MATERIALS™ EXPLORERS

STRUCTURAL MATERIALS

From bridges to automobile parts to helmets, the world is full of products designed to safely transmit or support a force. Researchers developing products don't select materials by guessing–they study the conditions the product has to withstand and carefully select a material that fits their needs.

In this module students will be able to:

- Identify examples of structural failures in everyday life
- Calculate stress and strain
- Determine Young's modulus
- Tabulate and graph calculated results for stress and strain
- Investigate the real life applications of structural materials

Class Activity

MATERIALS IN CONSTRUCTION

Background:
While no one likes failure, the stakes are much higher when it comes to construction and structural failures. To avoid bridge collapses or to keep skyscrapers pointing skyward, engineers have to design structures capable of withstanding significant amounts of **stress** and **strain**. To do so, they need an understanding of the forces that will be working on a structure but also, an understanding of the materials being used in its construction.

In engineering, stress refers to force exerted per unit area. Engineers must determine how much stress will be applied to different areas of an object and select a material capable of withstanding that stress. Stress can be calculated according to the following equation:

$\sigma = \frac{F}{A}$ where σ = stress (N/m^2), F = force (Newtons or lbs.), and A= Cross-sectional area (m^2 or in^2)

This equation shows that if force is constant over a small area, the stress will increase. Conversely, if the force is constant over a large area, stress will decrease. Strain, on the other hand, refers to how an object reacts to stress. Strain measures the percentage change in an object's shape when stress is applied. Strain can be calculated according to the following equation:

$\varepsilon = \frac{L-L_o}{L_o}$ where ε= strain, L= new length (mm or in), and L_o= original length (mm or in)

Once stress and strain have been calculated, Young's modulus can also be calculated. Young's modulus is the ratio of stress to strain and determines the elasticity of a material. The equation for Young's modulus is:

$E = \frac{s}{t}$ where E= Young's modulus (Pascals), s= stress, and t= strain

Class Activity

The higher the value of Young's modulus, the stiffer the material.

Every material can withstand a different amount of stress, so it's critical that engineers understand the properties of each material they select.

Problem

Your fellow students are decorating for the school dance by suspending decorations of various weight around the gym. The students would like to use clear fishing line, but are concerned that it may not be able to support the weight of heavy decorations such as lanterns. Your teacher has advised your class to test the strength of the wire first and to determine its Young's modulus.

Task:
Your task is to determine Young's modulus for the nylon wire by first calculating the strain on the material when stress is applied.

Requirements:
Determine Young's modulus for the wire by working as a group. Each group will be assigned to a workstation and will receive a ruler and a set of weights. Using your ruler, record the initial length of the wire. Then, add weights one at a time and record the new length with each weight added. Finally, remove all the weights and record the final length of the wire. Results should be recorded in the table provided.

Remember that, for accurate measurements, you should start at the same point each time you measure the wire. This can be done by fastening your ruler to the side of the table.

Questions

1. **Using the table below, record your results beginning with no load and ending with the final length of the wire after all the load has been removed. Then, calculate stress and strain for each step.**

Total Weight Applied (N)	Cross-sectional Area (m^2)	Stress (N/m^2)	Strain

Class Activity

2. **Graph your results for stress versus strain, placing strain on the x-axis.**
3. **What is the relationship between stress and strain? Use your data to support your answer.**
4. **Calculate Young's modulus for the wire.**
5. **How would your results differ if you used a material with a higher Young's modulus? Research two materials with a higher Young's modulus and discuss their applications in the real world.**

Definitions

Stress
A measurement of the force applied to the object per unit area. It can be calculated by dividing the force applied to the material by its cross-sectional area.

Strain
A measurement of the change in an object's shape when a certain stress is applied. Strain can be calculated by dividing the change in the material's length by its original length.

Young's Modulus
Also known as the elastic modulus, Young's modulus is a measure of the elasticity of a material. The higher the Young's modulus of a material, the more the material will resist stretching. It can be calculated by dividing stress by strain.

Extension Activity

MAKING THE OLD NEW: HOW MODERN SCIENCE BRINGS NEW LIFE TO FOSSILS

Curators at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, took on a mammoth project in 2008 when they decided to renovate the museum's dinosaur exhibit.

For 60 years, a Tyrannosaurus rex had stood tall in the museum, its ancient bones posed awkwardly erect, more like a sharp-toothed kangaroo than a tyrant lizard king. It was time for a change that would return the prehistoric giants to their original grandeur.

Today, visitors to the "Dinosaurs in Their Time" exhibit are treated to dynamic poses that make the fossils appear more lifelike and tell a story of the predator-prey relationships at play. The once-towering T. rex can be seen crouching low, neck practically parallel to the ground, ready for a Cretaceous period showdown with another T. rex. Over in the Jurassic section, the stately Apatosaurus cranes its long neck gracefully backward, facing a predator that seems to be closing in.

To be sure, the stars of the $36 million restoration are the Carnegie's renowned collection of fossils. But the supporting players, unnoticed and yet essential to the drama on the museum floor, are the steel **armatures** that encase them. These handcrafted frameworks allow the T. rex to crouch low, ready to fight. They raise the Diplodocus tail off the ground and support its unwieldy neck. And yet, the general public is unlikely to appreciate this one-of-a-kind hardware. That, says Matt Lamanna, the museum's assistant curator of vertebrate paleontology, is the sign of expert dinosaur mounting. "There is such attention to detail that a lot of people don't even see the armatures. That's the beauty of it," he said.

Deconstructing Dinosaurs

The museum tasked Phil Fraley, founder of Phil Fraley Productions, with what would be the largest renovation since the museum opened in 1895. Of course, the primary goal was to give the skeletons poses that reflected new thoughts on dinosaur **biomechanics**, but the secondary goal of the project was to imply action with enough color and drama to enthrall modern-day museum goers. That was where the art of metalworking was essential. When molded expertly, the steel framework brings an organic quality to the fossils, Fraley said. "Really, what an armature is doing is replacing all the tendons and ligaments—the soft tissue that used to hold the animal together," he said.

Safely dismantling the existing structures was no easy task.

Bob Zeller and Paul Zawisha attach dorsal ribs of the holotype T. rex to the armature during installation at the Carnegie Museum of Natural History. (Photo courtesy of Phil Fraley Productions)

Fraley's team had to remove the ancient bones from their pre-existing armatures, some of which had been in place for 100 years. They also had to safely move the bones without placing stresses on them—no easy task considering that the pelvic bones of some of the larger specimens weighed more than 3,000 lbs!

While the team anticipated the weight and age of the fossils, they could not predict the condition of either the metal or the fossils until the work began, and there were some surprises.

"When Carnegie began collecting dinosaur skeletons, their display was a relatively new art in the early

Extension Activity

20th century," said Phil Fraley, "The armatures for the Diplodocus and the Apatosaurus were really underbuilt…over the decades, shifting occurred. Two vertical supports under the pectoral girdle and the shoulder of the Apatosaurus, meant to share the weight of the structure equally, had spread over the years, three and a half inches in each direction." Fraley said, "They were going in opposite directions."

The separation was caused by a combination of the weight of the specimen and the likelihood that the skeleton was moved at some point without people taking proper precautions to stabilize it. In addition, during the disarticulation of the Apatosaurus, Fraley's team found that metal plates that had been bolted onto the pelvis had stress fractures in two places. "That was a pretty dangerous situation for the specimen," Fraley said. "Had there been a sudden jolt that would have caused this to move in one particular direction, there was a high probability that it would have broken," and with potentially disastrous consequences, he added.

Damage was also caused by what Project Manager Larry Lee described as "metallurgical mistakes." In particular, a **galvanic effect** resulted from welds of cast steel to cast bronze. "It kind of diseased those metals," he said. Lee found evidence of those poorly planned welds in the T. rex and the Allosaurus, where bronze was used in the underside of some vertebrae to create a seat that would hold the bone in position.

The bronze-steel welds held up, Lee noted, but the metal was deteriorated. Needless to say, no bronze mounts were used when Fraley's company reconstructed the dinosaurs. Instead, new steel cradles were made individually to fit each vertebra of the dinosaurs. And, in Lamanna's eyes, those cradles were more than steel supports. "Each cradle is a customized work of art that keeps the specimen safe," he said.

21St Century Dinosaurs

There may have been flaws in some of the original dinosaur mounts, but there was also a level of artistry that surprised Fraley and Lee. On the Apatosaurus and Diplodocus, in particular, the armatures were unique, Lee said, made of cast steel underneath the vertebra to create a support system.

"We did a metallurgical analysis of it and found it was an excellent mild steel," he said. "We were able to TIG-weld with it, bend it, drill it, and tap into it—it had excellent qualities. They used excellent iron in their castings. We really lucked out." For that reason, some of the oldest mounts could be reused and built upon, Lee said.

Those early castings were so unique that Fraley reused them in the new display. "We couldn't do a better job than what they had done in casting those ourselves," he said. "In some ways, it was our way of recognizing and appreciating the work that all these people a hundred years ago had done on the specimen. They were part of that specimen's history, and we're now a part of that specimen's history."

A Bona Fide Hidden Metals Craft

Lee's background was in sculpture when he turned his talents to dinosaur armatures. As he explored the workshops of the American Museum, he found remnants of the craftspeople who came before him. "I discovered this whole tradition of metal mount-making for dinosaurs. It included casting and blacksmithing, machining, all kinds of bending, all kinds of metal work. I discovered this bona fide hidden metals craft—a tradition that started with the folks at the Carnegie and at the American Museum at the turn of the 20th century."

Remounting dinosaurs at the Fraley studios extends that tradition. Once the skeletons have been painstakingly disassembled, the bones are stripped of all adhesives, paints, and shellacs layered on over the years to hide flaws. Then, for the larger pieces, such as femurs, the artisans make

Extension Activity

a cast so they can use those shapes without damaging the actual bones. The steel armatures are shaped while hot on the cast. For the smaller pieces, Lee said, “It’s a process of bending steel with heat, then cooling the steel, and then checking it to see how close it is to the shape we want to achieve. It’s rather painstaking: heating, bending, cooling, and comparing, and on and on, to make these custom fittings. It’s a process akin to jewelry making. You take a precious stone and make a setting for it—that’s what we’re doing.”

This article is excerpted from “Steel and Science Bring Dinosaurs into the 21st Century at the Carnegie Museum of Natural History” by Maureen Byko, published in JOM*, June 2008, Volume 60, Issue 6, pp 12-16.*

Questions

1. **What caused the supports under pectoral girdle and the shoulder of the Apatosaurus to spread apart?**

2. **What is the difference between ductile and brittle fractures?**

3. **What is casting and how is it used to study fossils?**

4. **Why is steel an important material not only in supporting dinosaurs in the Carnegie Museum of Natural History, but in all construction today?**

5. **Dinosaur armatures are not the only areas where designers marry function with artistry. Some popular smartphone makers switched their phone cases from aluminum to glass. Discuss some of the advantages and disadvantages of this decision for both the aesthetics and the function of the phone.**

Definitions

Armatures
A framework used to support heavy sculptures or displays. In fossil displays, armatures must be strong but also unobtrusive and delicate so they do not damage fossils or distract viewers.

Biomechanics
The study of movement in living organisms. This includes how bones and muscles create movement but the mechanics of other body functions such as blood circulation.

Galvanic Effect
The corrosion of a metal or a substance as a result of electrolytic action. This occurs when two different metals are in electrical contact in an electrolyte.

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