true. It is asking them to determine which are portrayed in the content of the reading. For more information, see the Literacy section of Teacher Resources II, "Diverse Learners."

3. Encourage students to think about how each person in the case study does or does not benefit from technology.

   a. For each case study, discuss who benefits.

      Aimee Mullens clearly benefited from developments in prosthetics technology that came about as she grew up. The technology that helped her mobility also helped expand social consciousness of what it means to be disabled. Brendan Monson has yet to benefit from the artificial pancreas, although his peers in the clinical trial are benefiting. Barney Clark did not benefit from the artificial heart in a substantial way, although it prolonged his life a bit. The ones who benefited were the scientists and engineers running the trial and future patients who received hearts based on what they learned from Barney's experience.

   b. Discuss where in the engineering development process each device is when encountered by the people in the reading.

For the prosthesis, the technology had been around for a long time, and the prostheses Aimee benefited from were fully developed and ready for the market. The artificial pancreas was in clinical trials with adults and teenagers like Brendan Monson. The artificial heart was at the beginning of its development and was a single unique machine not yet in clinical trials when Barney Clark agreed to receive it. These case studies indicate that individual benefits increase as a device progresses through the engineering process and is brought to a commercial product. This conversation leads students to understand the crosscutting concept of the short- and long-term consequences of science, engineering, and technology on the health of people and the environment.

c. Ask students, “What are the environmental consequences to developing these devices?”

Expect students to respond that items like IV bags and syringes are environmentally wasteful in that they can only be used once and can’t be recycled.

4. Students consider how criteria and constraints affect the development of biomedical devices.

a. Introduce the concepts of criteria and constraints.

Review the definitions provided in the Student Book, and let students know they will be using criteria and constraints to design devices themselves in the upcoming activities. It may be helpful to look back at the earlier activities and identify the criteria and constraints used, although not identified as such at the time. The directions from the activity, “Save Fred!,” were the criteria, and keeping an arm in a sling was a constraint used in the following activity, “Me, an Engineer?”

b. Ask students, “How have the criteria and constraints for the artificial heart changed since the Jarvik 7 was developed?”

When the Jarvik 7 was developed, there was no criterion for the device to be small. It was run by a compressor the size of a small refrigerator. Although acceptable by the designers at that time, these criteria would not be appropriate today. The constraint of the heart fitting into a small space was not possible due to the limits of powering it. The Jarvik 7 would not have been successful if it had the criteria and constraints used today for artificial hearts. The criteria and constraints of the artificial heart design problem was defined with just enough precision to ensure a successful solution. This concept is central to the Performance Expectation assessed in this activity, MS-ETS1-1: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

c. Discuss the role of usability and ergonomics.

In the case of the Jarvik 7, the technology developed was a completely new life-saving device, but there are many situations where engineers help people by improving a current solution instead of developing an entire novel one. In this work, engineers focus on the role of ergonomics and usability. For example, the driving mechanism for a wheelchair for a paraplegic is sometimes a device in front of the face that moves the chair around with breath movements. New designs include a control that is discretely kept inside the mouth like a retainer and is controlled by the tongue. There are engineers who specialize in device ergonomics by combining design with engineering to improve the usability of the device. Suggest that many solutions to biomedical problems are not as extreme as an artificial heart and simply address the need to improve quality of life.

BUILD UNDERSTANDING

5. (EXP ASSESSMENT) If you have not previously done so, introduce the SEPUP Assessment System.

a. Provide an overview of the Scoring Guides.

Explain that Analysis item 2 contains the first assessments in this unit, and you will use them to introduce the SEPUP Assessment System to your students. See Teacher Resources III, "Assessment," to be sure you are familiar with the overall system.

Before assigning the assessment, distribute the CONSTRUCTING EXPLANATIONS (EXP) SCORING GUIDE and use it to model how the system works. Point out the levels in the first column of the Scoring Guide. Tell students that these levels are the same for all Scoring Guides and range from 0–4. Then review the descriptions of each level. For example, a Level-4 response is complete and correct in all Scoring Guides. Point out that the scores (0–4) are based on the quality of student responses and do not correspond to letter grades. Allow students to refer to the Scoring Guide as they prepare their answers. Be sure that they understand that the Scoring Guides do not include the specific content students must provide in their responses but, rather, they explain the overall expectations for responses at various levels of performance on the task. For more information about the Scoring Guides and how you and students can use the system to improve their work, see Teacher Resources III, "Assessment."

b. Explain the expectations for student growth over time.

Explain to students that they aren't expected to always produce complete and correct work on their first attempts. Instead, they should work toward developing consistent Level-3 and Level-4 answers as they become more proficient with the concepts (both disciplinary core ideas and crosscutting concepts) and the science and engineering practices being assessed. It is not necessary (or even expected) that an "A" student will always write Level-4 responses, especially at the beginning of the course or when they are introduced to a new Scoring Guide.

6. Students define an engineering problem of their choosing.

Discuss student responses to Analysis item 4.

Analysis item 4 allows students to define a problem related to biomedical devices that fulfills the science and engineering practice of asking questions and defining problems. Encourage students to consider medical problems that now have partial solutions but that could fulfill new criteria in the future.

SAMPLE RESPONSES TO ANALYSIS

1. Describe at least three examples not found in the reading of ways in which technology helps people overcome physical limitations.

Student responses may vary. Examples offered by students may include simple devices, such as glasses and contact lenses for vision deficits, or more complicated electronics, such as pacemakers for arrhythmia, replacement joints for hips and knees, or hearing aids for partial deafness.

2. (EXP ASSESSMENT) For each case study, explain how the person did or did not benefit from biomedical engineering.

SAMPLE LEVEL-4 RESPONSE

Aimee Mullens has benefited from advancements in prosthetics technology because if the technology had not been available to her for the Paralympics, she may not have gained popularity in her modeling and acting careers. Brendan Monson has benefited from the insulin pump but not yet from the closed loop system. He hopes he will in the future. Barney Clank did not benefit from the technology because his quality of life after the operation was worse. Although his life was extended, it wasn't improved. Even though he was going to die either way, others benefited later.

3. For the case of designing prostheses for Aimee Mullens, what are some of the

   a. criteria of the design?

      The prosthesis needed to allow Aimee to walk and stay balanced. Some of the designs also had to look natural or provide a running platform (like the cheetah blade).

   b. constraints of the design?

      The prosthesis could not be too heavy to move easily or so expensive that she could not afford it.

   c. scientific principles involved?

      The principles involved are the understanding of levers, materials, and biomechanics of the leg.

   d. impact of the design on others?

      The prosthetic leg has had a huge impact because some people can walk now who could not before.

   e. impact of the design on the natural environment?

      The impact on the environment is the manufacturing waste and the use of the plastics and metals that become trash when the prosthesis is no longer used.

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.

   Student responses may vary. One sample response is shown here:

   I think that paralysis is one problem in society that needs a better solution. Currently people with paralysis are limited to wheelchairs, which do not provide a great quality of life. There has been a lot of progress with exoskeletons, so maybe that solution will be available soon.

5. Consider a biomedical device of your choosing that is not yet invented.

   Student responses may vary. One sample response is shown here:

   I choose an artificial eye to be used by the blind as my biomedical device that has not yet been invented.

   Describe the device and then explain

   a. the design criteria for the device.

      The device would have to provide images and some light to the brain of those who cannot see well. It would need to be small enough to fit into the eye socket and look somewhat like an eye. It would have to handle exposure to the outside, including wind, water, and impacts, without being damaged.

b. the science relevant to the design.

The science involved is knowing how parts of the eye work and how it connects to the brain.

c. the potential positive and negative impacts on people.

The positive would be that the wearer could see better and maybe function more safely and go without assisting devices, such as a cane and Braille books. The negative impacts could be if there are side effects, like it disturbs the wearer's balance or if it wasn't reliable and put them in dangerous situations.

d. things that limit possible designs.

The limitations could be that if the brain cannot interpret the visual input, the bionic eye could not connect to the brain, or if the eye were too expensive to buy or too bulky to fit in the eye socket.

6. **Reflection**: Would you ever participate in a clinical trial? Why or why not?

Student responses may vary. One sample response is shown here:

No, I would not. I know that it would help science but I don't want to try something that is not yet proven.

EXTENSION

Visit the *SEPUP Third Edition Biomedical Engineering* page of the SEPUP website at *www.sepuplhs.org/middle/third-edition* for links to more information about the Bionic Man project. The Bionic Man is the compilation of 16 artificial organs, including artificial heart, lung, spleen, pancreas, and kidneys. It also includes artificial bones, a bionic hand, and an exoskeleton that allows walking. The project highlights how far we have come and need to go for artificial parts.

REVISIT THE GUIDING QUESTION

How has the development of artificial body parts changed lives?

The development of artificial body parts has had immediate impact on people and changed lives of individuals like Aimee Mullens. Artificial joints, like knees and hips, have positively impacted people's mobility. Some people in clinical trials could have either positive or negative changes depending on the trial.

ACTIVITY RESOURCES

KEY VOCABULARY

biomedical engineering

constraint

criterion, criteria

function

structure

BACKGROUND INFORMATION

HISTORY OF THE PROSTHESIS

The earliest known prosthesis, made of bronze and iron, dates back to 300 BCE. In the early 1500s, small springs and leather straps helped prostheses have a freer range of motion. French surgeon Ambroise Paré developed a modern amputation procedure to the medical community and made for upper- and lower-extremity amputees. In the 1800s, there was a series of advancements that brought in the era of multi-articulated feet and aluminum legs.

The impact of each of the major U.S. wars brought a surge of need for better prostheses. After World War II, veterans demanded better products, and the government responded with designated funds for that purpose. This paved the way for modern prostheses that include better functionality, comfort, and appearance than ever before.

HISTORY OF THE ARTIFICIAL PANCREAS

The artificial pancreas is a technology still in development to replace the function of a healthy pancreas in people with diabetes by automatically controlling blood glucose levels. The first closed-loop control of diabetes was prototyped in the 1960s, and the artificial pancreas has been in development ever since. In the early 2000s, the insulin pump was released. However, a truly closed-loop system has been elusive, and it was not until 2009 that the National Institutes of Health (NIH) established an artificial pancreas initiative. Recent innovations have allowed the development of a closed loop system to begin large-scale clinical trials in 2016.

In 2014, a team at Harvard showed that insulin-producing pancreatic cells could be created from stem cells. They hope that someday these cells can be transplanted into diabetes patients, eliminating the need for manufactured insulin.

HISTORY OF THE ARTIFICIAL HEART

The first artificial heart was made in 1937 by the Soviet scientist Vladimir Demikhov, who transplanted it into a dog. It was not until 1952 that the first operational mechanical heart was used as a bridge heart during surgery. Artificial hearts are typically used to bridge the time to heart transplantation or to permanently replace the heart in case heart transplantation is impossible. Following the advances in bridge hearts, worldwide scientific interest for the development of a permanent solution for heart disease developed. In 1964, the NIH supplied the goal of putting a man-made heart into a human by the end of the decade.

The first artificial heart was successfully implanted in a human in 1982. The engineering team was led by the well-known biomedical engineer Willem Johan Kolff and designed by his graduate student, Robert Jarvik. After Barney Clark's controversial experience, the Jarvik 7 heart was erroneously reported as being banned. Today, the modern version of the Jarvik 7 is known as the SynCardia temporary Total Artificial Heart. It has been implanted in more than 1,350 people as a bridge to transplantation. There are also many other successful bridge hearts, but a permanent artificial heart does not yet exist.

In the early 1960s, ventricle assist devices (VADs) were developed for patients who have some remaining heart function but who can no longer live normally. These devices do not replace the human heart but complement it by taking up much of the function. The first FDA approval for VADs was in 1994.

In August 2006, a VAD called the Berlin Heart was implanted into a 15-year-old Canadian girl. Although it was intended to be a bridge heart until a donor heart could be found, doctors found that the Berlin Heart allowed for natural processes to occur and the girl's heart healed on its own. When the device was removed, the girl's heart was able to function properly on its own. Since then, the device has been successfully implanted in several children.

REFERENCES

Sakimura, J. (2013). *One mom's challenge: Raising a teen with Type 1 diabetes.* Retrieved from Everyday Health, http://www.everydayhealth.com/type-1-diabetes/one-moms-challenge-raising-teen-with-type-1-diabetes.aspx

Name____ Date___________

STUDENT SHEET 3.1

THREE-LEVEL READING GUIDE: BIONIC BODIES

1. Put an X next to the statements below that you believe are true based on the reading. Sometimes, the exact words found in the reading are used. At other times, other words may be used to communicate the same meaning.

________ a. Aimee Mullins was the first person in the world to use flex-foot "cheetah" running blades.

________ b. Clinical trials for the artificial pancreas are many years away.

________ c. Barney Clark accepted the artificial heart to make a contribution to science.

2. Put an X next to the statements below that you believe represent the intended meaning of the reading.

_________ a. Criteria and constraints should be identified in the process of solving a problem.

_________ b. Everyday citizens do not always benefit from biomedical devices.

_________ c. Everyone gains in the process of engineering a new biomedical device.

3. Put an X next to the statements below that you agree with, and be ready to support your choices with ideas from the reading and from your own knowledge and beliefs.

_________ a. Aimee Mullins is not "disabled."

_________ b. Clinical trials are too risky for patients.

_________ c. The solution to a problem should not be limited by the environmental impact of the design.

Name *Sample student response* Date

STUDENT SHEET 3.1

THREE-LEVEL READING GUIDE: BIONIC BODIES

1. **Put an X next to the statements below that you believe are true based on the reading. Sometimes, the exact words found in the reading are used. At other times, other words may be used to communicate the same meaning.**

   ___*x*___ a. **Aimee Mullins was the first person in the world to use flex-foot "cheetah" running blades.**

   ________ b. **Clinical trials for the artificial pancreas are many years away.**

   ___*x*___ c. **Barney Clark accepted the artificial heart to make a contribution to science.**

2. **Put an X next to the statements below that you believe represent the intended meaning of the reading.**

   ___*x*___ a. **Criteria and constraints should be identified in the process of solving a problem.**

   ___*x*___ b. **Everyday citizens do not always benefit from biomedical devices.**

   ________ c. **Everyone gains in the process of engineering a new biomedical device.**

3. **Put an X next to the statements below that you agree with, and be ready to support your choices with ideas from the reading and from your own knowledge and beliefs.**

   ________ a. **Aimee Mullins is not "disabled."**

   Students who support this statement may feel that despite her atypical body, Aimee has not been held back or disabled. Her multiple achievements point to this. Students on the other side of the argument are likely to have the position that she has had much to overcome, thereby supporting the idea that she has had to stretch beyond a limitation.

   ________ b. **Clinical trials are too risky for patients.**

   Students in favor of the use of clinical trials will cite that historically speaking, the use of clinical trials has helped bring many devices to market. Those in disagreement may feel it is not fair to allow people to risk their health with something unproven.

   ________ c. **The solution to a problem should not be limited by the environmental impact of the design.**

   Some students will think that solving the problem, especially one that helps saves people's lives, is worth any environmental impact because they value human health above all else. Those students who don't support this may feel that human health should not be valued above the environment.

4 *Artificial Bone Model*

DESIGN

2–3 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students are challenged to design, build, and test models of an artificial bone to meet precise criteria. They analyze the quantitative data from different prototypes and combine ideas to optimize their designs. Students investigate the scientific principles of bone construction that allow them to improve their designs. The design challenge allows them to develop possible solutions by considering structure and function, analyzing data and using computational thinking.

NGSS CORRELATION

Performance Expectation

Working towards MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Working towards MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

Working towards MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Disciplinary Core Ideas

MS-ETS1.A Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

MS-ETS1.B Developing Possible Solutions:

A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

Models of all kinds are important for testing solutions.

MS-ETS1.C Optimizing the Design Solution:

Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of the characteristics may be incorporated into the new design.

The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.

MS-LS1.A Structure and Function: In multicellular organisms, the body is a system of multiple interacting subsystems. These subsystems are groups of cells that work together to form tissues and organs that are specialized for particular body functions.

Science and Engineering Practices

Asking Questions and Defining Problems: Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.

Developing and Using Models: Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.

Constructing Explanations and Designing Solutions: Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

Analyzing and Interpreting Data: Analyze data to determine similarities and differences in findings.

Using Mathematics and Computational Thinking: Use mathematical representations to describe and/or support conclusions and design solutions.

Crosscutting Concepts

Structure and Function: Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

Common Core State Standards—Mathematics

MP.2: Reason abstractly and quantitatively.

6.RP.A.1: Understand the concept of a ratio and use ratio language to describe a relationship between two quantities.

6.RP.A.3: Use ratio and rate reasoning to solve real-world and mathematical problems.

Common Core State Standards— ELA/Literacy

SL8.4: Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound and valid reasoning, and well-chosen details: use appropriate eye contact, adequate volume, and clear pronunciation.

WHAT STUDENTS DO

Students design a model of an artificial bone that has the highest possible strength-to-mass ratio. Students first apply the concepts of criteria and constraints to the challenge and then build four prototypes to test. Students evaluate the test results and then optimize the design. The inquiry leads students through the process of designing artificial bones in a manner that parallels the design process used by engineers, although that process has not yet been formally introduced to students.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*
  - 1 Scoring Guide: ENGINEERING DESIGN (ENG)
  - 1 Group Interaction Student Sheet 2, "Developing Communication Skills" (optional)
  - 1 Literacy Visual Aid 1, "Oral Presentations" (optional)

- *For the class*
  - * 1–8 balance(s) sensitive to 0.1 gram differences

- *For each group of four students*
  - transparent tape
  - polyester filling
  - 1 wooden dowel
  - 4 pieces of printer paper, 8 ½ in x 11 in
  - 12 strips of paper, approximately 2 in x 11 in
  - 1 metric ruler
  - cylindrical container with string hanger
  - * 1 towel
  - * 50 pennies (1 roll)
  - * 1 scale

- *For each student*
  - 1 Student Sheet 4.1, "Initial Bone Prototypes"
  - 1 Scoring Guide: ENGINEERING DESIGN (ENG) (optional)
  - 1 Literacy Student Sheet 2, "Developing Communication Skills" (optional)
  - 1 Literacy Visual Aid, "Oral Presentations" (optional)

**Not supplied in kit*

Prepare a safe storage area for the prototypes that students make, and provide a way for them to label their prototypes.

You may wish to set up testing stations around the room in advance. At each testing station, make sure to place a towel on the floor as a pad under the drop site. The pad prevents the cylindrical container from breaking when loaded with weights and prevents the classroom from getting too noisy during testing.

Tape a piece of string (about 12 cm) to the cylindrical containers so they may be hung on the bone model as shown in the Student Book illustration of the testing procedures. Consider cutting some strips of paper about 2 in wide for students to use to reinforce parts of their model.

Determine if you would like each group to weigh their materials themselves in Procedure Step 3 or if you would like to provide the masses. If you choose the latter, measure the mass of material samples in advance using a digital scale. For the tape, use a larger sample and divide by the number of cm^2 in the sample. For the polyester filling, provide a mass per volume or area.

TEACHING SUMMARY

GET STARTED

1. Students take on the role of biomedical engineers.
    a. Introduce the design challenge.
    b. Demonstrate how the shape of an object can affect its strength.
2. Review the purpose of criteria and constraints in engineering design.
    a. Develop students' vocabulary by providing opportunities to use the terms in context.
    b. Use a simple example to emphasize the importance of criteria and constraints.

DO THE ACTIVITY

3. Discuss the criteria, constraints, and testing procedure.
    a. Refer to the diagram in the Student Book and explain the testing procedure.
    b. (MATHEMATICS) Explain strength-to-mass ratio.
    c. Review the design constraints.
    d. Estimate the mass of materials.
4. Students design and make initial prototypes.
    a. (ENG ASSESSMENT) Introduce the ENGINEERING DESIGN (ENG) Scoring Guide.
    b. Distribute Student Sheet 4.1, "Initial Bone Prototypes."
    c. Provide students with a materials budget (optional).
5. Students test and evaluate the performance of the prototypes.
    a. Help students use their prototype results to optimize one of their designs.
    b. Ask students to make a list of possible improvements.
    c. Suggest that students change only one variable at a time.
    d. Support students in the iterative process of design.

BUILD UNDERSTANDING

6. Students share their designs and design process.

   a. (LITERACY) Support students in preparing an oral presentation on their design process.

   b. Discuss how their results do and do not apply to building a real prosthesis.

   c. Discuss the process of engineering design.

7. If you have not previously done so, introduce the concept of trade-offs.

   a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

   b. Provide an example of trade-offs.

   c. Develop some examples of trade-offs in students' lives.

TEACHING STEPS

GET STARTED

1. Students take on the role of biomedical engineers.

   a. Introduce the design challenge.

      Review the terms *model* and *prototype* as described in the introduction in the Student Book. Emphasize that this is a design activity, so students will develop and build prototypes to meet the engineering challenge. Let students know that the goal is to create a prototype structure similar to a bone, such as might be used in a prosthesis. As such, the prototype must be strong while also light and flexible.

      Teacher's note: This activity helps students to connect the process of design to the life science content in the SEPUP middle school unit "Body Systems." See this unit for more activities on body systems. If appropriate, discuss how the tissues that make up the system in the wing are specialized for particular body functions.

   b. Demonstrate how the shape of an object can affect its strength.

      Emphasize the cross cutting concept of structure and function in the example of paper, which wouldn't work well as a bone when crumpled up because it would not hold much weight; however, it is stronger in the form of a tube. For tubes, let students discuss whether a narrow or wider diameter is stronger. Demonstrate with two paper tubes how the smaller diameter will hold more weight. Because the diameter of the model bone in this activity heavily influences the results, students are required to use the same diameter. By holding that variable constant, students have more room to explore the other variables that effect the performance of the model. Require all students to start with the same paper tube by tightly wrapping paper around a marker and then removing the marker. The sample data for this activity was taken from a model that was made using a marker with diameter 1.4 cm.

2. Review the purpose of criteria and constraints in engineering design.

   a. Develop students' vocabulary by providing opportunities to use the terms in context.

   Review the definitions from the previous activity, and then use student suggestions to complete a sentence. Project this sentence: "If you were to build a ____________, an important criterion would be ______________ and an important constraint would be ____________." Ask students to use an everyday example to complete the statement to demonstrate that they understand the basic concepts of criteria or constraints. A typical response could be "If you were to build a bridge, an important criterion would be that it not fall down in high winds and an important constraint would be the cost must stay within the budget."

   b. Use a simple example to emphasize the importance of criteria and constraints.

   When discussing the importance of criteria and constraints, identify that the precision of the criteria can determine the success of the project. For example, have students compare these two different criteria for the design of the lid to a beverage container:

   Criterion 1: The lid must fit on top of the container.

   Criterion 2: The lid must fit a diameter of 8 cm.

   Constraint 1: The lid cannot cost more to build than it will sell for.

   Constraint 2: The lid cannot cost more than $5 to build.

   Ask, "Which criterion and constraint are more likely to lead to a successful design?" Expect students to see that Criterion 2 and Constraint 2 are more likely to lead to a good design than Criterion 1 and Constraint 1.

DO THE ACTIVITY

3. Discuss the criteria, constraints, and testing procedure.

   a. Refer to the diagram in the Student Book and explain the testing procedure.

      Using the diagram in the Student Book as guidance, demonstrate how to test a bone prototype by placing a prototype on the tabletop and holding it down with a pencil 2 cm from the end of the table. Hang the test mass 3 cm from the end of the model bone that is extending past the edge of the table. Explain that testing includes increasing the mass in the container until it fails (i.e., slips off the prototype). Make sure to place a towel under the test mass so that it does not crack when it falls. Emphasize that consistent testing will produce the most reliable results.

   b. (MATHEMATICS) Explain strength-to-mass ratio.

      When reviewing the criteria in Part A of the activity, provide students instruction on the significance of strength-to-mass ratio and support their calculation of the ratio. Illustrate how to determine the ratio by comparing these two examples:

      Stool 1: This 2-kg stool holds a mass of 90 kg before breaking.

      Stool 2: This 3-kg stool holds a mass of 210 kg before breaking.

      The ratio for Stool 1 is

      90 kg/2 kg = 45

      which is not as high as for Stool 2:

      210 kg/3 kg = 70

   c. Review the design constraints.

      The function of the design constraints is to provide uniformity in testing. For example, prototypes cannot have a rim on the end that prevents the testing mass from sliding off. This design would provide an unfair advantage in keeping weights on the end of the prototypes.

   d. Estimate the mass of materials.

      Make a table for the class that displays the approximate masses of the materials students will use in the challenge. Either provide the masses or have students measure them and report out to the class.

4. Students design and make initial prototypes.

   a. (ENG ASSESSMENT) Introduce the ENGINEERING DESIGN (ENG) Scoring Guide.

      The Procedure in this activity, specifically Procedure Step 16, is the first use of the ENG Scoring Guide. Optionally project or distribute the Scoring Guide. Point out how it has the same levels but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment."

   b. Distribute Student Sheet 4.1, "Initial Bone Prototypes."

      Explain to students that the Procedure instructs each group to produce an initial set of four prototypes using Student Sheet 4.1, test them, and then refine one of those prototypes further based on the results. Encourage each student in the group to share ideas and to get started on their own prototype. Make sure students within each group coordinate the prototypes so they do not duplicate the same prototype design. To facilitate group interaction, you may want to use the sentence starters found in Literacy Skill Sheet 3, "Developing Communication Skills," also found in the Student Book, Appendix E.

   c. Provide students with a materials budget (optional).

      If students are not efficient about their use of materials, consider providing them with a budget or maximum allowable supplies. To do this, provide artificial costs for each kind of material so they can work within the total provided, or simply limit the quantities that students can use. The purpose is not to add a constraint to the design but to simply preserve materials for the classroom and reduce waste. Alternatively, consider allowing students to bring materials from home.

5. Students test and evaluate the performance of the prototypes.

   a. Help students use their prototype results to optimize one of their designs.

      Encourage students to review the test results and the strength-to-mass ratios for the prototypes together as a group and to collaboratively decide on the next design step. This should include using aspects of the best performing prototype and combining it with other features from other designs.

b. Ask students to make a list of possible improvements.

If students are not sure how to optimize a design, ask them to brainstorm a list of potential design improvements and the reasoning behind each improvement. As a group, they can go through the list, eliminate the weakest ideas, and select the strongest.

c. Suggest that students change only one variable at a time.

Review the term *variable* as used in scientific investigations. Encourage students during the optimizing stage of developing the design to change just one variable at a time. If students keep all other variables the same, they will be able to draw more definitive conclusions about the effect of the one changing variable. If multiple variables are changed at once, it is often difficult to determine what effect each change had. On the other hand, in a complex design, variables may act synergistically, and it may be necessary to vary several variables at once to obtain optimum performance with an efficient use of time and materials.

d. Support students in the iterative process of design.

Encourage students to test, evaluate, and redesign as many times as it takes for them to be satisfied with their work. The Student Book indicates to do this once, but repeating it is acceptable. Through this Procedure, help students gain the understanding that repetitively testing and redesigning is a natural part of the design process.

SAMPLE LEVEL-4 RESPONSE, PROCEDURE STEPS 4–16

We first built four prototypes and tested them.

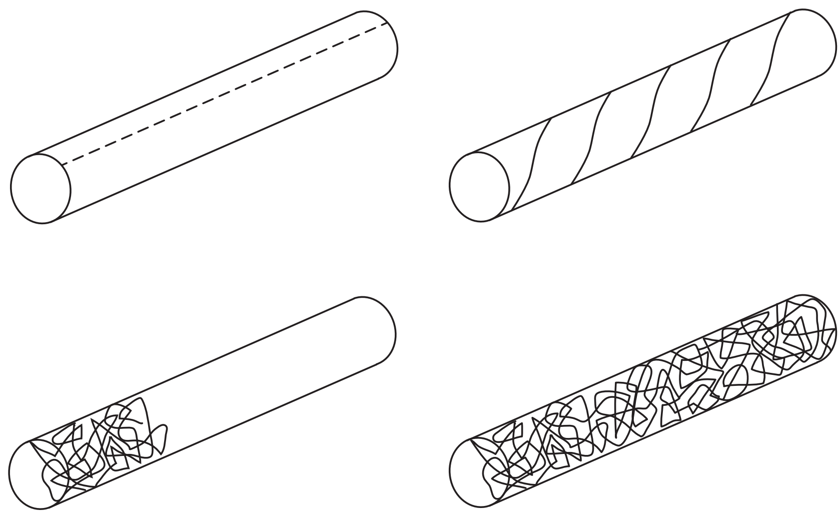
Prototype 1: just bone model, nothing added

Prototype 2: bone model with 1.25 papers wrapped

Prototype 3: bone model with just stuffing at the table end

Prototype 4: bone model with stuffing throughout the model

Four Prototypes



Through testing, we realized that the most force happened at the edge of the paper where it met the table, so for the optimized model, we jammed stuffing (polyester fill) to the end where it touches the table and removed some of it from the other side That decreased the mass while increasing the strength. Then we kept reducing the mass by removing the stuffing at the far end away from the table until the ratio was highest. Mass was the only variable we changed during optimization. Our final bone model combined prototypes 2 and 3, which had the highest strength-to-mass ratio in the testing. The optimized model had 1.25 papers wrapped and stuffing added on the table end. Here is the data we collected during testing:

Bone Prototype Testing Results

Prototype	Failure mass (g)	Mass (g)	Strength : mass
1: nothing	*53.0*	*4.6*	*11.5*
2: wrapped	*86.2*	*5.9*	*14.6*
3: stuffing at end	*49.7*	*6.4*	*7.8*
4: stuffing throughout	*58.3*	*5.3*	*11*
Optimized	*135.5*	*7.4*	*18.3*

We concluded that if these ideas would be used to build a real prosthesis, extra reinforcement would be needed at the locations that the artificial bone connects to something else, like at a joint or connection to the body.

BUILD UNDERSTANDING

6. Students share their designs and design process.

   a. (LITERACY) Support students in preparing an oral presentation on their design process.

   During the Procedure, let students know that each group will give an oral presentation for their response to Procedure Step 16. Consider distributing Literacy Visual Aid 1, "Oral Presentations," in the Teacher Resources and found in the Student Book, Appendix E, to help students organize what they will say. Encourage students to make attractive presentations, but stress that the evidence and ideas presented on the posters are crucial to a good presentation. For guidelines on oral presentations, see the Literacy section of Teacher Resources II, "Diverse Learners."

   b. Discuss how their results do and do not apply to building a real prosthesis.

   The testing procedure, like the prototype construction itself, is only a simulation. It does not necessarily represent the kinds of stress to which an actual bone or prosthetic bone might be subjected. Discuss with students what kind of testing they would want to do if they were developing a real product. Expect students to respond that they would want to test it next in an actual prosthesis and in real-world circumstances.

   c. Discuss the process of engineering design.

   Find commonalities in the way that students worked on their designs, such as brainstorming, testing, and redesigning. In this activity, students were guided through the steps of the engineering design process in the Procedure. Let students know that the process they experienced through the different sections of the Procedure is typical of engineers.

   Teacher's note: The engineering design method, which students experienced in a prescribed way in this activity, will be formally introduced in the beginning of the next activity.

7. If you have not previously done so, introduce the concept of trade-offs.

   a. Introduce the idea that decisions about solutions to scientific and engineering problems often involve trade-offs.

This unit includes issues that relate to science and/or engineering and that may lead to decisions about the best solutions or designs for solving problems. One goal of this curriculum is to teach students that

- decisions about possible solutions often involve trade-offs.
- identifying trade-offs involves analyzing evidence.

Explain to students that in this unit they will make several decisions about design. In this activity students had to make decisions on how to increase the strength to mass ratio of their bone model. In a decision involving trade-offs something is given up to gain something else. Since many decisions involve trade-offs, students should understand that a perfect choice is often not possible. It is possible, however, to recognize and analyze the trade-offs associated with each decision.

b. Provide an example of trade-offs.

For example, when asked, "Paper or plastic?" at a store checkout counter, most shoppers make the choice quickly. But there are several trade-offs attached to choosing paper or plastic. A shopper who chooses paper over plastic may do so to avoid generating plastic waste. In requesting the paper bag, though, they are contributing to other environmental problems, such as increased water and energy use, and the higher amounts of solid waste and CO_2 emissions associated with making paper bags. Neither choice is ideal, and both choices have a downside. Identifying the trade-offs helps clarify the reasoning that is being applied to make a decision.

c. Develop some examples of trade-offs in students' lives.

To further explore trade-offs, brainstorm with the class a list of decisions they make every day that involve trade-offs. Choose one and talk through the associated trade-offs of deciding one way or another. This practice will familiarize students with ways of identifying and considering trade-offs in this and subsequent activities.

SAMPLE RESPONSES TO ANALYSIS

1. Which of your prototypes

a. was strongest?

Student responses may vary. One sample response is shown here:

Prototype 4 with the filling was the strongest because it held 32.6 g.

b. was lightest?

Student responses may vary. One sample response is shown here:

Prototype 1 with no modifications was the lightest at 17.9 g.

c. had the highest strength-to-mass ratio?

Student responses may vary. One sample response is shown here:

Prototype 4 with the stuffing had the highest strength-to-mass ratio, so it was the most promising.

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.

Student responses may vary. One sample response is shown here:

Our final design was not as strong as one of the prototypes but it was a lot lighter. We gave up the overall strength of that bone to gain a better strength to mass ratio.

3. Describe the similarities and differences of features in your prototypes.

Student responses may vary. One sample response is shown here:

The prototypes all used the same materials, had roughly the same dimensions, and looked approximately the same. However, they performed differently under the load of the weight. Some had more reinforcement in the outer layer and others had reinforcement inside.

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.

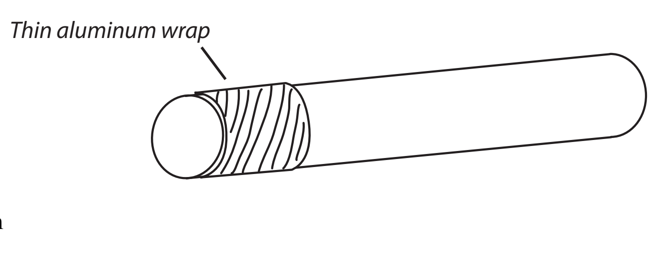
Student responses may vary. One sample response is shown here:

If high strength was the only factor, we would have just kept wrapping more and more paper around it and added as much filling as possible.

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.

Student responses may vary. One sample response is shown here:

If we could explore more materials, we would add reinforcement that was stronger than paper near the end of the table and at the testing point. We would try a light but strong metal like aluminum. That would make the area under the most force stronger.



6. Which of the class's artificial bone prototypes looks most promising for future development? Explain.

   Student responses may vary. One sample response is shown here:

   The most promising prototype was group 2's prototype because they got the highest strength-to-mass ratio by super compacting their filling. In the future, perhaps the fill could be made denser like that.

7. How might a light but strong tube be used other than to replace bones? List at least three ideas.

   Student responses may vary. One sample response is shown here:

   A light but strong pole could be useful in canes for the blind, street signs, fishing rods, poles for pole vaulting, airplanes, and machined parts.

REVISIT THE GUIDING QUESTION

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

Students should discover through this activity that a bone filled solid will be strong but not light and a hollow bone will be light but not strong enough. The ideal model, as with natural bones, is optimized by a combination of the strength of the outer bone and selective placement of inner fill. This design challenge showed how the structure of the bone model directly resulted in its function.

ACTIVITY RESOURCES

KEY VOCABULARY

constraints

criteria

function

model

prototype

structure

trade-off

variable

BACKGROUND INFORMATION

BONES

Bone is a rigid yet flexible organ that is constantly being created and replaced and has several functions within the body. Bones provide structural support for the body by providing a frame and attachment points for muscles, tendons, ligaments, and joints. Bones provide protection for soft internal organs, such as the skull's protection of the brain and the ribs' protection of the lungs and heart. Within the bone is bone marrow, which is the site for blood cell production. Bones also serve as a storage place for minerals, fat, and growth factors. Bones even play a role in hearing as there are three small bones in the middle ear required for sound transduction.

If significant amounts of bone are lost due to severe fractures or disease, artificial bones or bone grafts can be used as a replacement. Replacement bone can come from other parts of one's own body (autograft) or from other bodies or donors (allograft). If using an autograft, the amount of bone available is limited to avoid compromising other parts of the body. Artificial bone is composed of a variety of porous materials including, but not limited to, ceramics, metallic alloys, gelatin, wood, agarose, and collagen alginate. Artificial bones must be strong to provide structural support but also flexible so they do not snap or break. Ideal replacement bones serve as a structural scaffold to which the body can connect muscles, tendons, ligaments, and joints. A successful result is when the artificial bone tissue is gradually replaced with natural bone. For natural bone growth, blood vessels must be able to attach to and invade the artificial bone. Scientists are now pursuing the use of stem cells to regrow entire bones in the laboratory.

REFERENCES

This activity was adapted with permission from

Chang, R. P. H. (1996). *Design project 1: Designing a fishing pole*. Available from https://www.materialsworldmodules.org/index.php/modules-and-user-support/list-of-modules/composites-module

Name____ Date__________

STUDENT SHEET 4.1

INITIAL BONE PROTOTYPES

Draw and label your group's preliminary designs.

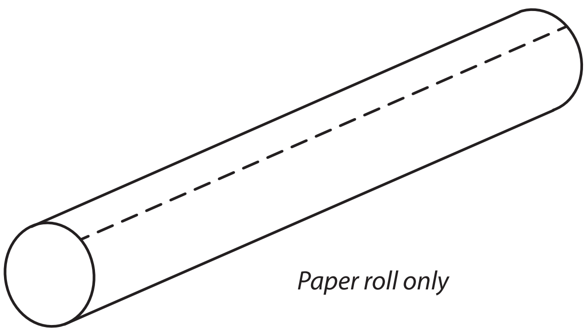
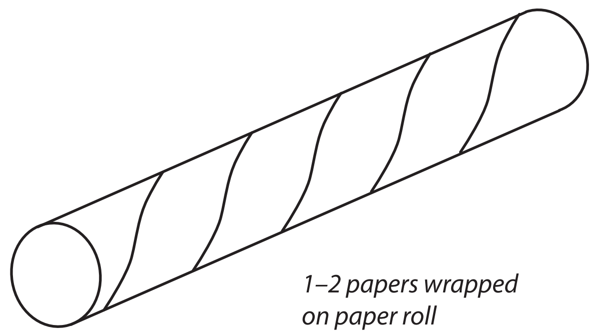
Prototype 1 Mass of model: Mass supported:	Prototype 2 Mass of model: Mass supported:
Prototype 3 Mass of model: Mass supported:	Prototype 4 Mass of model: Mass supported:

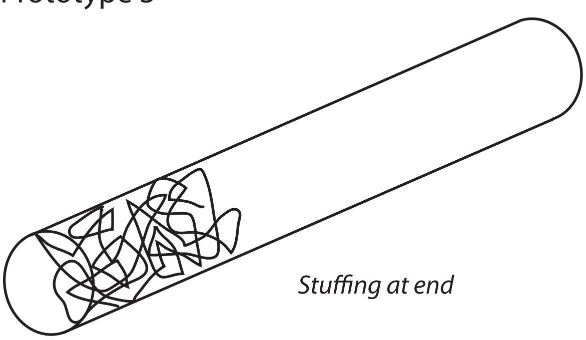
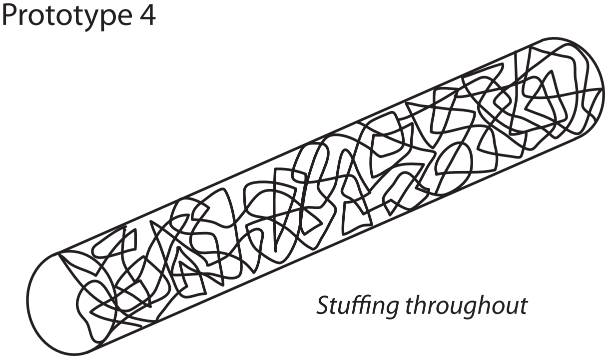
Name *Sample student response* Date

STUDENT SHEET 4.1

INITIAL BONE PROTOTYPES

Draw and label your group's preliminary designs.

Prototype 1	Prototype 2
 *Paper roll only*	 *1–2 papers wrapped on paper roll*
Mass of model: *4.1 g*	Mass of model: *5.9 g*
Mass supported: *30 g*	Mass supported: *177 g*

Prototype 3	Prototype 4
 *Stuffing at end*	 *Stuffing throughout*
Mass of model: *10 g*	Mass of model: *16 g*
Mass supported: *160 g*	Mass supported: *160 g*