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NINA TANDON

Reverse Engineering Bones to Become a Great Engineer

STEM Lesson Plan for Grades 6-8

Helping all students, especially girls, to be interested in engineering as a possible future can be challenging. Research suggests that role models are important for helping students to see themselves in a jobs where they have been underrepresented. In addition, having challenging and fun engineering experiences help students to want to become engineers.

Many engineering projects though are focused on competitions, but that isn't the essence of engineering. The cycle of determining a problem, identifying what's needed to solve the problem, trying and testing possible solutions, and optimizing and iterating to find an adequate solution is what makes an engineering project.

In this lesson plan, students will watch a video where Nina Tandon explains how she became a successful engineer. After figuring out what she says are some key factors to being a great engineer, they will embark on a reverse engineering project where they will try to determine what makes bone strong. Finally, they will look back at their work habits to determine how closely they matched skills that the engineer suggested were important.

NGSS Standards

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

CCC HS:Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.

CCC HS: The functions and properties of natural and designed objects and systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of its various materials.

Part I: Watching the Nina Tandon Video

Before the students watch the video, the teacher should explain that in this video an engineer will explain what makes her a successful engineer. The teacher should ask students to record what personality traits, desires, and behaviors are important to becoming an engineer.

For younger students, you may need to use sentence starters like

Nina Tandon said that she had to overcome the obstacles of _________

Nina Tandon said that she want to _______

The video has on-screen icons that will help students when she is saying key components of her success. For some students, pausing the video at those moments will help them better record what is going on.

In small groups have the students summarize what they saw and then make sure that the entire class has all of the points. While they may have more than these, they should at least note:

- Nina Tandon has made engineering her career.
- Nina Tandon is an engineer because it gives her a chance to be creative.
- Nina Tandon persevered to overcome obstacles.
- Nina Tandon works with others as a team.

Making a Great Engineer Checklist

Students now should now make a checklist of things for themselves to do if they want to be a good engineer. Then when they do something on the checklist, they should mark it off. For example

Activity	
I helped someone	卌 I
I didn't give up when something didn't go the way I planned	卌 III

Students will use this checklist several times in the following projects. Don't assign points or give too much praise, otherwise students will just game the system. We just want them noting when they are doing something a good engineer does, helping them to internalize that they can be an engineer. Alternatively, you can make it the task of one of the members of the group to note when their groupmates are being good engineers.

Part II: Reverse Engineering

Reverse engineering is the process where an engineer takes apart an object to see how it works. While it is often performed on a engineered objects, it is sometimes done on natural objects to see how they work and to inform engineering design for future objects. The field of biomimicry revolves around the design and production of materials and structures inspired or modeled on biological entities.

Figuring out Bones

Students often perceive bones as lifeless rocks that make up the structural supports of animals. Bones are actually complicated organs consisting of widely spaced living cells that respond to external stimuli by reshaping and rebuilding the matrix between them the a process called remodelling. The matrix of bones consists of about 25% collagen, 25% inorganic salts -- mainly calcium phosphate, and 50% water.

Bones are a composite material. The collagen and the minerals both contribute to the bone's strength. Removing one while leaving the other intact can help students understand the function of each.

Materials

- Safety glasses
- 4 chicken bones, legs or thighs work best, flesh removed
- Rubber, latex, or nitrile gloves
- Scissors
- 2 beakers and covers
- 200 mL distilled vinegar (5% acidity)
- Hydrochloric acid (muriatic acid), nitric acid, descaling agent (optional)
- Tongs
- 200 mL Deionized or distilled water
- 5 mL Sodium oxalate 1% solution (optional)
- Slow cooker, pot and hotplate, or pressure cooker
- Container for the broth
- Shallow disposable roasting pans or loaf pans (optional)
- Newspaper, string, rubber bands, spaghetti, macaroni etc. (optional)
- Tap water to fill roasting pans to approximately 2 inches deep (optional)

Getting the salt out (demineralizing the bones)

Raw chicken can contain salmonella and other pathogens. Students should wear gloves and not touch their face until they have cleaned up. Surfaces where raw chicken have touched should be cleaned with a bleach and water solution (25 mL bleach to 1 L of water).

An optional component of this activity is using strong acids. Handling strong acids requires appropriate lab safety -- at minimum splash eye protection -- and should only be done if you have experience working with them and students understand appropriate lab safety.

Chicken bones make for good model bones as they are reasonably sized and inexpensive, but other animal bones will work though the time for completion may be much longer. If you leave the bones uncovered in refrigerator for two days or more, it will make it easier to remove all the flesh. If you are having students do this, scissors are a good way to remove the flesh.

Place one or more bones in a glass container and cover with acid. Cover with plastic or a watch glass. Place an additional bone in distilled water and cover. If you are using vinegar, the reaction can take more than five days for completion, but other acids may work faster.


Ideally, you'd like to remove the calcium phosphate and other inorganic salts from bones without disrupting the collagen strands left behind so that the collagen's properties can be examined separate from the salts'. Calcium phosphate is readily attacked by acids, though some will attack collagen, especially in higher concentrations, and many others yield compounds that aren't particularly soluble in water.

Having students try several acids at different concentrations is a good introduction to reverse engineering and the difficulty of disassembling something without destroying it. For less experienced students, you may need to assign which acids to try, but for older students, you might be able solicit ideas from their experiences in chemistry or have them search on the internet. Hydrochloric and nitric acids work if the concentrations are kept low enough (1 M or less) not to attack the collagen too much. Handling strong acids requires appropriate lab safety -- at minimum splash eye protection and should only be done if you have experience working with them and students understand appropriate lab safety. Strong acids will need frequent replenishing as the calcium neutralizes the acid.

Acetic acid (vinegar) works well as calcium acetate is fairly water soluble and the relatively high pH minimizes disruption to the collagen. While weak acids are usually a higher pH (less acidic) than strong acids, they can have a higher capacity for attacking the calcium over time.

A combination of lactic acid and gluconic acid, found in commercial descaling products like CLR, works well since the yield of calcium lactate gluconate is extremely soluble.

	Pros	Cons
Strong acids	• Fastest demineralization time	• Extra precautions necessary to work with them • Becomes exhausted quickly
Weak acids	• Highest safety • Familiar materials	• Slowest demineralization time
Descaling agents	• Requires some safety precautions outlined on the containers • Available in hardware stores	• Can stain the bones • Contains ingredients not necessary for demineralization

Students can also investigate levels of agitation and temperature if access to materials is available.

During the demineralization process the solution can sometimes turn a dark red. Typically, this is from the red marrow which is more abundant in young animals.

Demineralizing the bones removes most of the bone's stiffness and resistance to compression. Without it, only the flexible collagen is left behind and the bone can be easily bent.

Some students will express little surprise that the bone has been changed by the acid, thinking that acids degrade many materials. This thinking isn't entirely wrong: the acid does attack the bones. Its method of attack is relatively specific though. In this case the acid removes the calcium from the matrix and leaves it in solution. To check for this, decant a bit of the clear liquid from the beaker. Add a couple of drops of sodium oxalate. They will turn white as the drops form calcium oxalate, and insoluble form of calcium. The collagen is left behind.

Making gelatin (removing the collagen)

Add bones to a pot, a slow cooker, or a pressure cooker. Add just enough water to cover. For the slow cooker and the pot, cook just below the boil for eight to ten hours. Add water to make sure that the bones remain covered. In a pressure cooker, cook on high pressure for 90 minutes.

Removing collagen from bones relies on a transition that occurs in collagen as it is heated. In a moist environment, starting at about 55°C the collagen in meat and bones begins to denature and unravel and become soluble gelatin. The process greatly accelerates starting at about 70° C and continues into higher temperatures as long as the environment remains wet. In drier environments, the collagen breaks down and is oxidized but does not convert to gelatin.

While these guidelines work, having students try different temperatures for different lengths of time is a great way for them to help understand what is happening. Lower temperatures will still succeed in releasing the collagen, but will take longer, while higher temperatures take less time.

After the time is up remove the bones and allow to cool. Remove any remaining meat. Place the liquid in a refrigerator or on ice and allow to cool.

Try bending the cooled bone. You should notice it break in your fingers. Many people describe the cooked bone as crumbly. The calcium phosphate in the bones isn't one large monolithic rock, but rather in very small pieces. These are held together by the collagen. Without the collagen, the bone is brittle.

You can show, though, that the collagen hasn't just gone away but been transformed into gelatin. As the liquid cools it will set up into a gel very much like commercial gelatins.

Going Further (optional)

Freeze a layer of water approximately 2.5 cm thick in a roasting or loaf pan. Remove the ice from the pan. When hit with a hammer, it will easily shatter.

Ask students to determine a way to make the ice stronger without making it much heavier using the information that they learned in this unit. Using the different long materials like newspaper and string frozen into the ice, they can make the ice much stronger, similar to how the collagen strengthens bone. In addition, they can freeze opens space into the ice with pasta which will make the ice lighter.

Part III: Evaluation

Having students look at other composite materials like safety glass, carbon fiber resins or fiberglass reinforced products will help them to make the connection between how bones and how some engineered materials get their strength.

In addition, each group should report out on how well they worked together. Even for classes that didn't have time for the groups to work on their own project, having the students briefly present their work to their classmates tends to give the best opportunity to figure out what happened in their group. They should explain

- What their problem/goal was
- What they tried
- Whether or not it was successful
- How they could tell if it was working
- What they did if they didn't all agree on what to do
- How often did they get to put a mark on their checklists