Elective 3: Review of Resource “Strong as a Feather”

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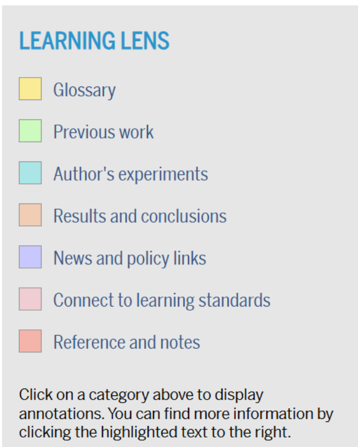
https://www.scienceintheclassroom.org/research-papers/light-feather-strong-ox

This is an annotated professional journal article from 2014 regarding ultralight, ultrastiff materials.

It has a “Learning Lens” on the left that allows the user click to highlight only certain aspects of the article.



I am not someone well-versed in literacy, but I am not sure how this is very helpful in developing literacy. Perhaps it is helpful in tuning out the scientific “noise,” but I think that is more helpful in getting students to focus on the bare minimum, which is still pretty complex.

For example, if you highlight “results and conclusions, these are the first statements that come up:

- We found that these materials exhibit ultrastiff properties across more than three orders of magnitude in density, regardless of the constituent material.
- This loss of mechanical performance is because most natural and engineered cellular solids with random porosity, particularly at relative densities less than 0.1%, exhibit a quadratic or stronger scaling relationship between Young’s modulus and density as well as between strength and density.
- The stretch-dominated microlattices populate the highly desirable ultralight, ultrastiff space toward the upper left of the chart (17) and have stiffness-to-weight ratios that do not substantially degrade as density decreases by several orders of magnitude.

If the student focuses on that and that alone, how helpful is that, really? I read the entire article, and I have a decent understanding of it despite not being a materials engineer, and if I just tune all of the information I got out of it, I really would have no understanding of what any of those bullet points mean. By using just clicking boxes on the left, you are doing all of the work for the students and yet, contributing to zero of the understanding.

I think which would be much more helpful is to give a worksheet with guided instruction, something that helps the students focus and tune out the overly complex analysis but not “give it all away.”

What is great about this writing is that it is very rigorous, and involves a lot of rich engineering, physics, and mathematics (mostly topology), with good explanation of each, and also how a scientist or engineer designs experiments.

It is too high level for any high school student to understand as is, even with the clickable supports in place. I had to do a lot of background reading, and re-reading, to understand everything in the journal, but I learned a lot from it, and I think it is a great real-life motivation for students of mathematics and engineering. In fact, I think it’s a richer journal for mathematics versus physics, so it really spoke to me, especially as someone who appreciates geometry and is interested in topology, but studied neither.

Background information: Classification of Cellular Structures: Very clear and simple explanation of 3D cell structures and their applications, especially the difference between stretch-dominated and bend-dominated structures, which structure is most effective where
https://www.padtinc.com/2016/08/29/classification-of-cellular-solids-and-why-it-matters/

Below is some suggestion for guided reading/writing for a student.

Strong as a Feather

https://www.scienceintheclassroom.org/research-papers/light-feather-strong-ox

This research reports on finding an appropriate material and structure of low density that maintains stiffness under pressure. In other words, a lightweight material that is also very strong. Iron or steel is very strong, but it is very heavy. Paper is very light, but not strong at all.

Engineers are always seeking to be “efficient.” The meaning of “efficient” changes depending on what they are trying to do.

Let's say you were designing a package to hold granola to sell at a store. Often this is sold in a cardboard box in the shape of a rectangular prism. Why is this choice of material and shape "eficient?" Sometimes the granola is in plastic inside the box. Is this more or less efficient? Why do you think plastic might be involved if it isn't more efficient?

The author gives a hit at what is coming by the summary sentence "This performance derives from a network of nearly **isotropic** microscale unit cells with high structural connectivity and **nanoscale** features, whose structural members are designed to carry loads in tension or compression. Production of these **microlattices,** with **polymers**, metals, or **ceramics** as constituent materials, is made possible by projection microstereolithography (an additive micromanufacturing technique) combined with nanoscale coating and postprocessing."

5 words are bolded. Do you have a sense as to what each of these words mean? Does it give you a hint as to the size, shape, and/or composition of the material the author is speaking about? Write down your predictions here.

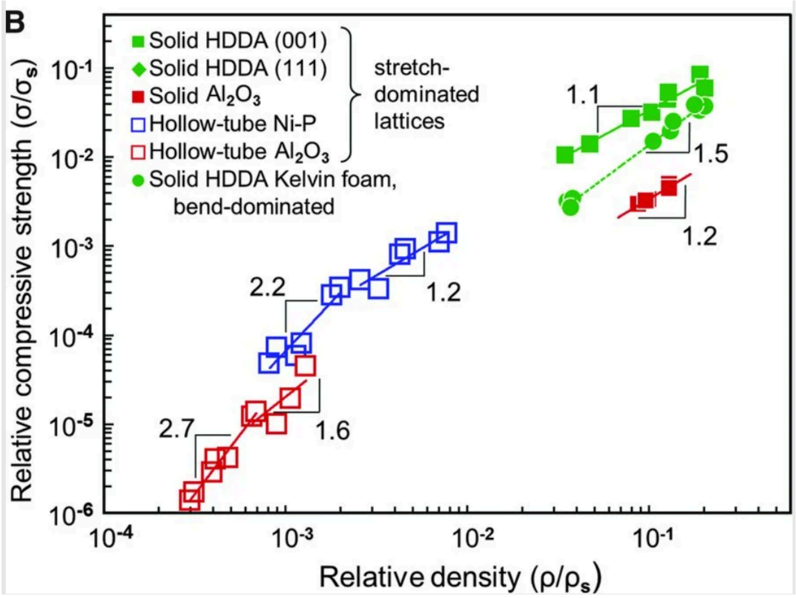
Under "Report" the author states "Nature has found a way to achieve mechanically efficient materials by evolving cellular structures. Natural cellular materials, including honeycomb (1) (wood, cork) and foamlike structures, such as trabecular bone (2), plant parenchyma (3), and sponge (4), **combine low weight with superior mechanical properties.** For example, lightweight balsa has a stiffness-to-weight ratio comparable to that of steel."

What shape are the cells of the honeycomb? What is the honeycomb made of? Why is the shape of the honeycomb an "efficient" use of the materials?

In paragraph 3 of "report," the author says, "loss of mechanical performance is because most natural and engineered cellular solids with random porosity, particularly at relative densities less than 0.1%, exhibit a **quadratic or stronger scaling relationship** between Young's modulus and density as well as between strength and density."

They continue, "We report a group of ultralight mechanical metamaterials that maintain a **nearly linear scaling between stiffness and density** spanning three orders of magnitude in density, over a variety of constituent materials."

Look at the graph below. Explain why the red and green (open icon) quadratic graphs on the lower left of the graph indicate a less effective structure than the solid green and red linear graphs on the upper right.



There are a few variables the author discusses in looking for a strong material with low density. The structure can vary in cell size, material (metal, polymer, etc.), type of coating, and **orientation of the cells.**

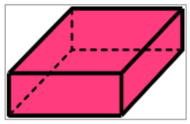
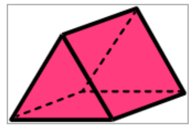
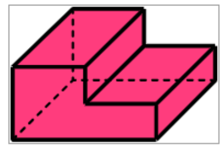
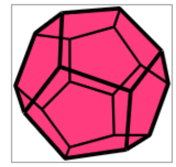
"We use the term "mechanical metamaterials" to refer to materials with certain mechanical properties **defined by their geometry rather than their composition."** The materials described here are highly ordered, nearly isotropic, and have high structural connectivity within **stretch-dominated**, face-centered cubic (fcc) architectures."

https://en.wikipedia.org/wiki/Topology
According to wikipedia, "Topology (from the Greek words τόπος, 'place, location', and λόγος, 'study') is the branch of mathematics concerned with the properties of a geometric object that are preserved under continuous deformations, such as stretching, twisting, crumpling, and bending; that is, without closing holes, opening holes, tearing, gluing, or passing through itself."

When we talk about the "topology" of a structure, we are not just talking about its overall shape, but how the pieces are put together.

One famous theorem in topology was discovered by Leonard Euler: that the relationship between the vertices (V), edges (E), and faces (F) of a polyhedron could be simply represented by $V - E + F = 2$.

From
https://thirdspacelearning.com/gcse-maths/geometry-and-measure/faces-edges-and-vertices/

	Tetrahedron	*Cuboid*	*Triangular prism*	*L-shaped prism*	*Dodecahedron*
Image					
Vertices	4	8	6	12	20
Edges	6	12	9	18	30
Faces	4	6	5	8	12

Verify that Euler’s formula holds true for each of the above polyhedra.