Macrophages engineering design challenge

How might the engineering design process help to design an immune cell to "capture" an invader (bacteria, virus, etc.)? How is the immune cell affected when a mutation occurs?

Students will use the engineering design process to create an immune cell that can pick up invading microbes. Students should have a strong foundation in protein synthesis to understand that the resulting immune cell is built according to the information encoded in DNA. A mutation can cause the resulting cell to be built incorrectly, which could result in a weakened immune system.

This lesson was adapted from adapted from:
teachengineering.org/activities/view/nds-2224-bio-engineering-proteins-dna-modeling-testing

Ohio standards

Biology

- B.H.1 Cellular genetics
- B.H.2 Structure and function of DNA
- B.H.4 Mutations
- B.C.2 Cellular processes
- Scientific and engineering practices

Student prior knowledge

Students should have a basic understanding of the engineering design process used to solve a problem, as well as the basics of protein structure and function, and a strong foundation in protein synthesis to understand that the resulting immune cell is built according to the information encoded in DNA.

Suggested timeline

Two 45-minute class periods

- Day 1: design and build
- Day 2: test, improve, and mutate

Materials

- 3 bags of mini marshmallows or any small item (for example, pony beads)
- Masking tape, used only as a connector piece when building
- Scissors, used only as a tool
- 1 ruler, used only as a tool
- 1 die or online dice roll
- Twine or string
- Construction or brown wrapping paper
- Aluminum foil
- Paper bags
- Balloon, small or medium size
- Popsicle sticks
- Paper plates
- Floral wire
- Copy paper or bulletin board paper
- Plastic wrap or wax paper
- Plastic bag
- Water bottles
- Toothpicks or wooden skewers
- Cup, any size paper or plastic

Teacher preparation

1. Determine whether students will complete the pre-lab questions. Links may be found in the support information section.
2. Choose a testing space for testing (i.e., a lab table or other surface that is at least 2 feet by 5 feet and is accessible to all students).
3. Gather materials and determine amounts needed based on the number of groups. Prototype building tools for each group include masking tape, scissors, and ruler.
4. Students must use at least 2 of the building materials in Round 1. Determine the specific amounts of each material to be given to groups. Material choices to build the immune cell may be modified, but twine or string, up to 1 foot (~30 cm), construction or brown wrapping paper, aluminum foil, up to 1 foot (~30 cm), 1 paper bag, 1 balloon, small or medium size, 5 popsicle sticks and a paper plate are suggested.
5. For Round 2, students will substitute materials they used in Round 1 for different ones because of a mutation which will be determined by a roll of a die. Prepare the additional materials needed: floral wire (same length as twine), copy paper or bulletin board paper, plastic wrap or wax paper (up to 30 cm), plastic bag, water bottles, toothpick or skewer, and cup).
6. Review basic lab safety, as students are using scissors. Check for any food allergies if using food.

Procedure

Day 1

1. Optional review questions for discussion (may be assigned as pre-lab research):
    - What monomers make up proteins?
    - Where in a eukaryotic cell are the instructions for making a protein located? What are these instructions called?
    - What is the process called that makes proteins? Where do these processes occur?
    - What does a protein's shape have to do with its function?
    - What is the function of a defense protein?
    - What are mutations, and how do they affect protein structure?
    - What are the levels of the nonspecific (innate) immune system?
    - What is a macrophage and how does it work?
2. Show this clip on how a macrophage operates: ***youtu.be/3KrCmBNiJRI***.
3. Review the innate immune response and the first line of defense, including the cellular response.
4. Review the Engineering Design process by discussing/describing the steps: *empathize, define, ideate, prototype, test, and implement.*
5. Guide groups of 3–4 students through the design process to make a prototype. Use this scenario:
    a. **Empathize:** Scenario: You are walking through the cafeteria at lunch with friends. A freshman lets loose a huge sneeze, and never covered their face! You have been studying the immune system in Biology and know that your body is built to withstand the invasion of foreign microbes. You wonder how your white blood cells will engulf the potential viruses or bacteria.
    b. **Define:** How do we get sick? What mechanisms do our bodies have to help combat this invasion?
    c. **Ideate:** How might you design an immune cell that will recognize and pick up invader molecules? Each group chooses at least 2 of the supplies for round 1.
6. Give students the remainder of the period to design on paper or create small examples to communicate ideas to the group. It is easy for the group to split off into individuals during this phase. Walk around and ask them to get ideas about what they are trying from their other group members to see if it is meeting the needs they defined above. This process is cyclical and will rotate back and forth between steps to get to the "best solution."
7. Groups should have a design in mind by the end of the period. You may collect a drawing or notes

as an exit ticket.

Day 2

Round 1

1. **Prototype:** Ask student groups to build a prototype of the design using the materials provided.
2. **Test:** Try out the design, then go back to iterating to “tweak” the design.
3. **Implement:** Ask other members from other groups to try the prototype.

Round 2

1. Round 2 is used to illustrate a mutation in the immune cell. Tell students there are mutations in the DNA that have affected their design. Students must roll a die and replace one of the design tools they used based on the result. Have each group use the engineering design process again, using the same initial materials and those replaced due to mutation. You may choose to give students more than one mutation.
2. Example: For Round 1, a group chose twine, a paper bag, and popsicle sticks to make their model. For the second round, they will still make their model using those supplies, but one will be switched out according to their die roll. If they roll a 2, they switch their popsicle sticks to skewers.
3. Determine the number of mutations and the item to be mutated.

If you used this material in Round 1	Substitute these materials in Round 2 (roll a die and replace one of your Round 1 items with...)
Twine or string, up to 1 foot (~30 cm)	Floral wire (even number die roll)
Construction or brown wrapping paper	Copy paper or bulletin board paper (odd number die roll)
Aluminum foil, up to 1 foot (~30 cm)	Plastic wrap, up to 1 foot (~30 cm) or wax paper, up to 1 foot (~30 cm) (odd number die roll)
1 paper bag	Plastic bag (even number die roll)
1 balloon, small or medium size	Water bottles (odd number die roll)
5 popsicle sticks	Toothpicks or skewers (even number die roll)
Paper plates	Cup, any size or material (odd number die roll)

- *Note:* If a group only has 2 items in Round 1, only do one mutation.

Suggested wrap-up

Lead a discussion with all or ask students individually to answer the questions below, then share out.

- What was the hardest part of the process? The easiest?
- Was their design successful?

Differentiation

Students may be grouped cooperatively or in pairs. Offer varied ways to demonstrate learning: allow students to complete tasks in different formats, such as giving an oral report instead of a written one, using a choice board, or using a graphic organizer.

Extensions

- To simplify for lower grades, just focus on one type of disease.
- Discuss different immune therapies and the costs associated with each.
- Discuss the immune system diseases, e.g., measles, SCID (which is genetic and associated with mutated T-cells), or AIDS.

Support information

Many times, the solution to a problem involves designing a product (like a machine or computer code) that meets certain criteria and/or accomplishes a certain task. This process differs from the steps of the scientific method, with which you may be more familiar. If your project involves designing, building, and testing something, you should probably follow the Engineering Design Process. The Engineering Design Process is a solution-based approach to solving problems—from the very simple to the very complex. The approach is non-linear and iterative. It is very common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change to your design.

The human body is 16% protein. These proteins do many things: they work as enzymes to speed up chemical reactions; they store and transport substances; they make up channels in cell membranes to permit specific substances to go in and out of cells; they copy genes to make more proteins; they keep the body healthy by destroying bacteria; they make up our muscles to enable movement; they transmit messages; and they are what we see when we look at a person's skin, nails, and hair. Proteins use a combination of 20 different amino acids to form different shapes to perform different functions. If mutations exist in the DNA sequence or errors occur in transcription or translation, various consequences result. Sometimes a protein will not be made. Other times, an incorrect protein will be made. Both of these situations may or may not result in disease.

See additional resources below:

- Links for pre-lab activity: **learn.genetics.utah.edu/content/basics/proteins**
  - **learn.genetics.utah.edu/content/basics/mutation**
  - **learn.genetics.utah.edu/content/basics/proteintypes**
  - Amoeba Sisters: **youtu.be/fSEFXl2XQpc**
  - Immune Deficiency Foundation YouTube channel: **youtube.com/channel/UC-e7Jua_piexR70CVoaofYw**
- *Everything Everything* book by Nicola Yoon (novel about a young girl with Severe Combined Immunodeficiency, a rare genetic disorder where a baby is born with a critically weak or absent immune system, lacking functional T-cells and often B-cells, making them unable to fight off even mild infections)
- "Everything Everything" trailers: **youtu.be/mAC-nh9PU5s**, **youtu.be/xd5IVPGDlkY**
- How the immune system is impacted by measles: **theguardian.com/science/2019/oct/31/measles-wipes-out-immune-systems-memory-study-finds**
- TED Talk: What makes tattoos permanent? **ted.com/talks/claudia_aguirre_what_makes_tattoos_permanent**
- How AIDS impacts the immune system: **who.int/news-room/fact-sheets/detail/hiv-aids**

- Intro to Immune System Hook videos:
    - White blood cell engulfing bacteria: ***youtu.be/3KrCmBNiJRI***
    - How your immune system works: ***youtu.be/1KdlU1sQcyc***
    - Macrophage in action: ***youtu.be/X_T4m3iA5WA***
    - Adaptive immune system: ***vimeo.com/227178817***
    - Innate immune system: ***vimeo.com/227178345***
    - How do antibodies work? ***vimeo.com/227176366***
- Immunology 101: ***ucir.org/immunology-101/getting_to_know_the_immune_system***
- Vaccine Makers Project resources: ***vaccinemakers.org/resources/videos-animations***
- Chapter 1: Proteins are the Body's Worker Molecules. 2011. The Structures of Life, Science Education, National Institute of General Medical Sciences, National Institutes of Health, U.S. Department of Health and Human Services, Bethesda, MD. ***especialidades.sld.cu/histologia/files/2020/06/Booklet-The-Structures-of-Life.pdf***
- Components of the Blood > The Circulatory System. In Boundless Biology (online textbook). Lumen Learning Courseware, LumenCandela. ***courses.lumenlearning.com/boundless-biology/chapter/components-of-the-blood***

Career connections

- **Computational biologist:** Develops algorithms (sets of instructions that tell computers what to do) and models to support programs for machine learning. They use machine learning to classify or categorize data or to make predictions related to the models. Scientists also must test the algorithms and models for accuracy, including for updates with newly collected data.
- **Process engineer:** Designs, analyzes, and optimizes manufacturing or industrial systems to maximize efficiency, quality, and cost-effectiveness. They troubleshoot production issues, implement new technology, and ensure compliance with safety and regulatory standards. These professionals work on-site, managing production workflows in industries like chemical, food and beverage, and manufacturing.
- **Biomedical engineer:** Applies engineering principles to medicine and biology to design, develop, and evaluate new products and processes that improve health and healthcare, such as artificial organs, prosthetics, diagnostic tools, and medical software.