Biomimicry is a uniquely engaging and important tool for teaching students about design innovation.

Besides having students design things, what else as a teacher can you do with biomimicry?

Are You Young and Idealistic?

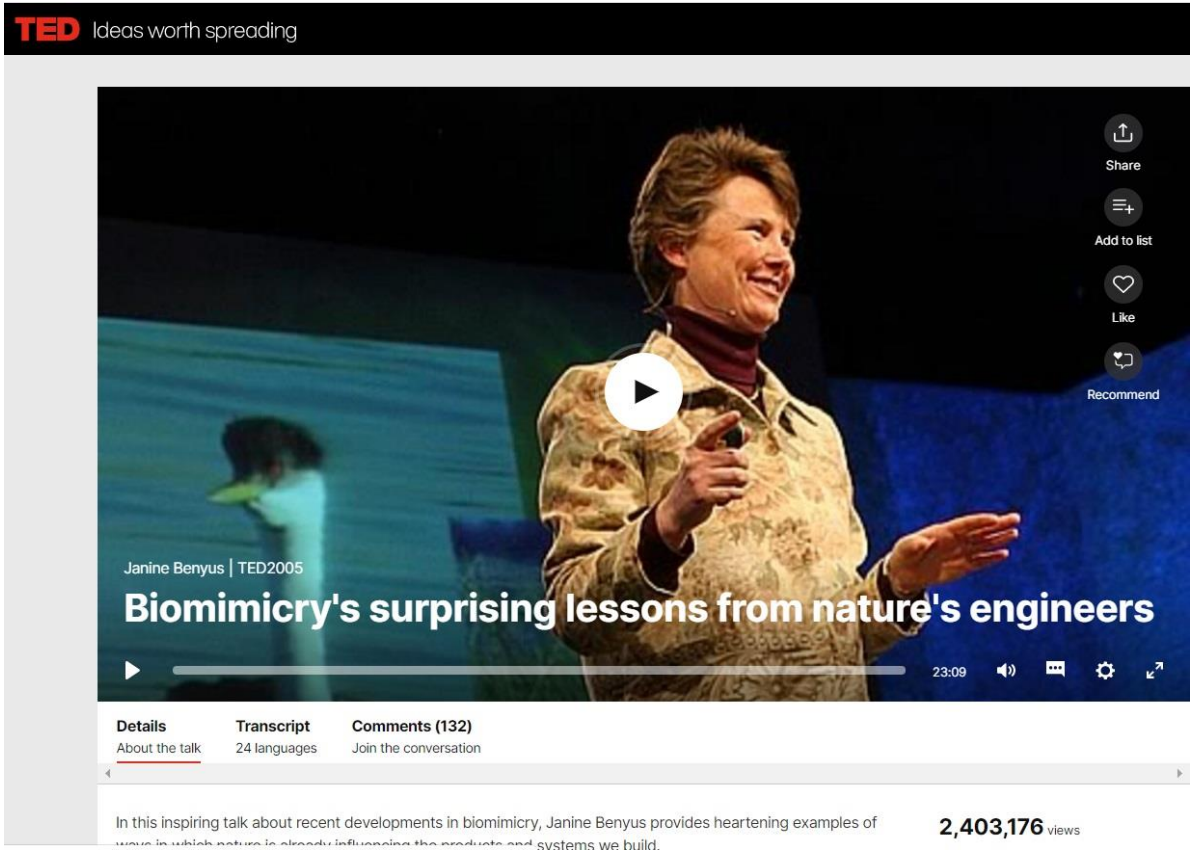
Are You Young and Idealistic?

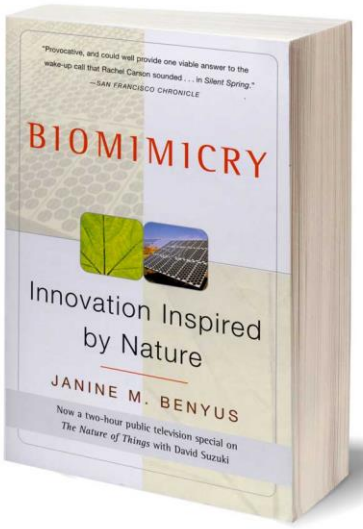
Want To Get Away From The Human-built World?

Are You Young and Idealistic?

Want To Get Away From The Human-built World?

Become A BIOLOGIST, And Join The Peace Corps!





Biology as a mentor for the sustainable development of the human-built world.

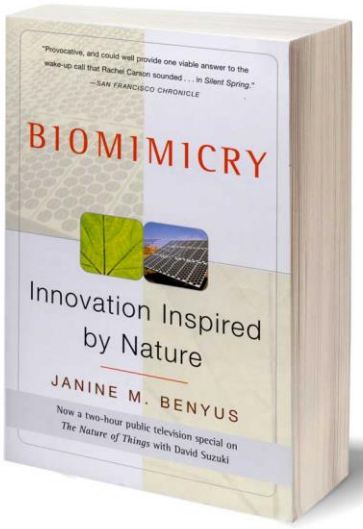
Biology as a mentor for the sustainable development of the human-built world.

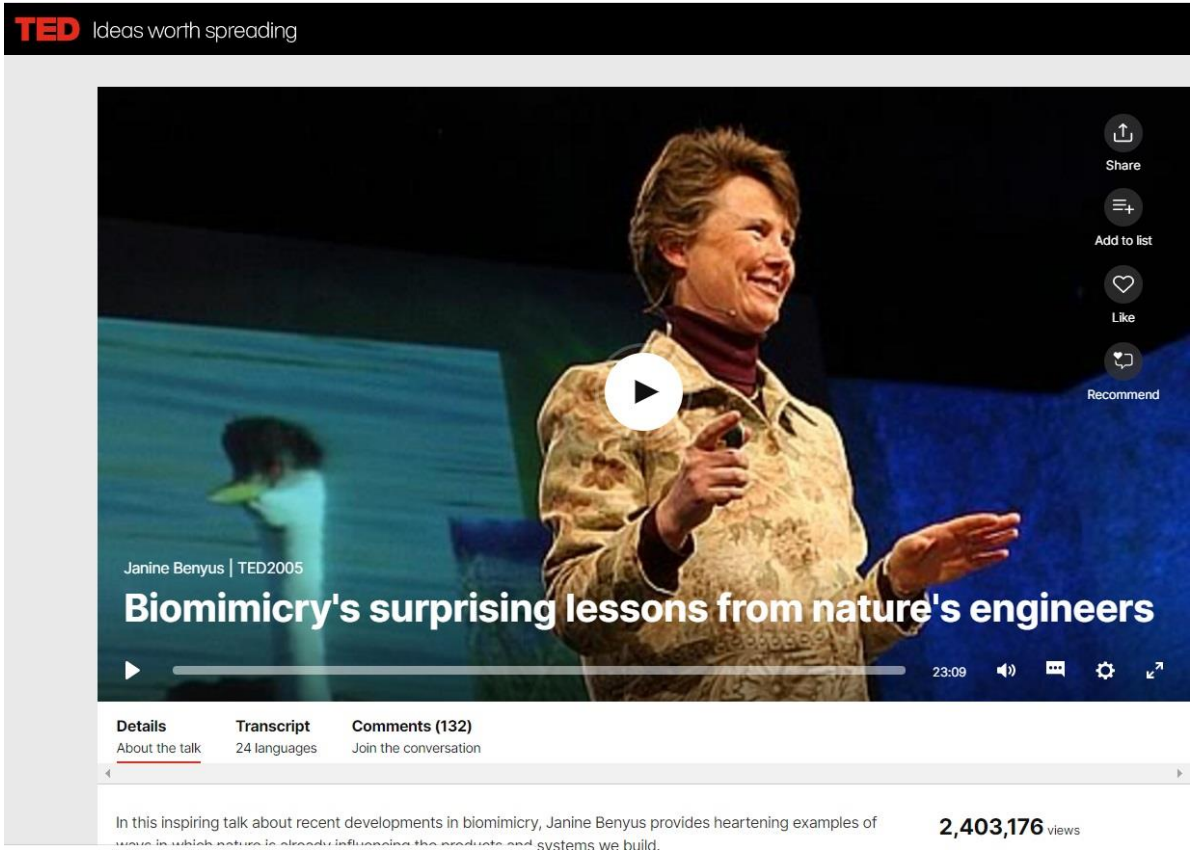
TED Ideas worth spreading

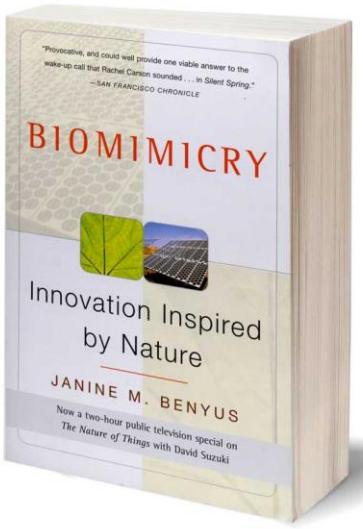
Details About the talk | **Transcript** 24 languages | **Comments (132)** Join the conversation

In this inspiring talk about recent developments in biomimicry, Janine Benyus provides heartening examples of ways in which nature is already influencing the products and systems we build.

2,403,176 views







Director of Youth Education

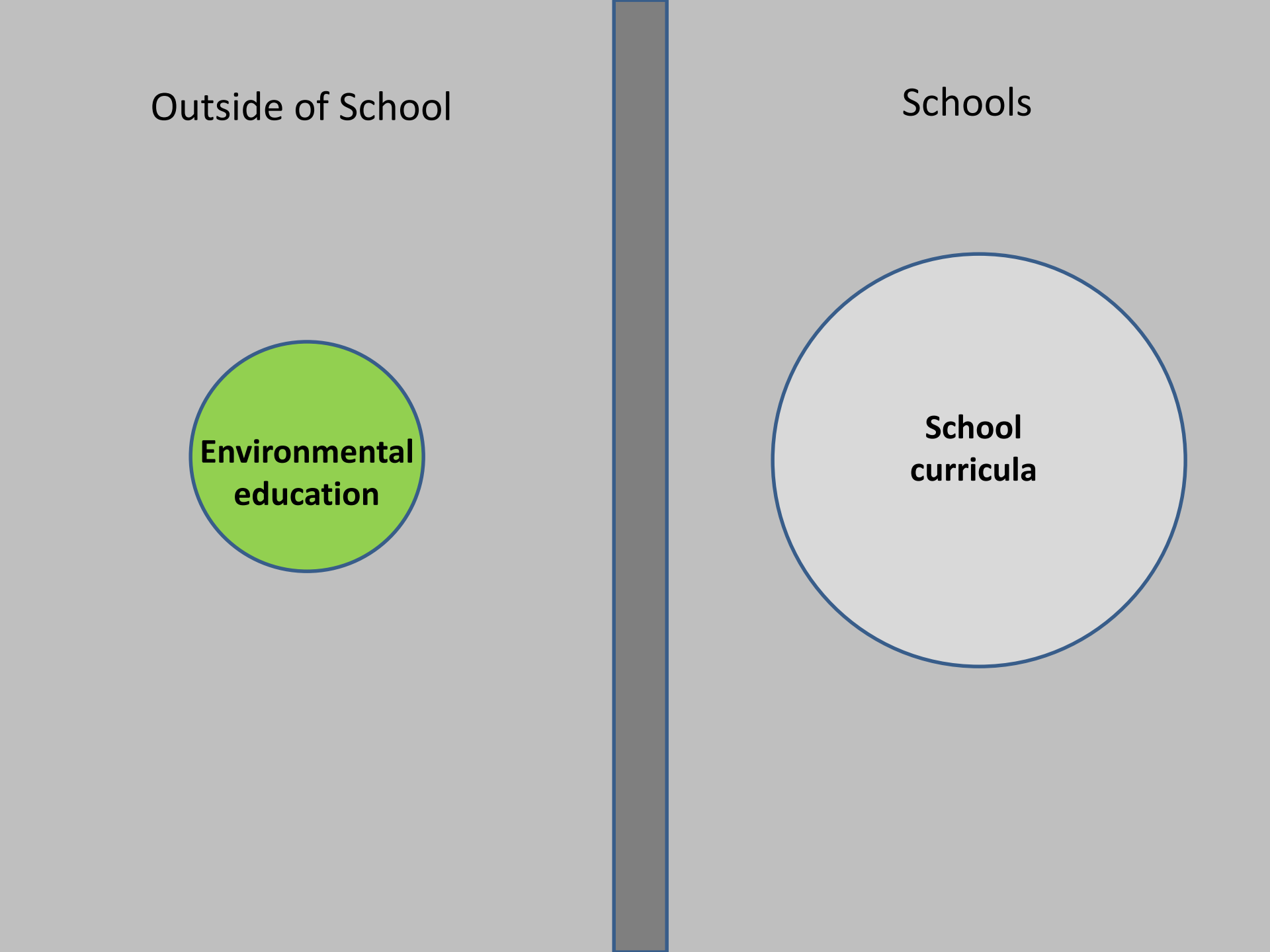
BIOMIMICRY INSTITUTE

How do we strengthen the next generation's awe of the living world?

How do we strengthen the next generation's awe of the living world?

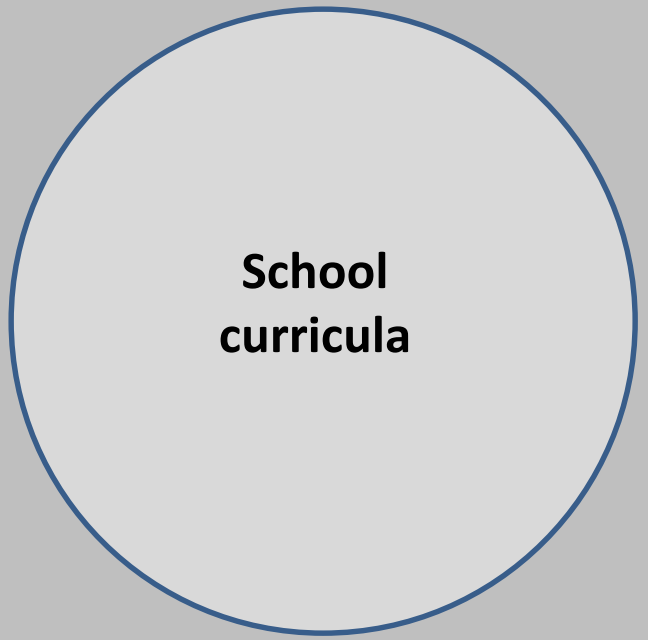
And their aspiration and capacity to make a human-built world that works with it?


Environmental
education


Outside of School
Schools
Environmental education
School curricula

Outside of School

Schools



?

~ 7 hours/day

Outside of School

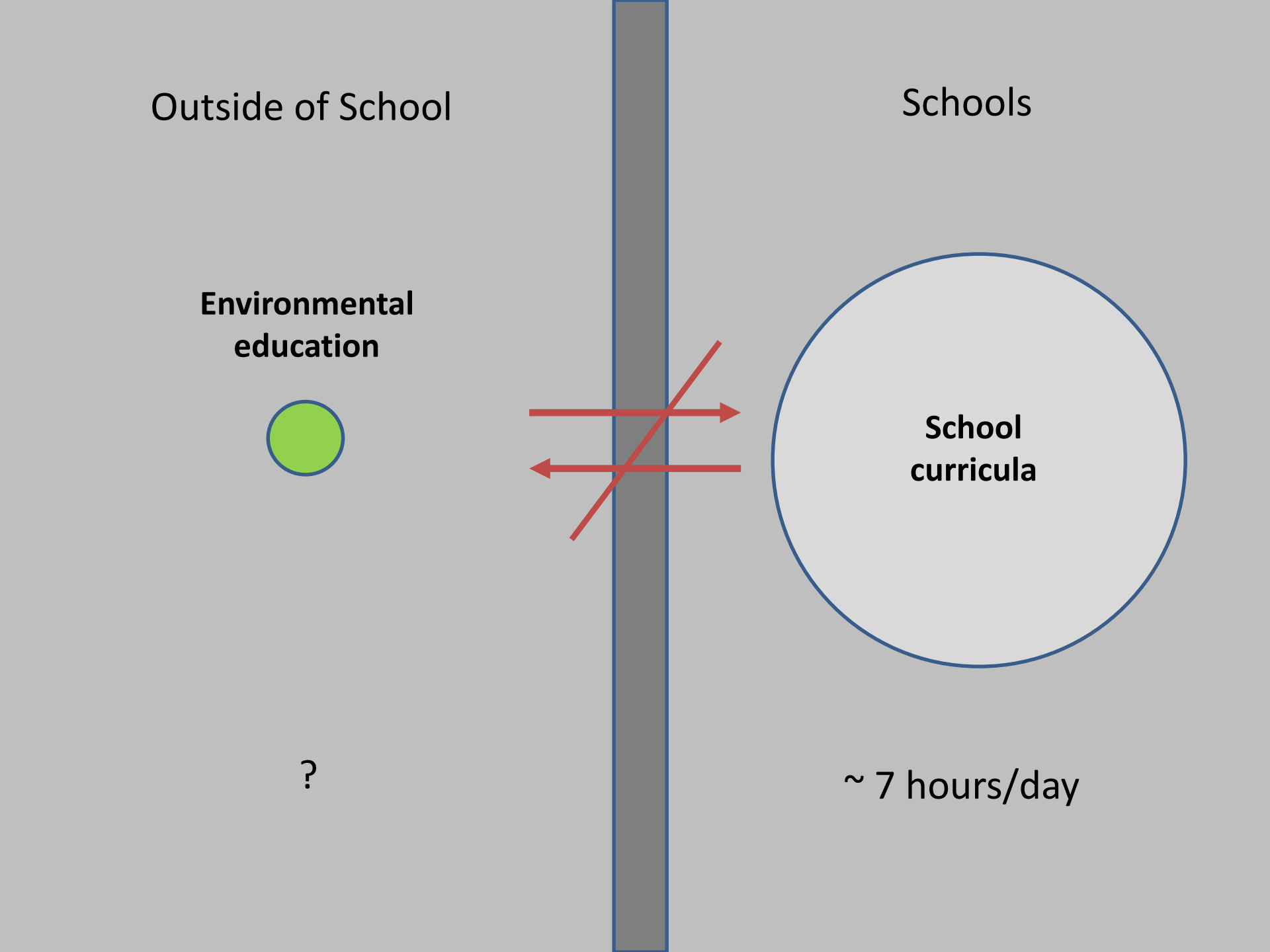
Schools

Environmental education

School curricula

?

~ 7 hours/day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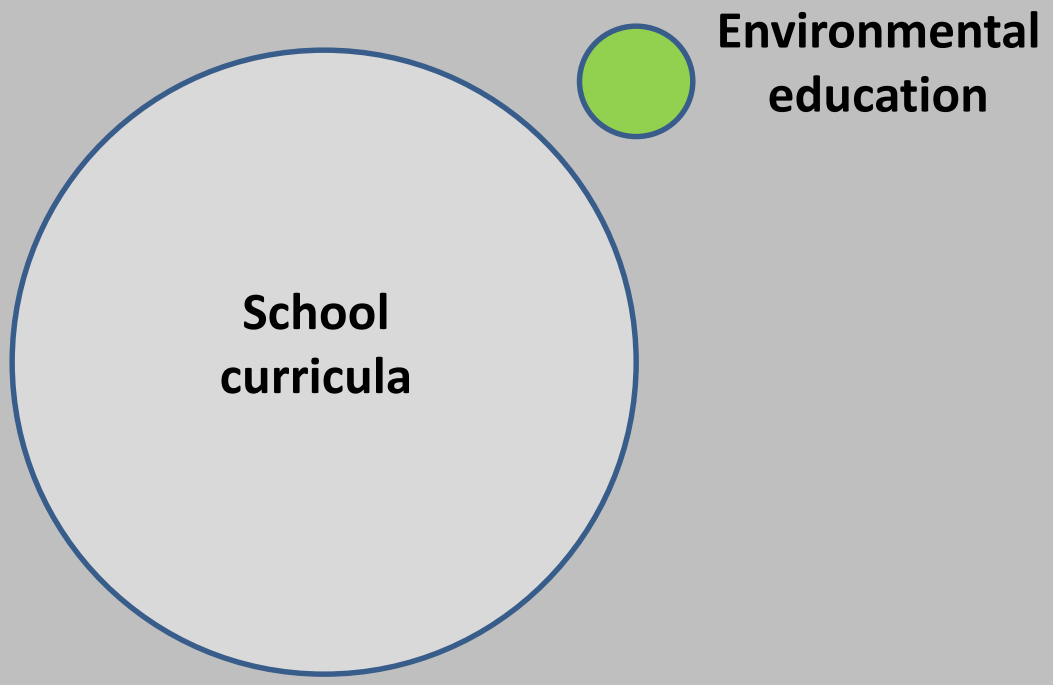
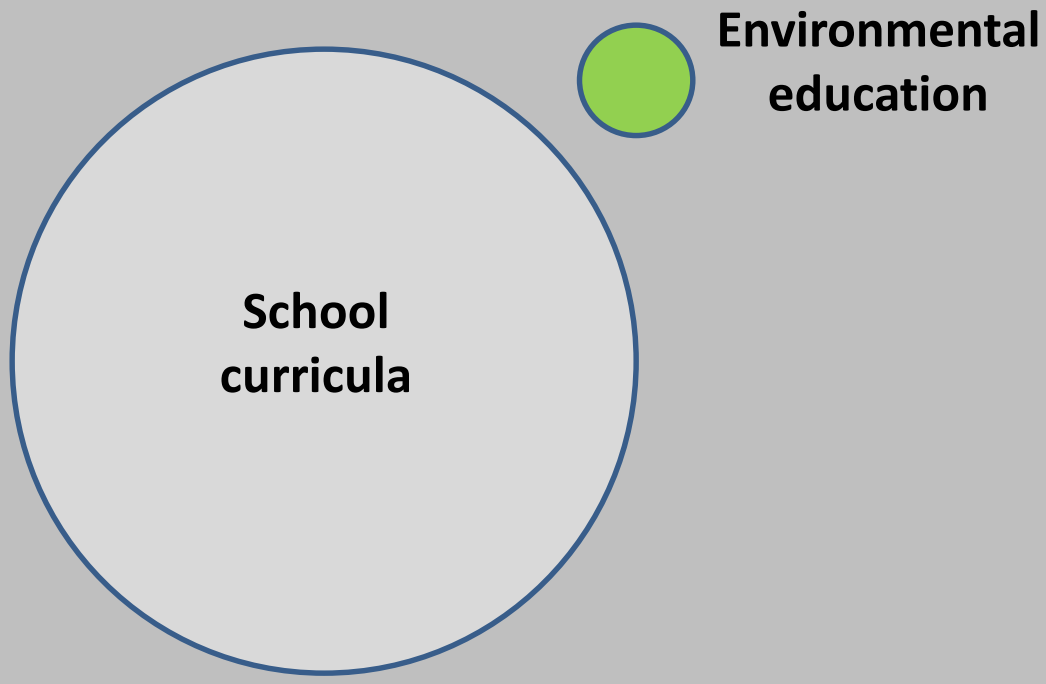
Schools



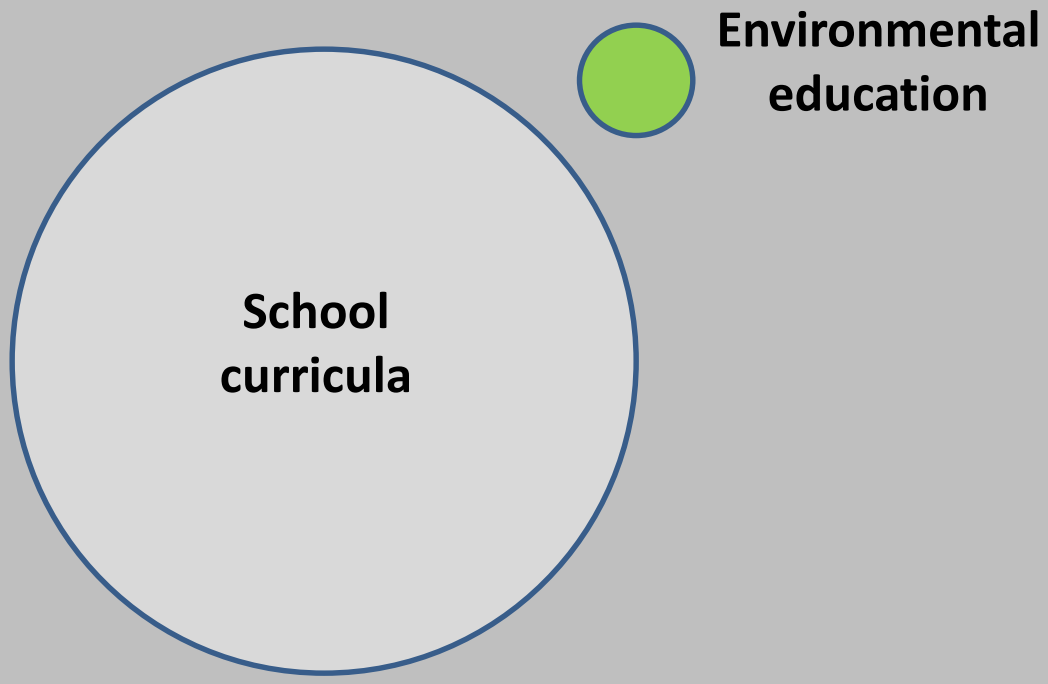
Schools



“All education is environmental education.”

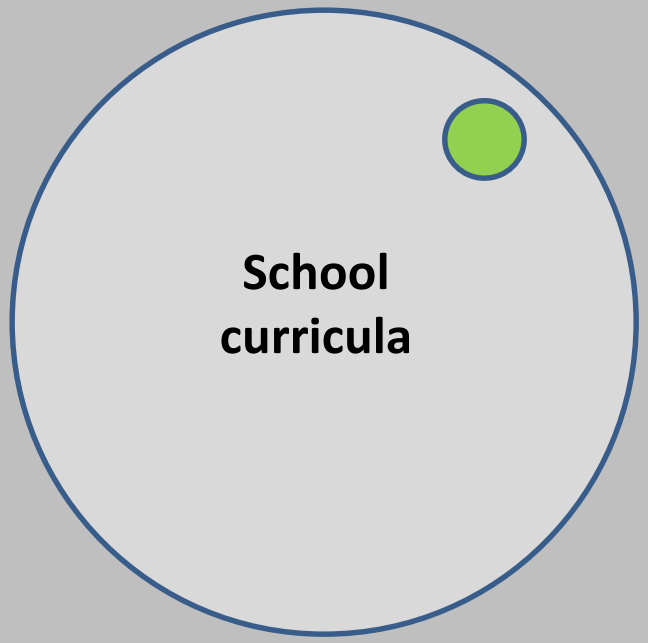
- David Orr

Schools



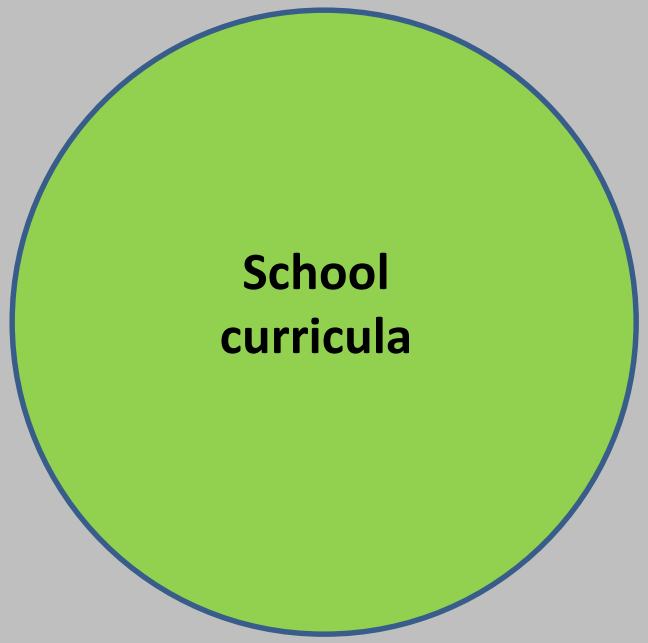
Environmental education is not as important as the rest of what you learn in school, and it doesn't really have anything to do with what you learn in school either.

Schools

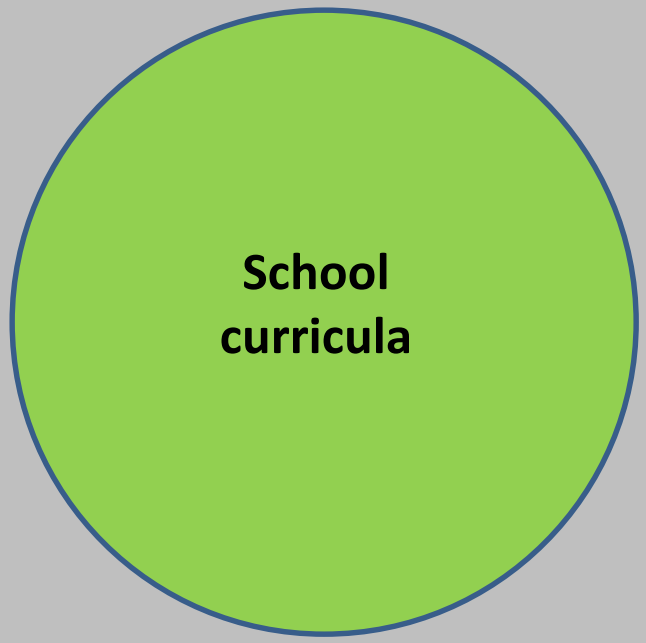


*Environmental education is not as important as the rest of what you learn in school, and it doesn't really have **much** to do with what you learn in school either.*

Schools



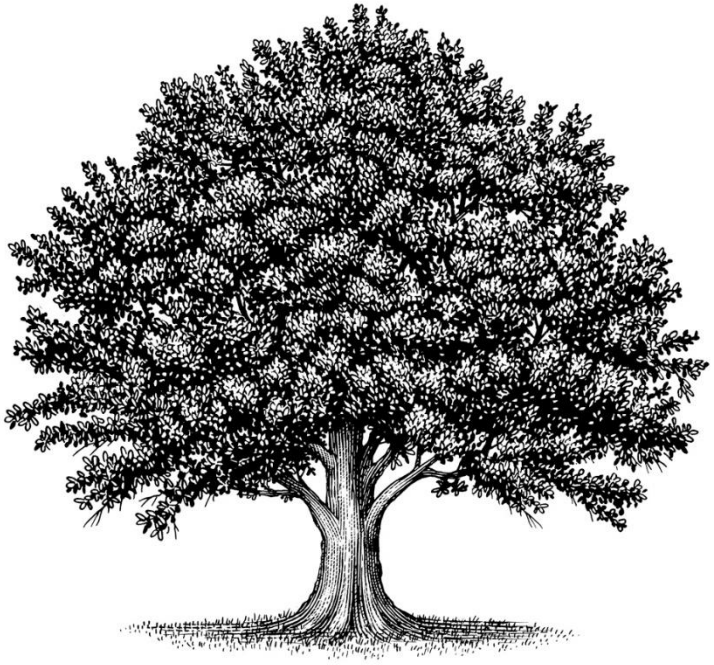
Schools



*Environmental education is as important as the rest of what you learn in school, and it has **everything** to do with what you learn in school, and what you do in the world after school.*

THE CENTER FOR

LEARNING WITH NATURE



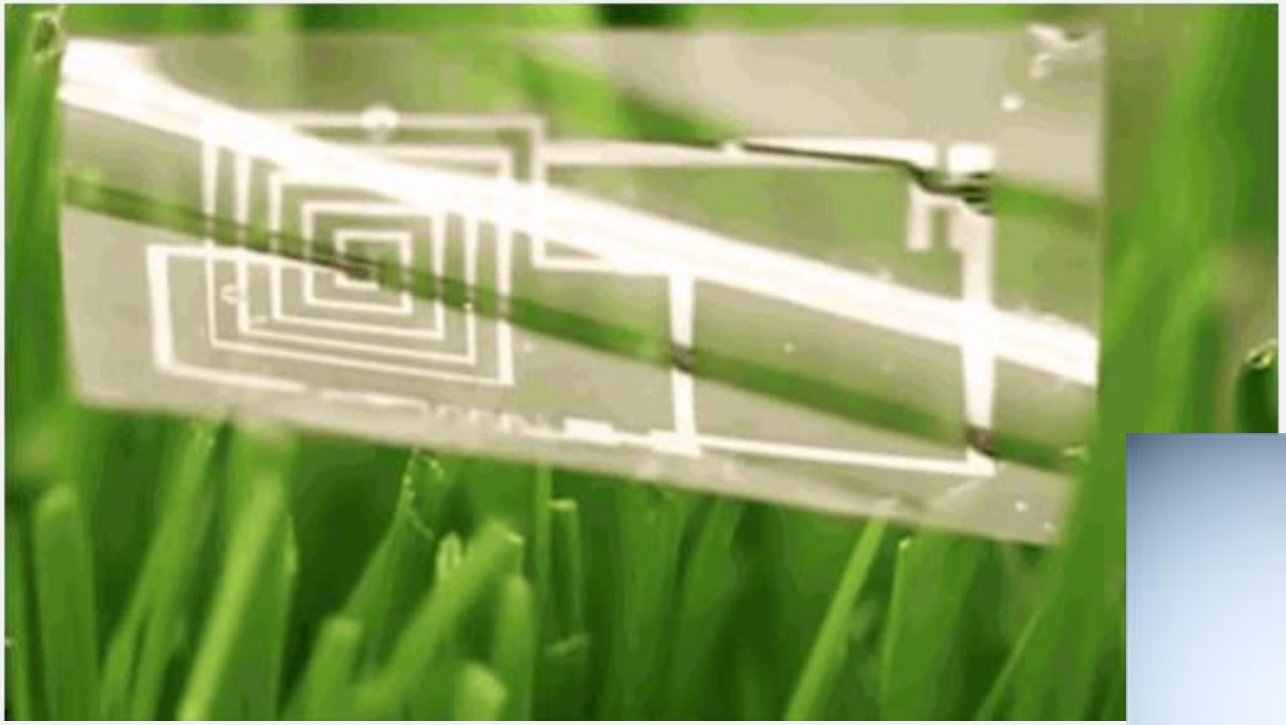
www.LearningWithNature.org

Use biomimicry to:

Use biomimicry to:

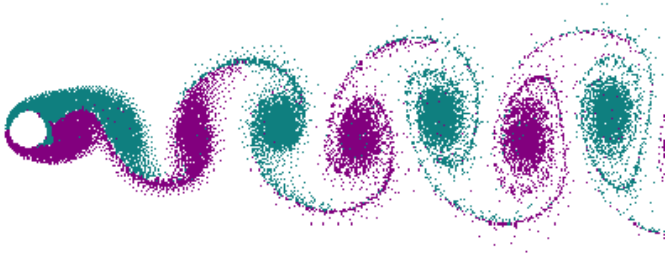
- Enrich students' **imagination** of what's possible in technology.

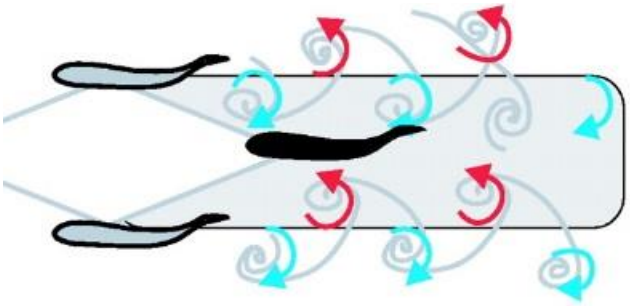
Biodegradable electronics



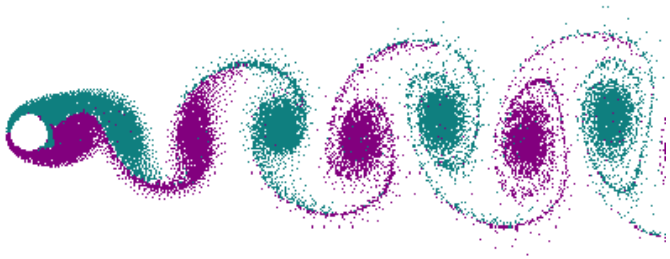
Dr. John Rogers, U. of Illinois

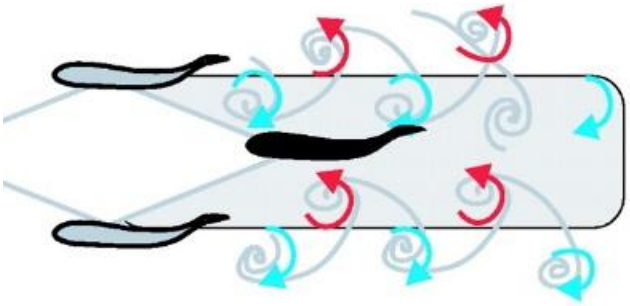
Apply Fish School Principles to Wind Turbine Arrays:

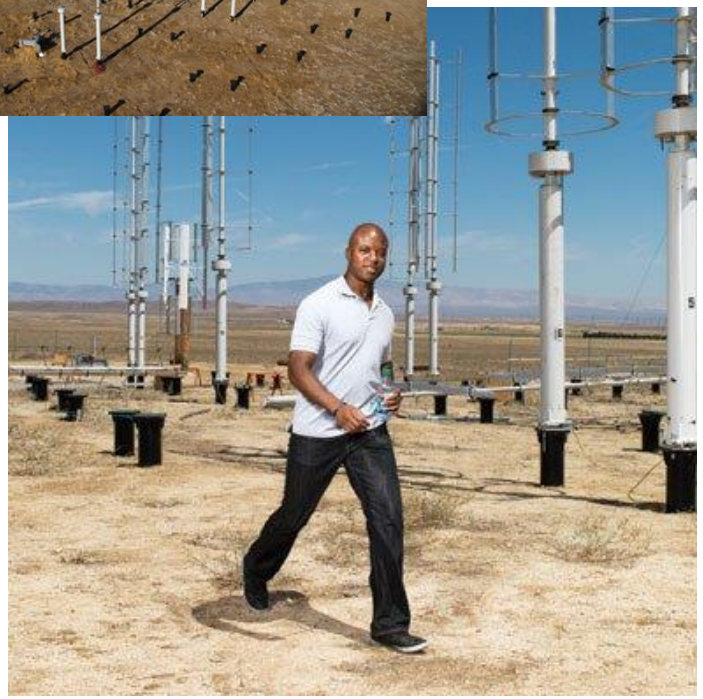




Apply Fish School Principles to Wind Turbine Arrays: Improves Output by 1000%







Dabiri, 2011. Journal of Renewable and Sustainable Energy.

Use biomimicry to:

- Enrich students' **imagination** of what's possible in technology.
- Foster a **love of Nature** in future generations.

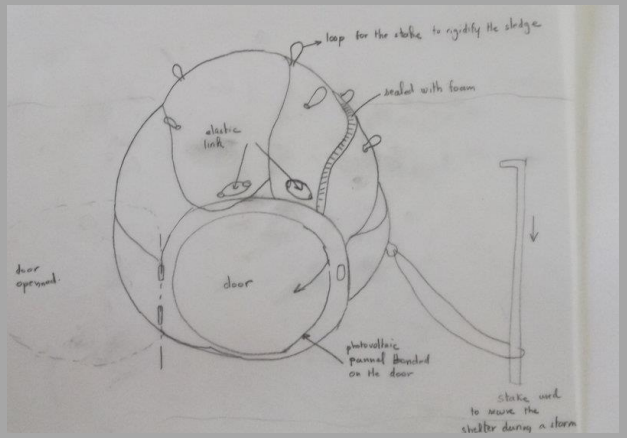
Admiring how impressive Nature’s designs are can transform our relationship with Nature.

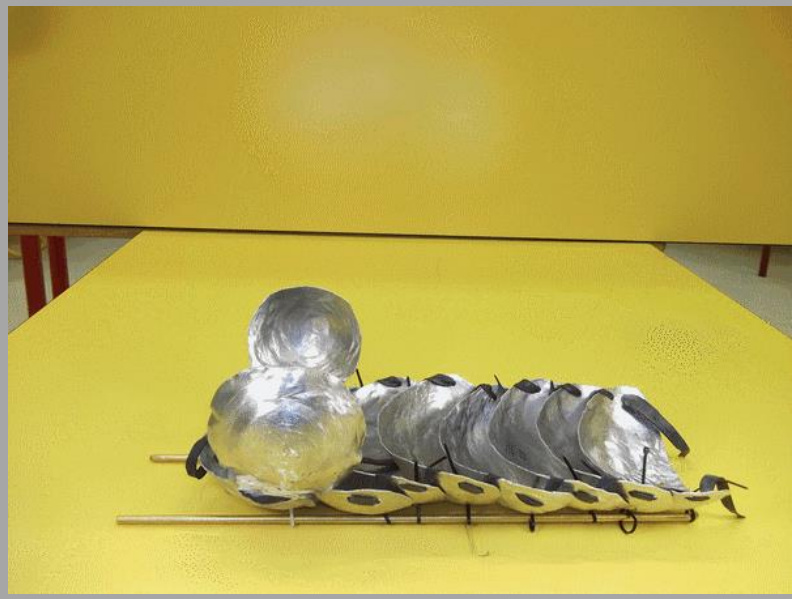
Admiring how impressive Nature’s designs are can transform our relationship with Nature.

Use biomimicry to:

- Enrich students' **imagination** of what's possible in technology.
- Foster a **love of Nature** in future generations.
- Raise students' **aspirations** and **abilities** to create a life-friendly modern world.

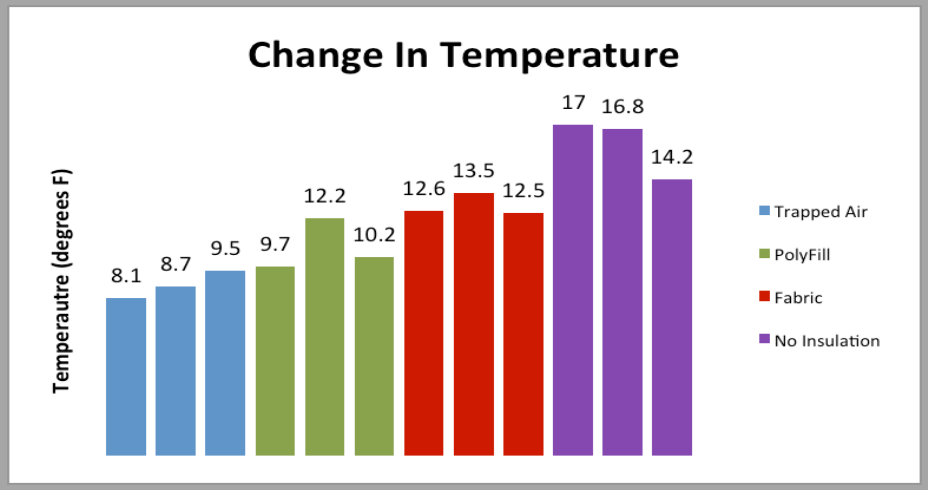
Bromeliad-inspired water collection device





Roly Poly bug-inspired sled and shelter


Black/White
Reversible
Waterproof
Material
Pocket of air
that can be
inflated
Inflation/
Deflation Tube
or Pump


Change In Temperature
Temperautre (degrees F)
8.1
8.7
9.5
9.7
12.2
10.2
12.6
13.5
12.5
17
16.8
14.2
Trapped Air
PolyFill
Fabric
No Insulation

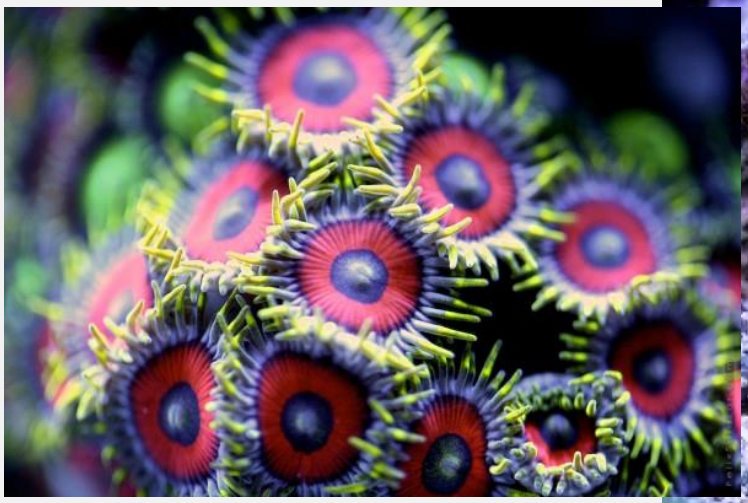
Follow in the footsteps of greatness…

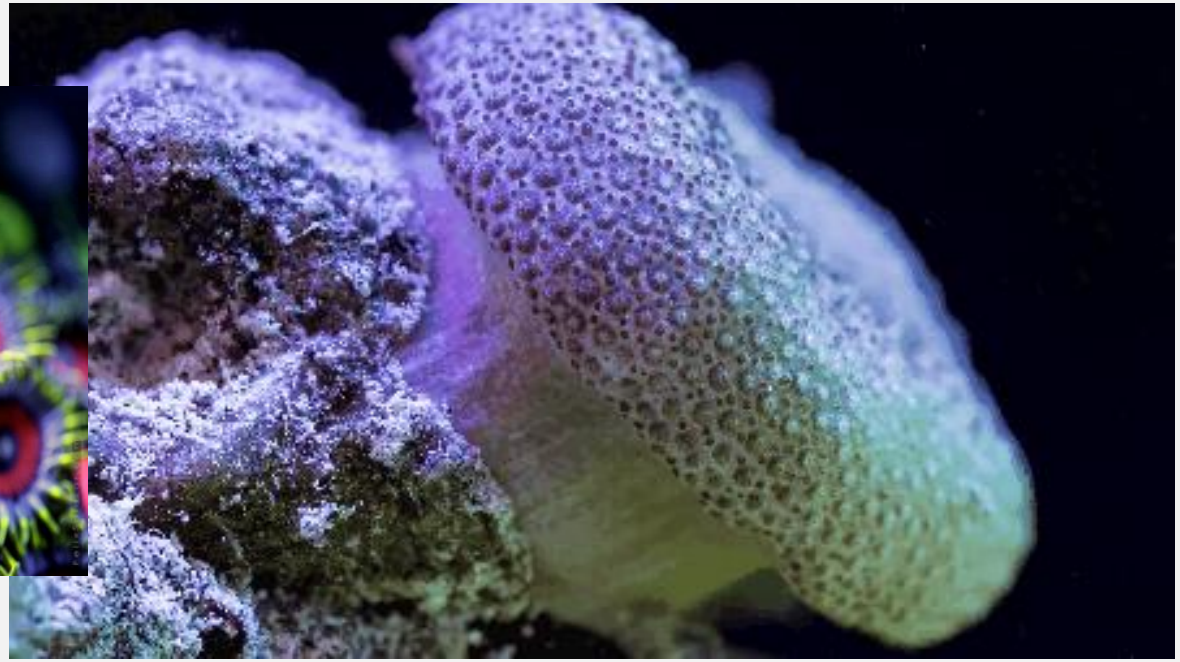
Brent Constanz
Inventor of a carbon-neutral concrete

How we make cement (the main component of concrete)

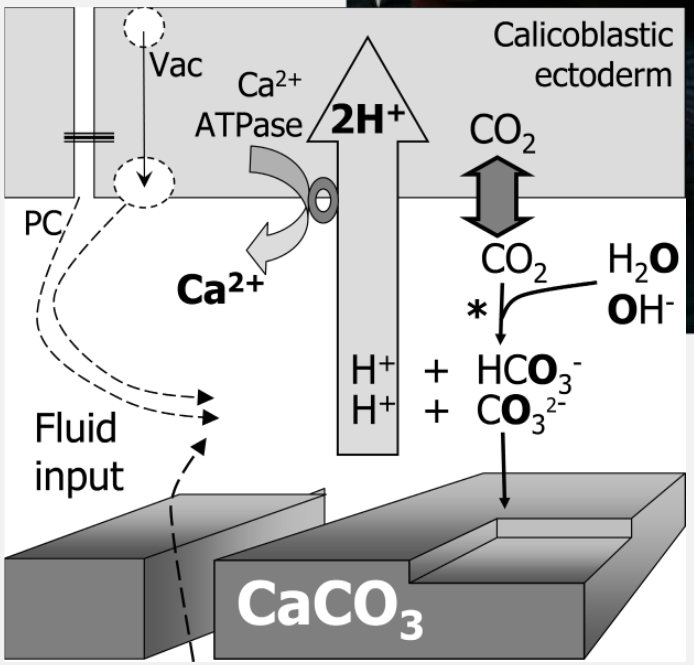
1. Mine it
2. Cook it at 1500 C,
3. Release approx. 6-8% annual GHG emissions

We’re not the only species making cement…



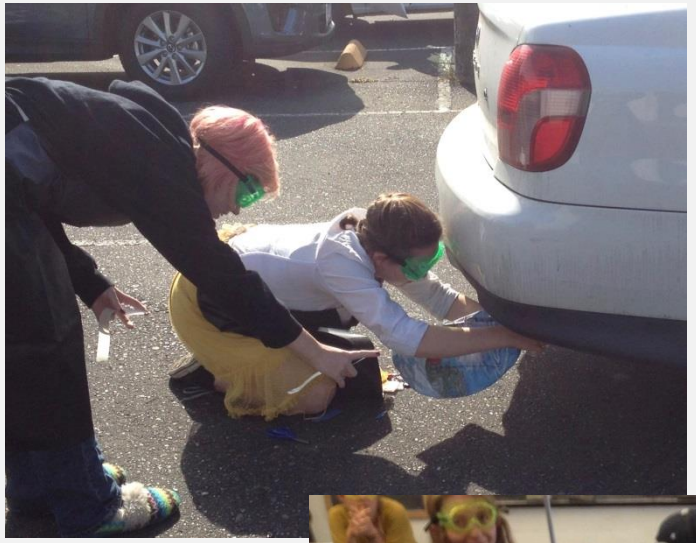


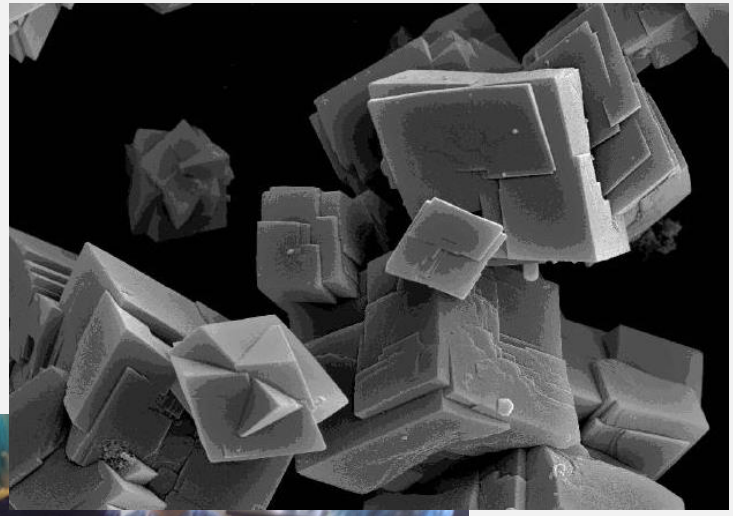
- Make cement too
- Make it out of seawater
- At ambient temperatures
- *Removing* greenhouse gases from the atmosphere



(Cohen and McConnaughey 2003)

Making (Carbon Neutral) Cement Out of Car Exhaust

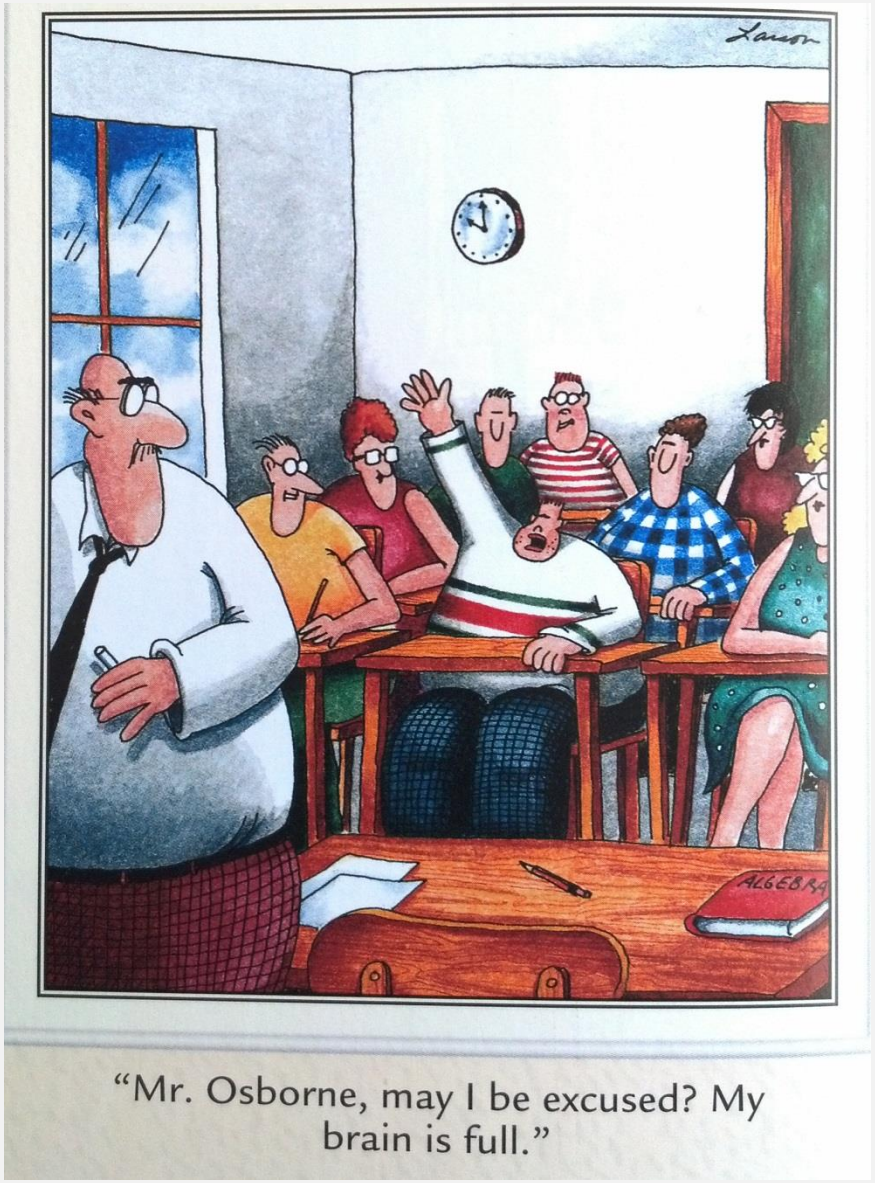




$CO_2 + H_2O + CaCl_2 \rightarrow H_2CO_3 + CaCl_2 + NaOH \rightarrow NaHCO_3 + H_2O + CaCl_2 + NaOH \rightarrow Na_2CO_3 + CaCl_2 + H_2O \rightarrow CaCO_3 + 2NaCl + H_2O$

How do you fit biomimicry into the regular school curriculum?

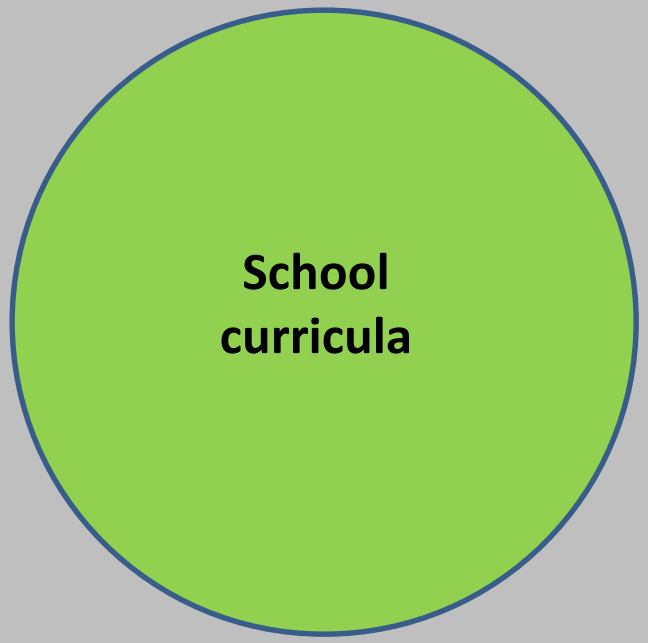
Integrating biomimicry into daily school



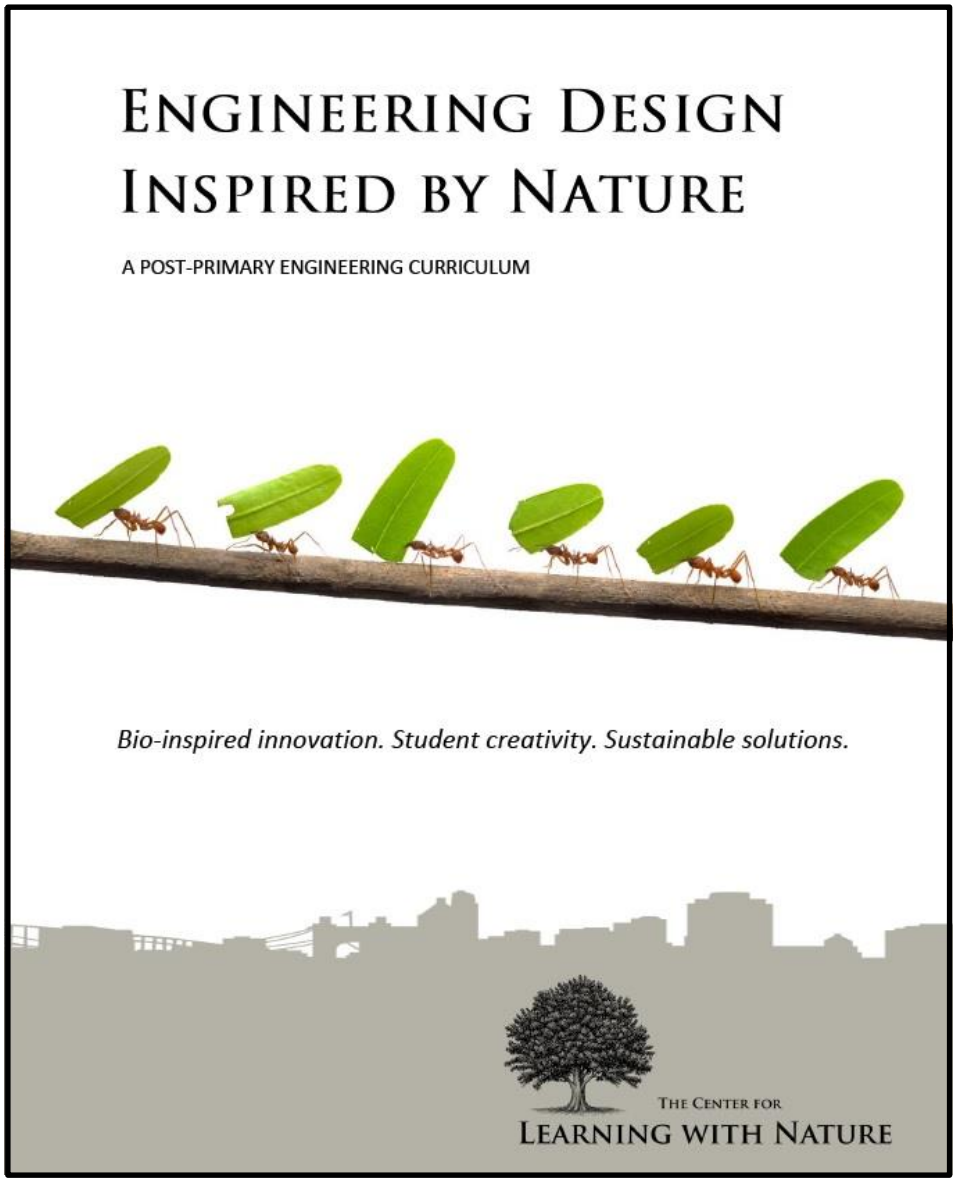
"Mr. Osborne, may I be excused? My brain is full."

Biology as a mentor for the sustainable development of the human-built world.

Schools



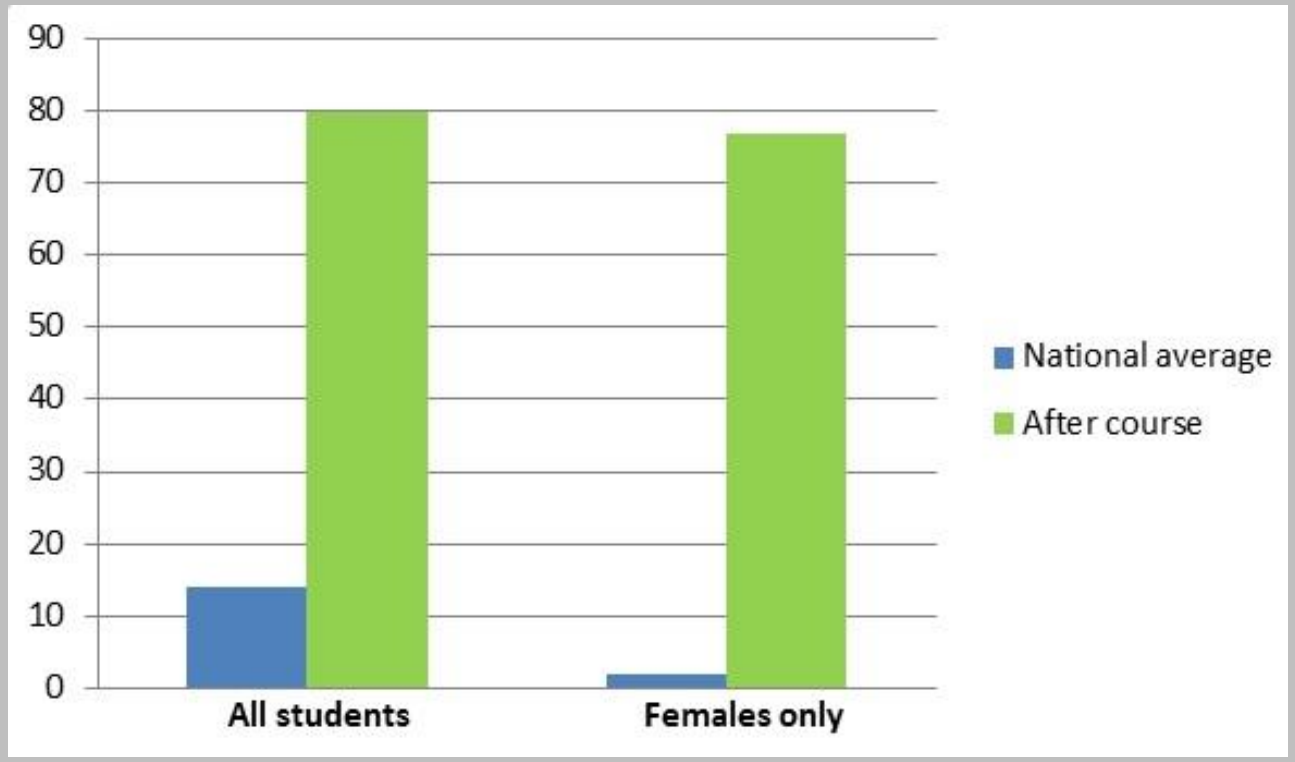
Middle/High School (ages 13-18)



WINNER
INNOVATION
WHOLE
CURRICULUM
REVERE AWARDS
AAP
2016

TOP
EDUCATIONAL
PRODUCT
DISTRICT
AMINISTRATION
MAGAZINE
2015

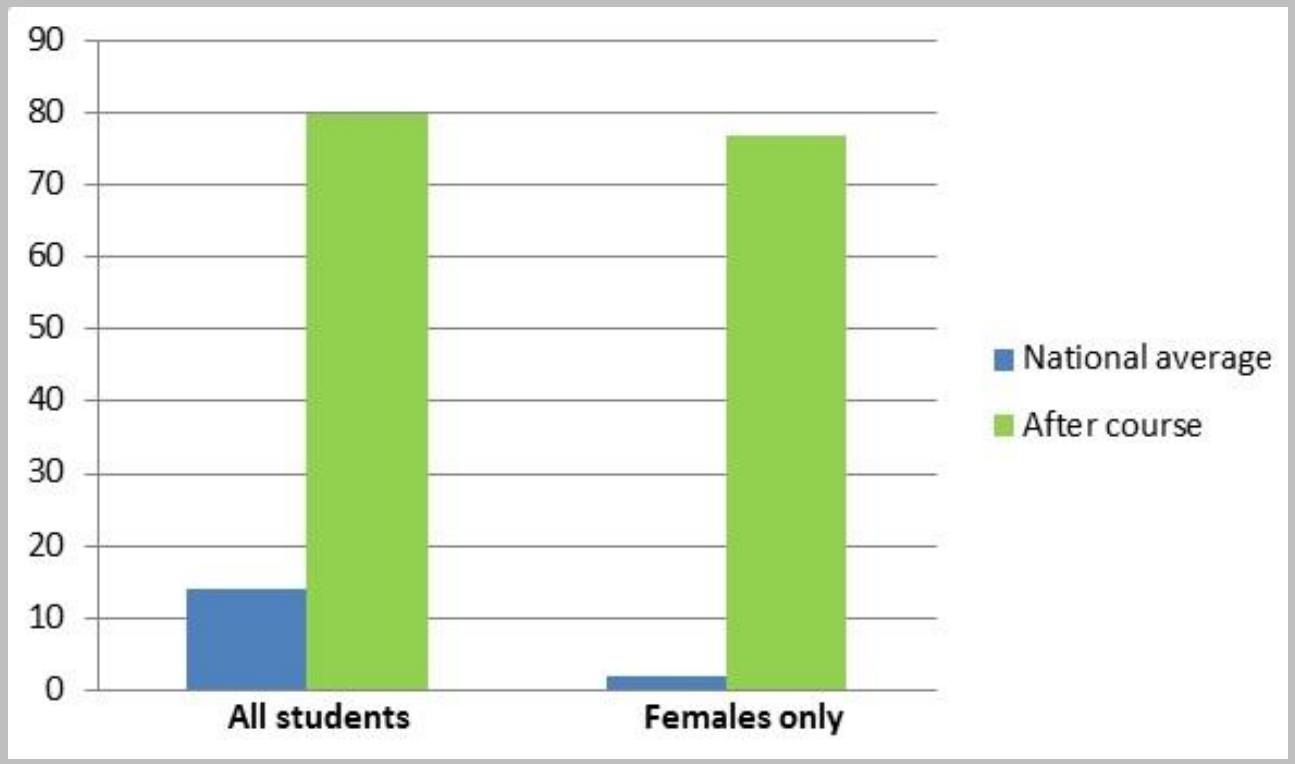
Engineering Interest



5X

"This course has been, without a doubt, my most absolute favorite course we've had at school so far! I wish we could have it all year like we have math. The lessons were so unbelievably fascinating!"

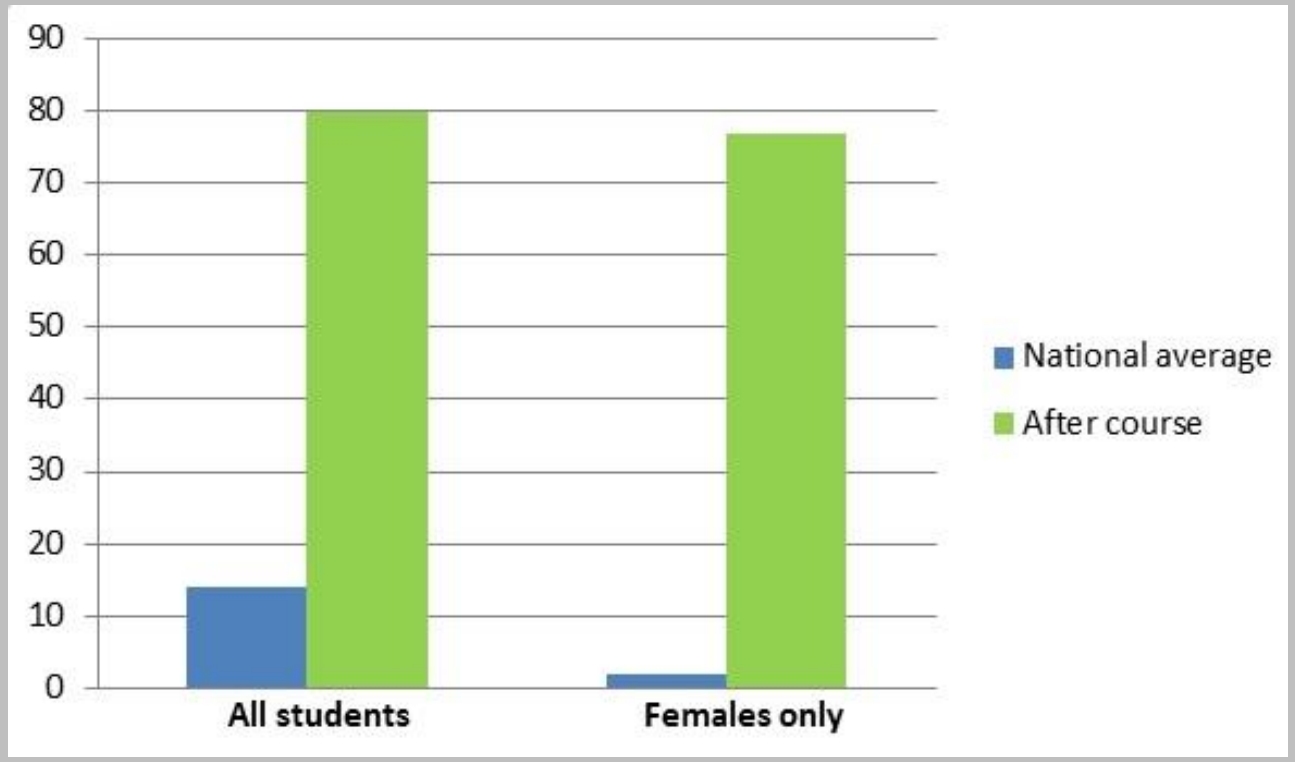
Engineering Interest



38X

Female students

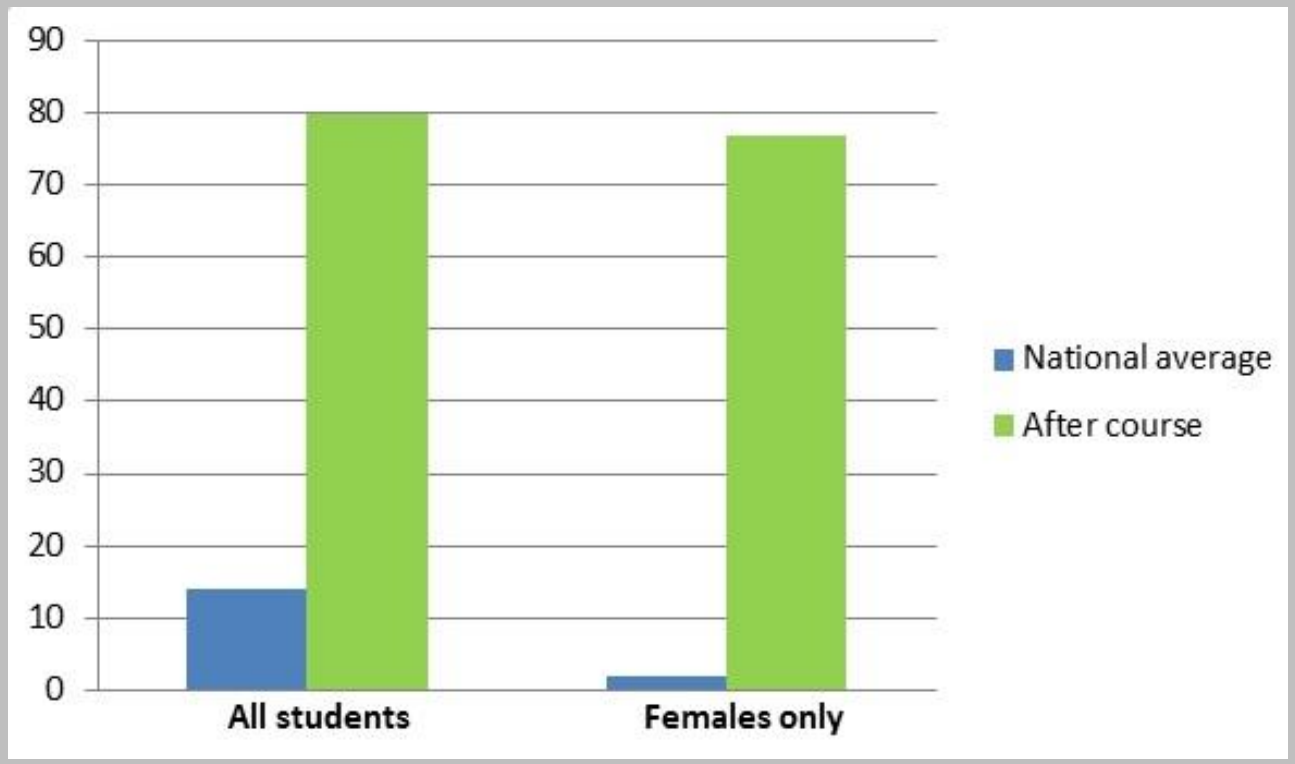
Engineering Interest



38X

Students meeting education standards: 100%

Engineering Interest

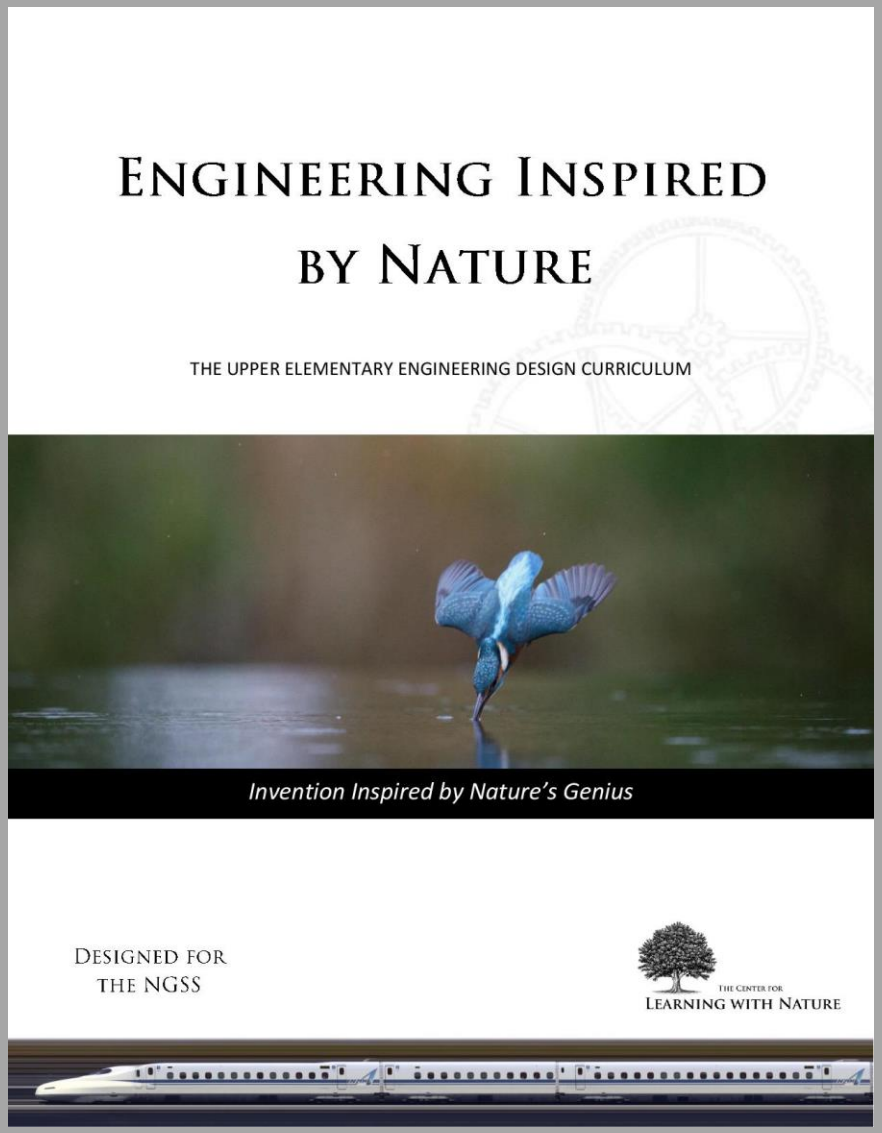


38X

Students meeting education standards: 100%

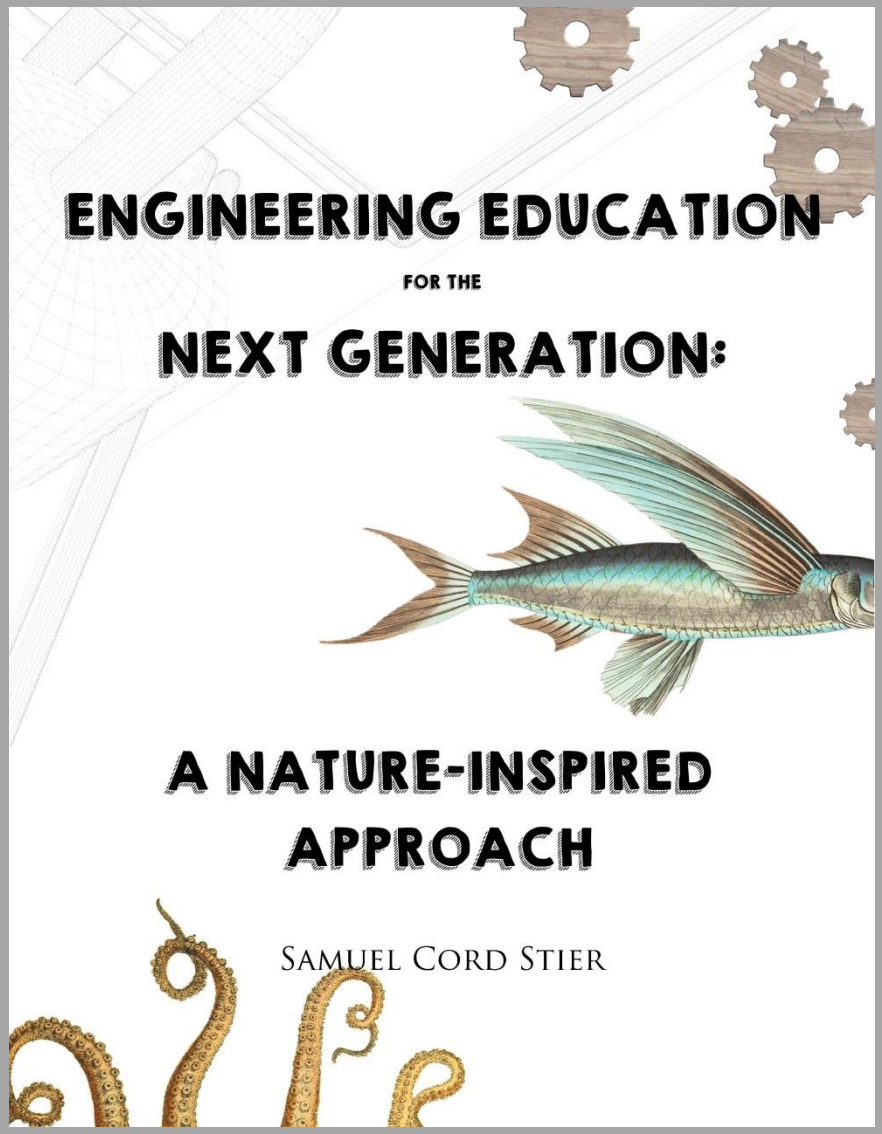
Increased interest in sustainability: 80%

Upper Elementary (ages 8-12)



Kit version:

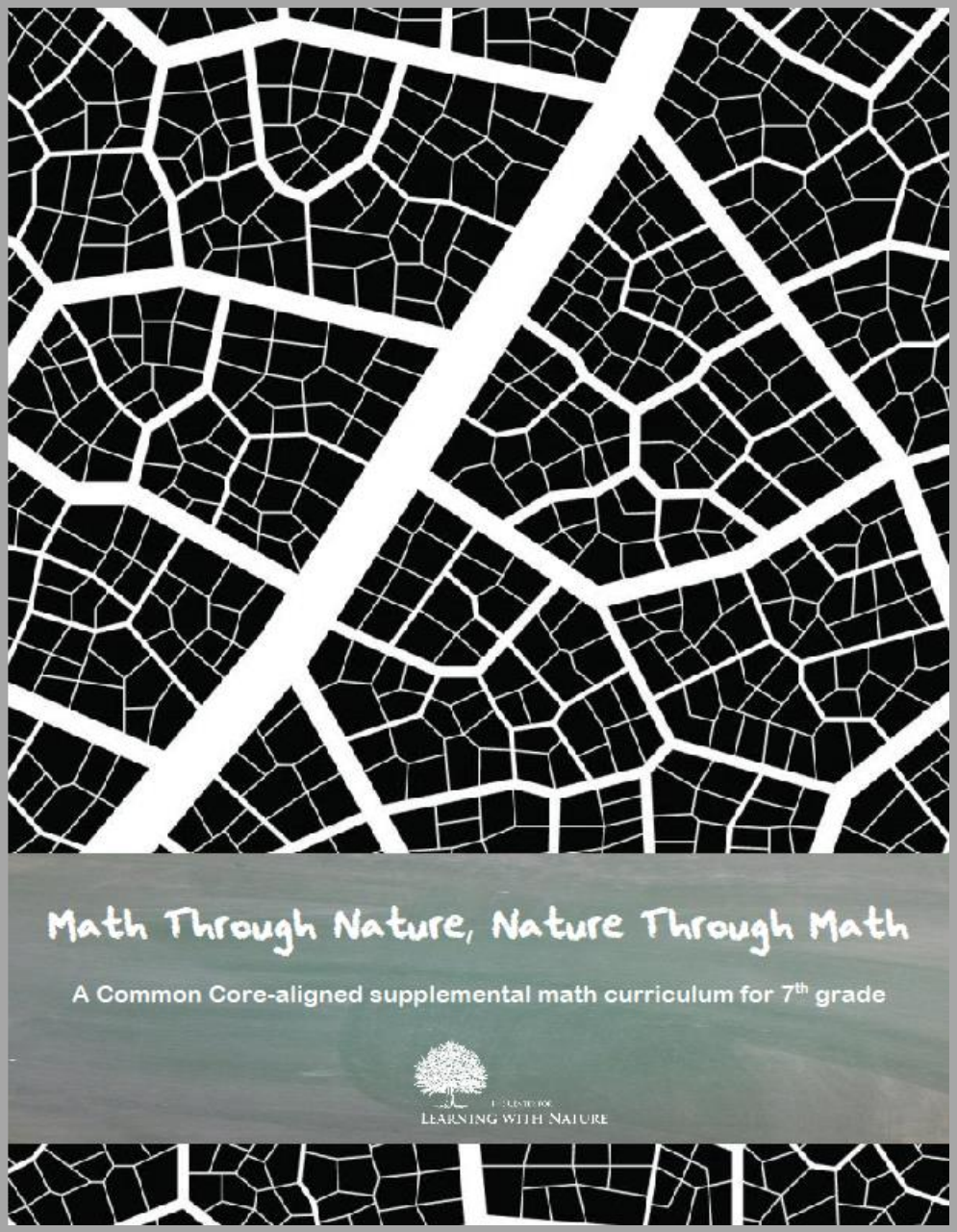
Upcoming book

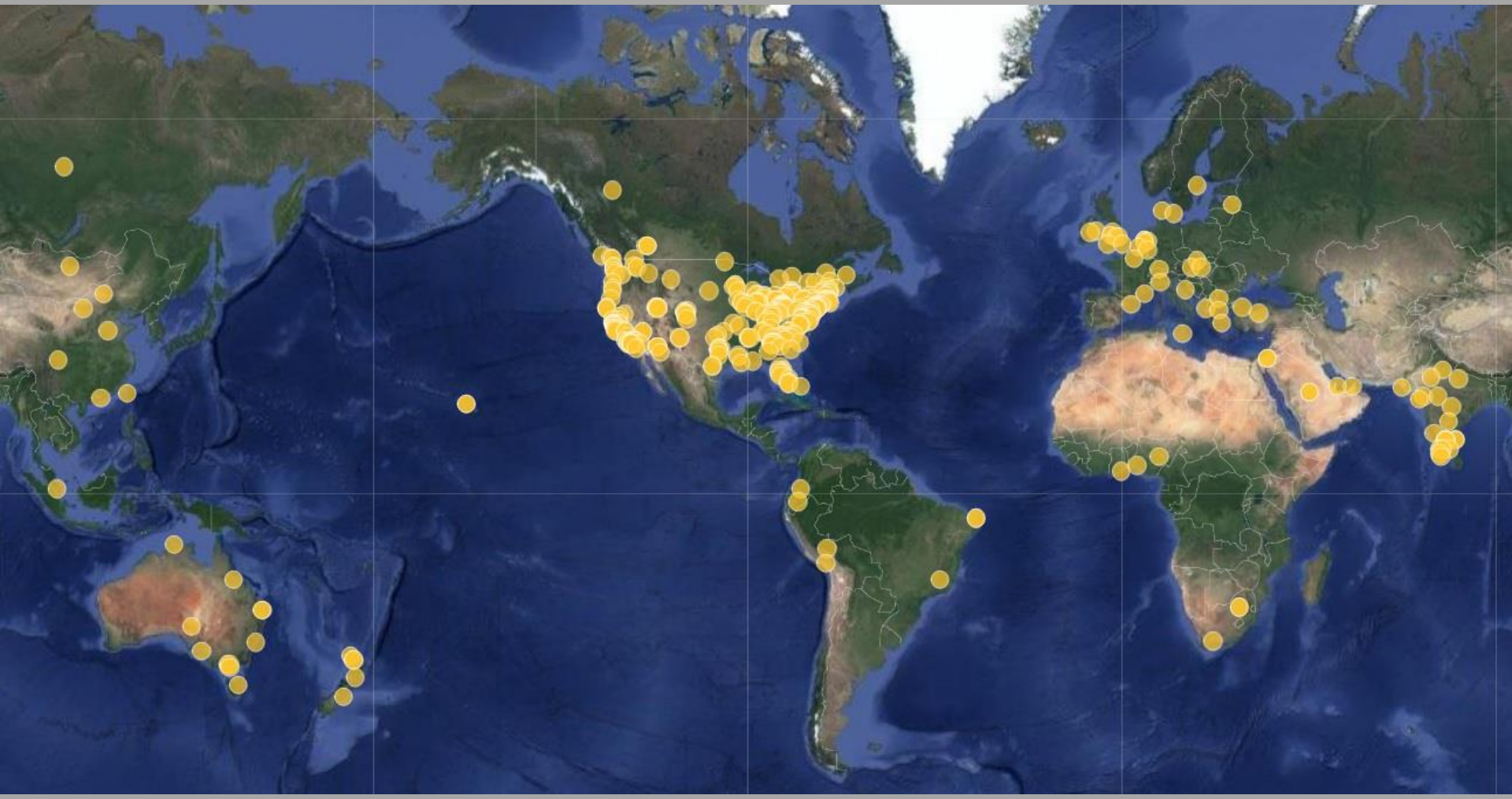


"I only wish that some of my K–12 teachers would have read this extraordinary book."

- **March 2020 (W.W. Norton & Co.)**
- **bit.ly/LearningWithNature**

Math inspired by Nature curriculum





Schools we've served.

Pedagogical philosophy

People learn best when:

Lessons are interesting, fun, and/or surprising.

Lessons are hands-on and make you think.

People get to experience the truth of something first-hand.

Lessons seem meaningful; they relate to things that matter.

Lessons enrich your daily experience of being alive.

The Tutelage of Trees

The Tutelage of Trees

Objective:

(1) Students learn scientific and engineering principles related to material science and structural engineering;

(2) Students learn that Nature can give us ideas for how to improve what we make

Guiding Question: What can trees teach us about structural engineering?

Grades: 6-12 (ages 11-18)

Connection to NGSS:

- MS-Engineering Design
- MS-LS1 From Molecules to Organisms: Structures and Processes
- HS-Engineering Design
- HS-LS1 From Molecules to Organisms: Structures and Processes
- HS-PS2 Motion and Stability: Forces and Interactions

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Where to start?

Kinds of engineering and engineering-related subdisciplines:

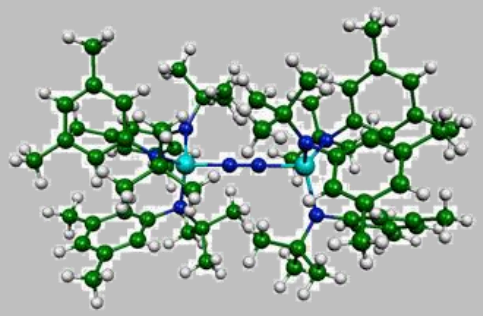
Material science
Mechanical engineering
Structural engineering
Chemical engineering
Electrical engineering
Civil engineering
Biomedical engineering
Aerospace engineering
Industrial engineering
Systems engineering
Urban planning
Architecture

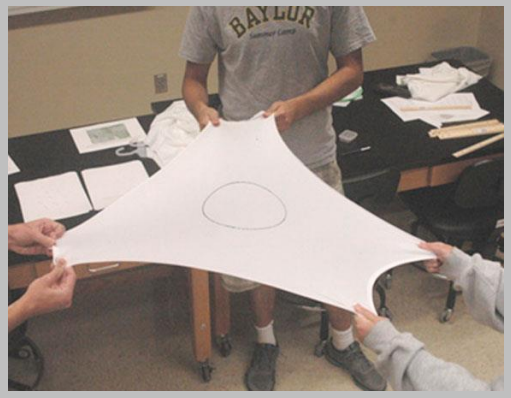
Construction engineering
Agricultural engineering
Environmental engineering
Software engineering
Biotechnology
Automotive engineering
…

Engineers do a lot of things in society and engineering covers LOTS of subdisciplines

Engineers work at many spatial scales, from:

Atoms, molecules, materials, components, products, agriculture, infrastructure , urban landscapes…





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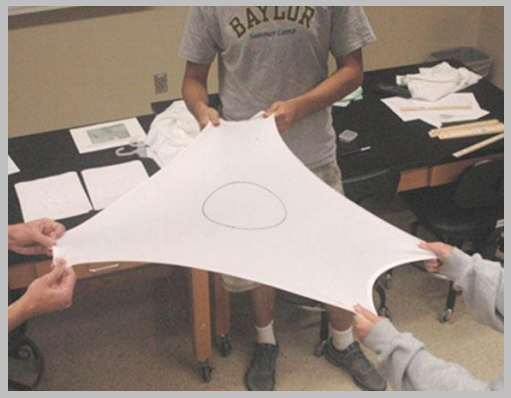

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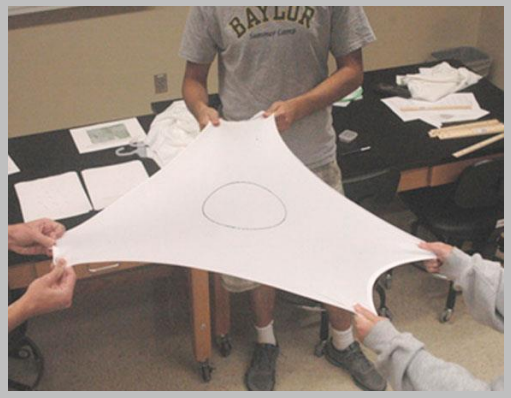


- Everything engineers make is made of materials; it's a "fundamental" basis of all engineering
- Manageable for the classroom
- Tangible, visceral, relatable
- Can be surprisingly interesting
- Relates strongly to the work of structural engineers, the kind of engineer many people implicitly think of when they hear the term "engineer"

Material TOUGHNESS:

Tangible, accessible, surprisingly interesting

Strength/toughness is one of the first qualities of materials we naturally wonder and think about

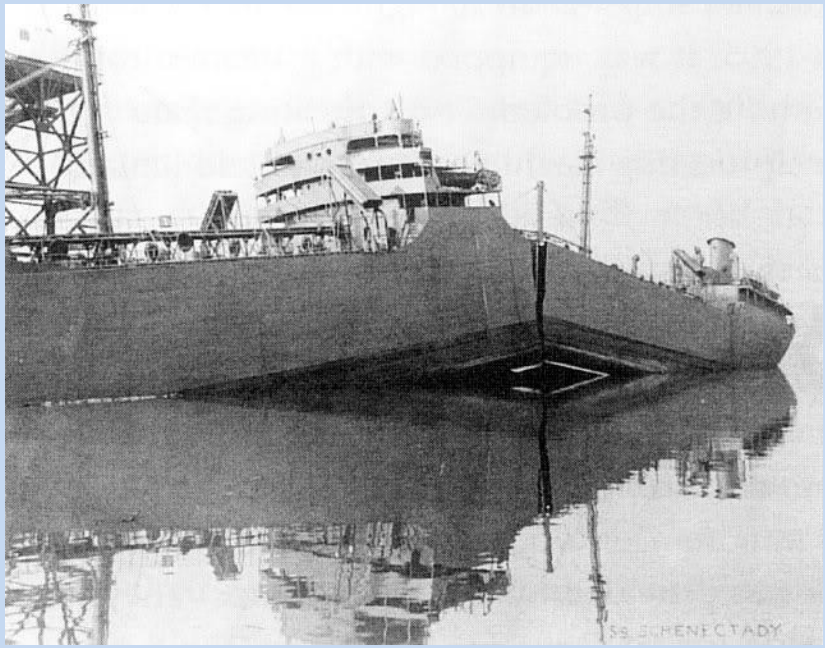
The history of the attempts to prevent cracks spreading or to evade the consequences, is almost the history of engineering.

James Gordon (1913-1998) - forefather of material science and biomimetics

Structural engineering matters!

Material performance is a major part of our world and cracking is a great example of why

1942



The U.S. was the last force left on Earth capable of stopping the Axis Powers from world domination, but the U.S. Navy's ships kept forming mysterious cracks

De Havilland Comet, world's first commercial jetliner (1950s)… In 1954, two mysteriously cracked apart in mid-air, killing dozens and bankrupting the company.

Boeing emerged as the world's #1 airplane manufacturer…

The I-35W Mississippi River Bridge cracked apart suddenly in 2007.

13 people killed, 145 wounded

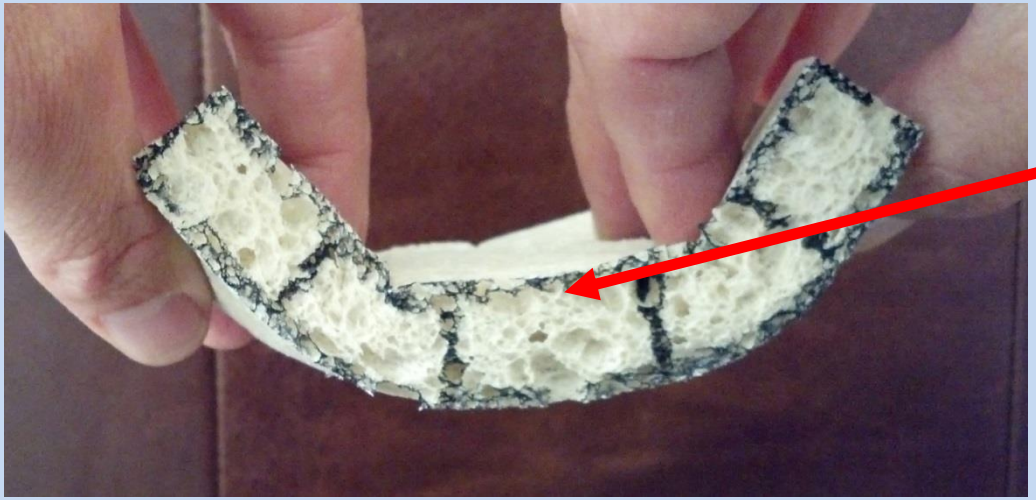
How can we understand these catastrophes from an engineering perspective?

Start to introduce structural engineering concepts…

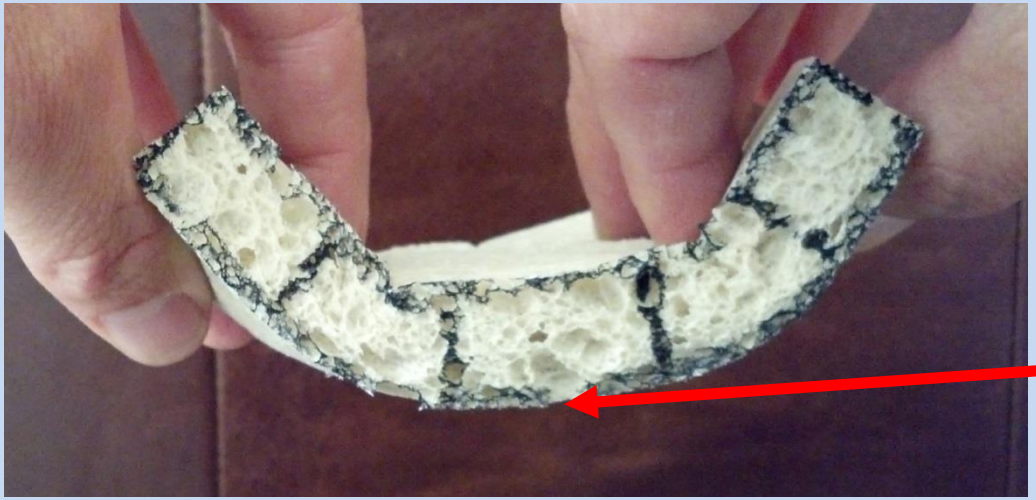
How can we understand these catastrophes from an engineering perspective?

Start to introduce structural engineering concepts…

The forces of tension (pulling) and compression (pushing) are opposites.



Compression

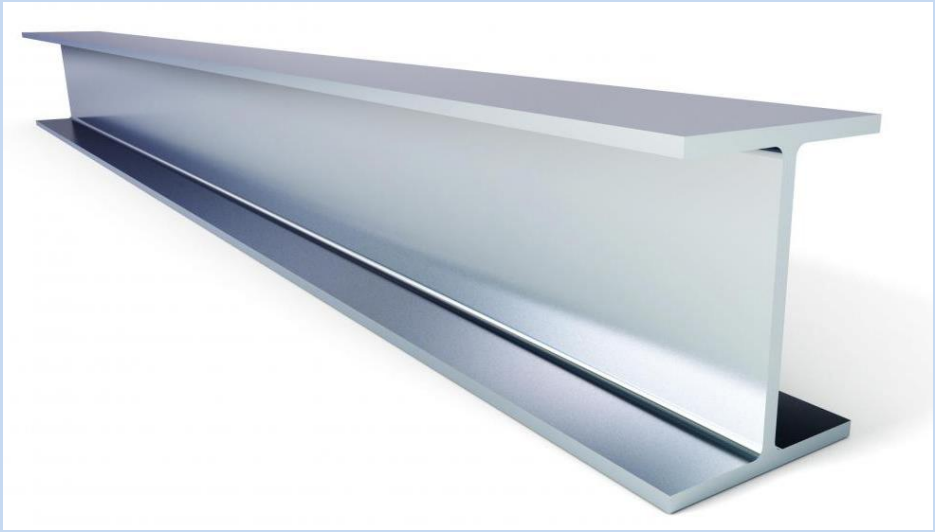


Compression

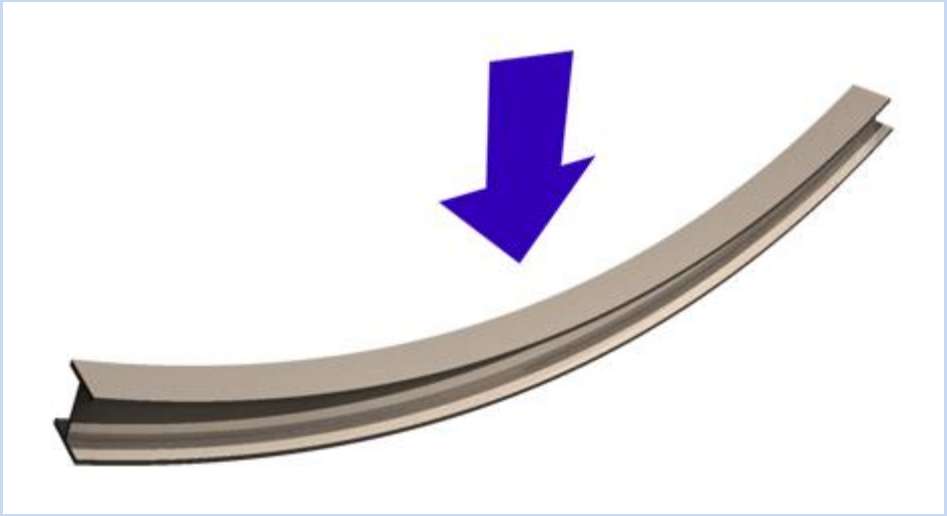
Tension

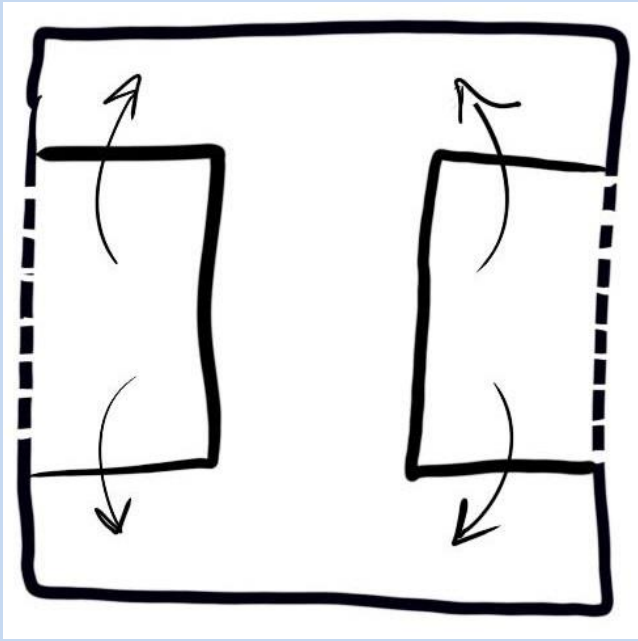
The neutral axis…

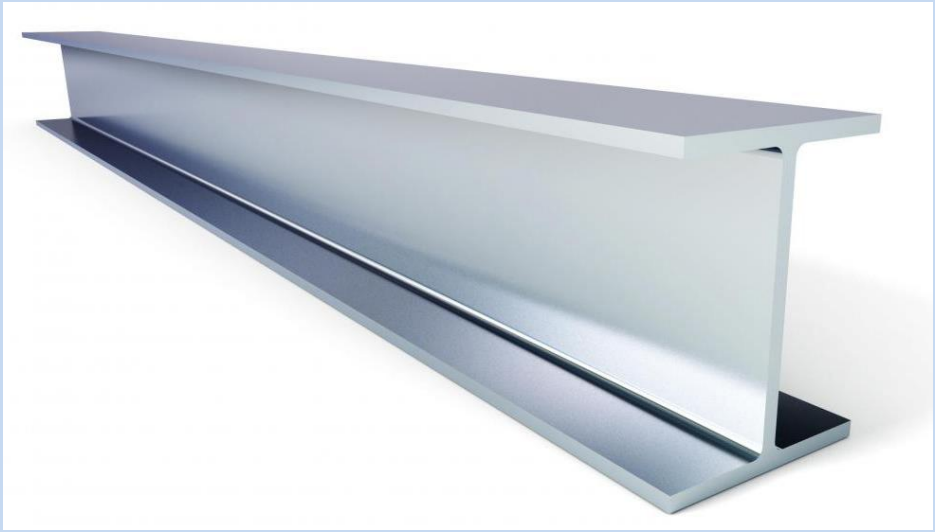
Knowing what you know, can anyone tell me why an I-beam is shaped like an I?

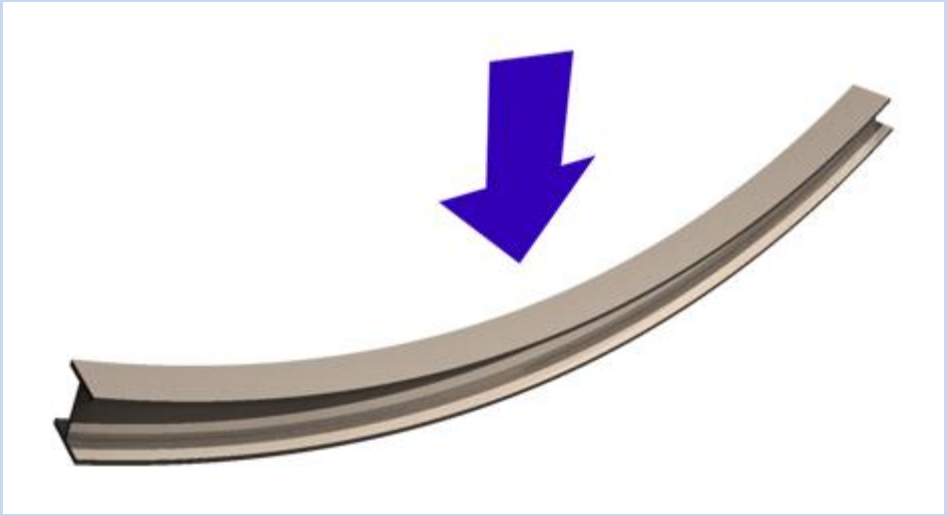


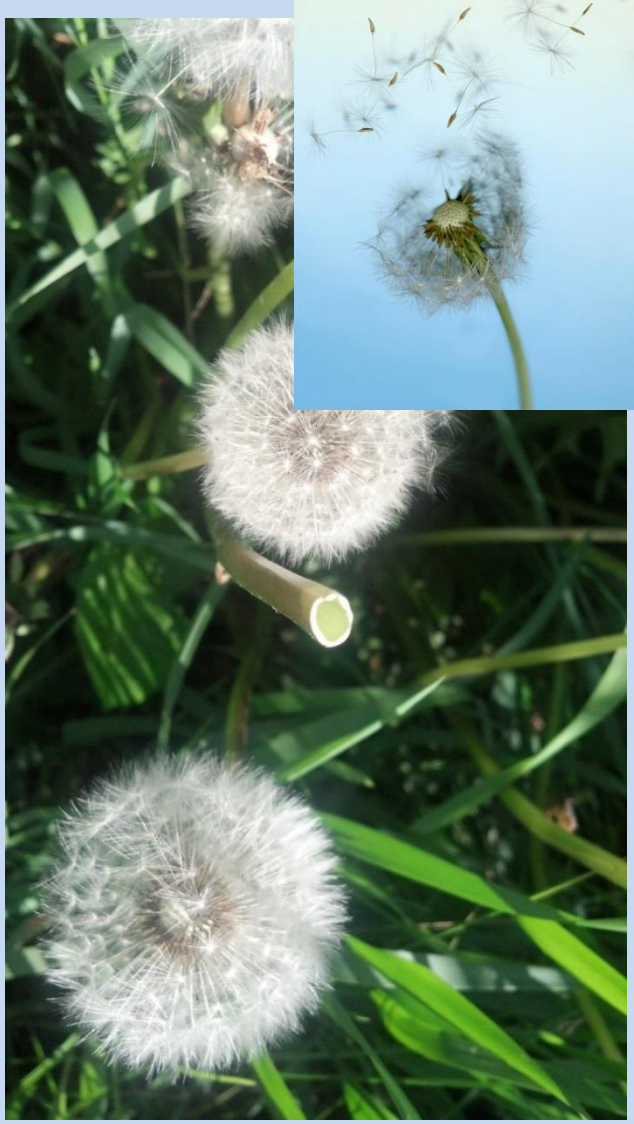
Knowing what you know, can anyone tell me why an I-beam is shaped like an I?



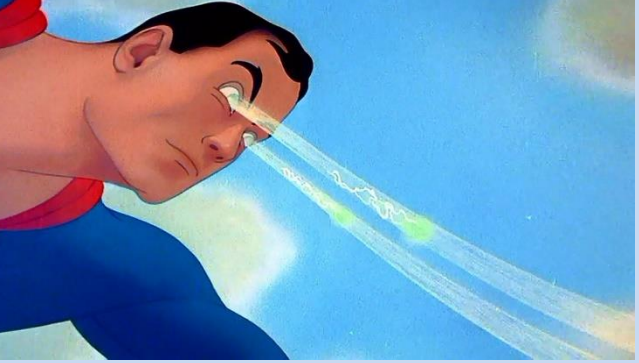




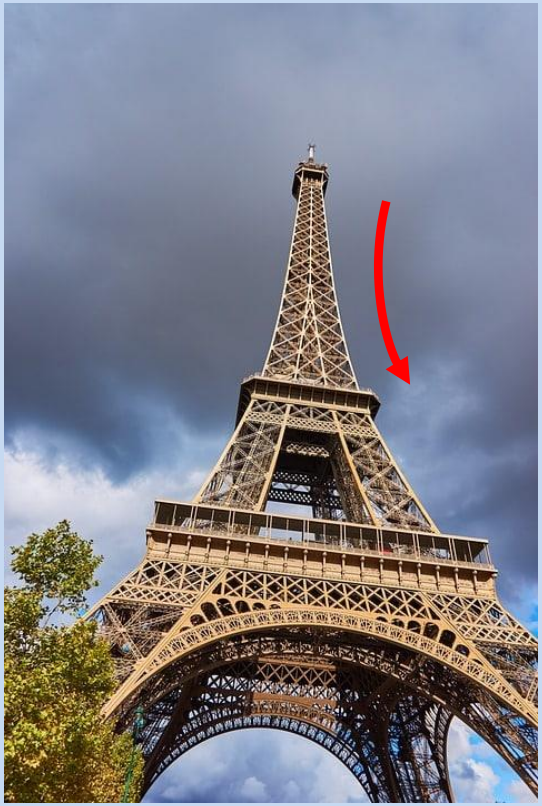




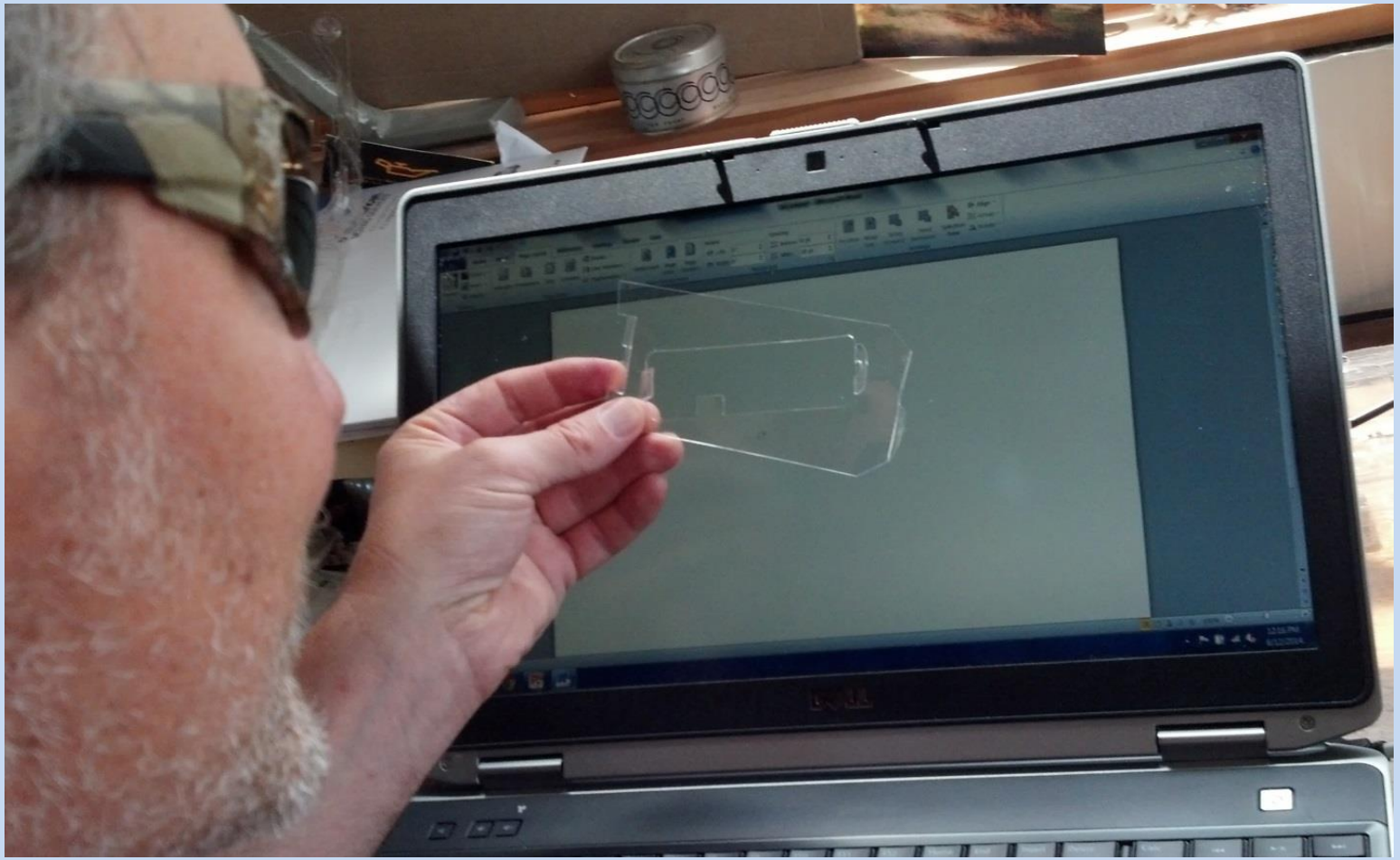
How is a dandelion stem like an I-beam?



Structural engineers can see these physical forces flowing through things…

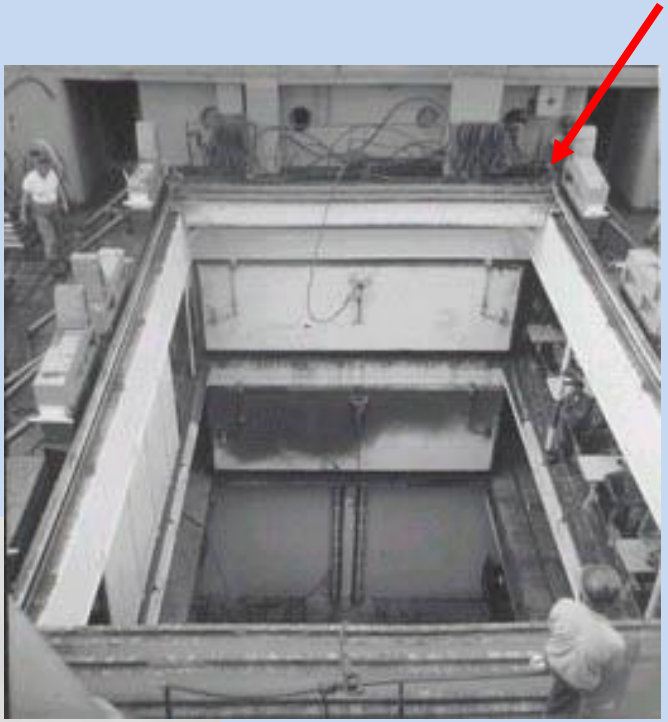


…and now so can you!

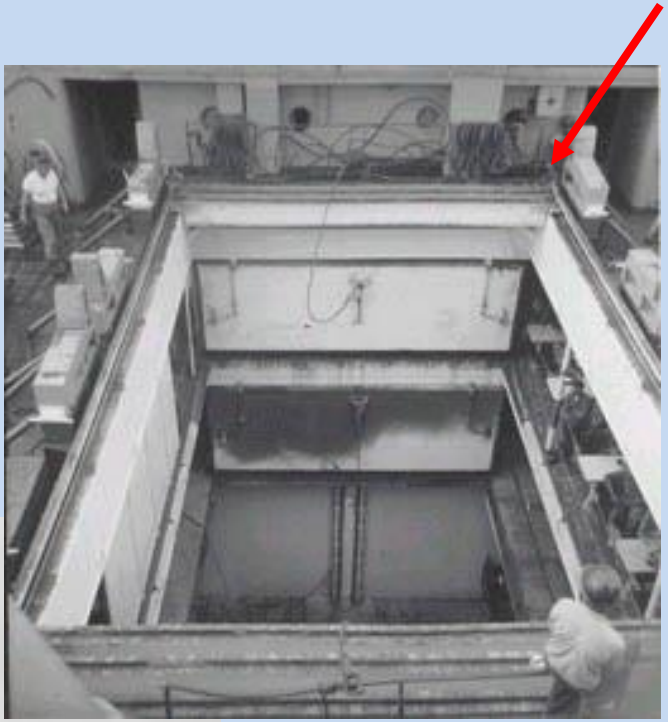


Try it for yourselves…

We can use the photoelastic effect to model simple and fundamental ideas in material science and structural engineering, to better understand these ideas first-hand.



Cracks in Liberty Ships started at squared corners of hull openings



Cracks in Liberty Ships started at squared corners of hull openings

Crash of the Comet due to cracks that formed in the window corners (that’s why airplane windows today are oval)

De Havilland Aircraft via R.A. Scholefield

Can we use the photoelastic effect to understand this phenomena of cracking better?

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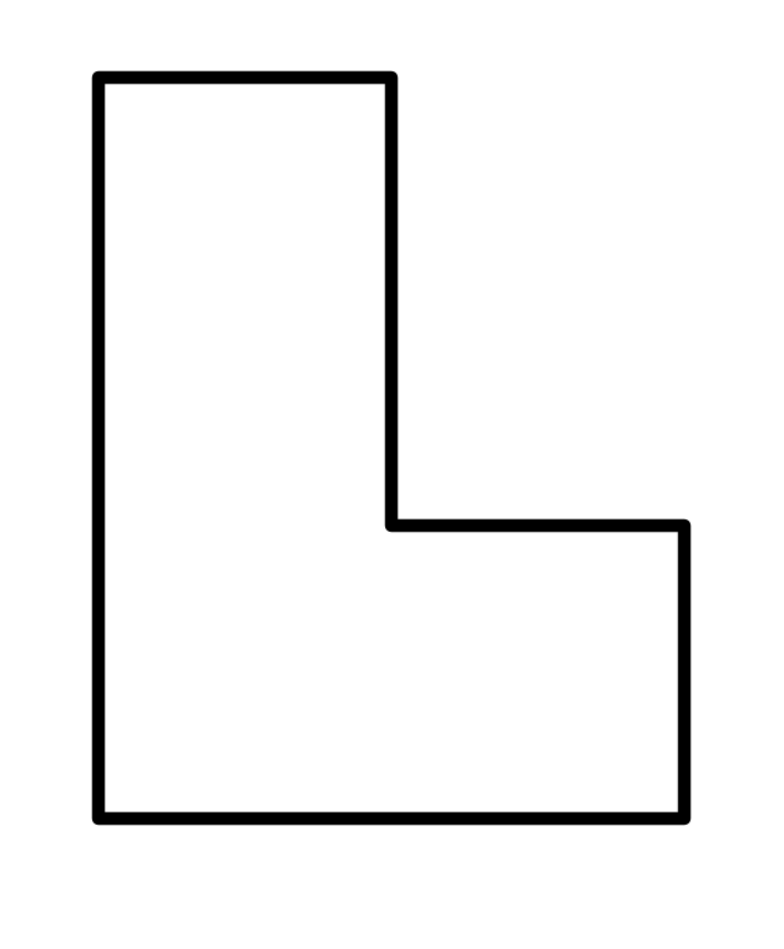
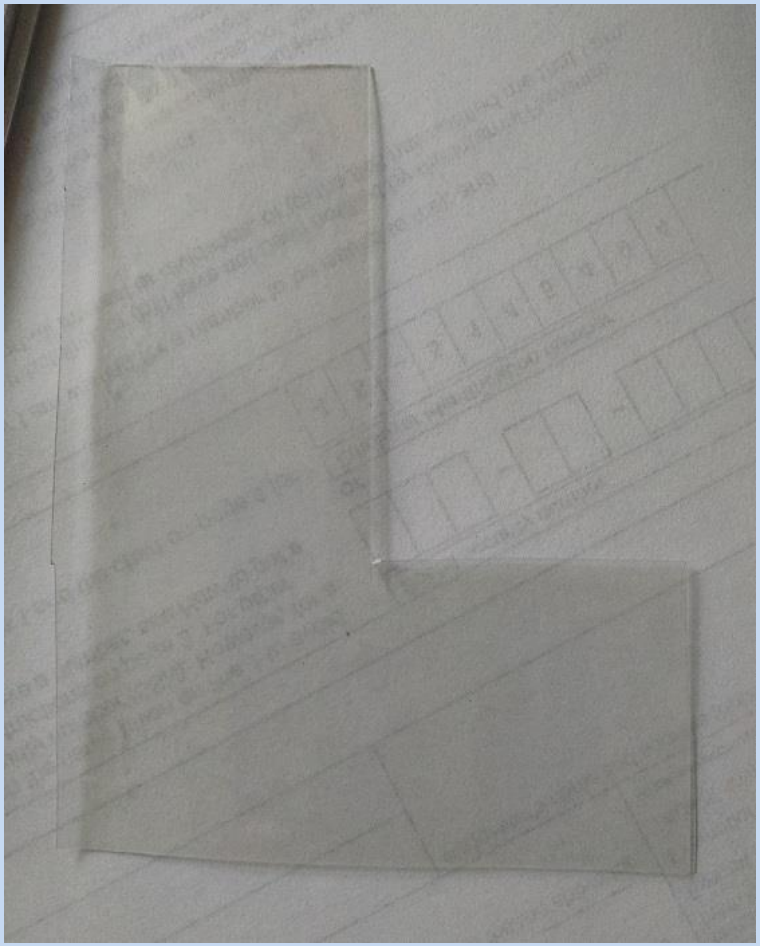
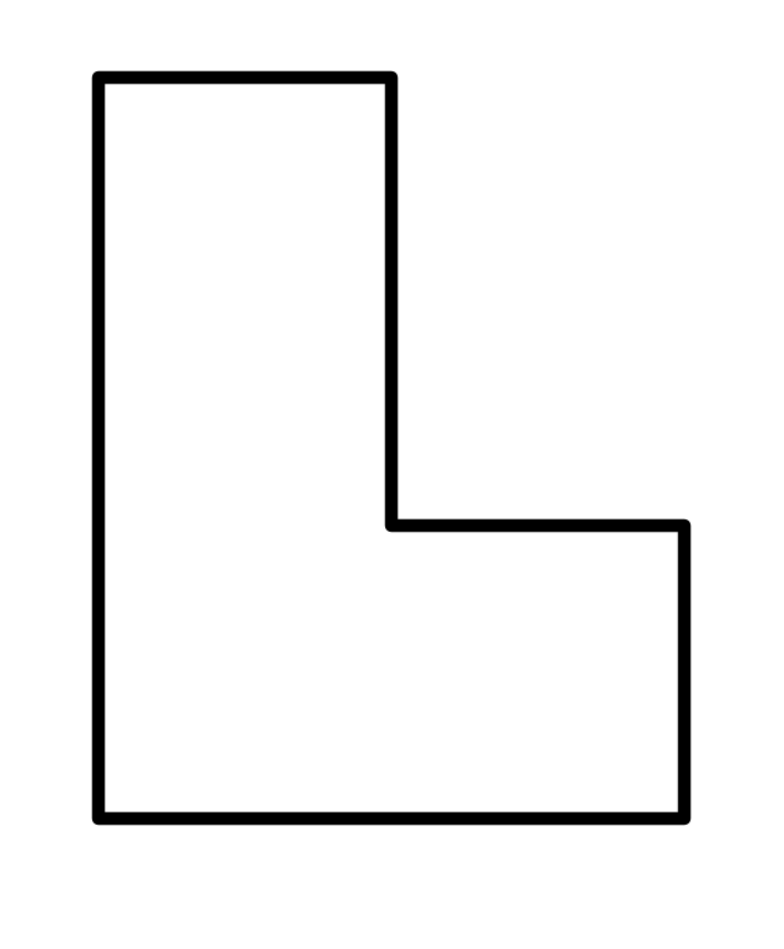
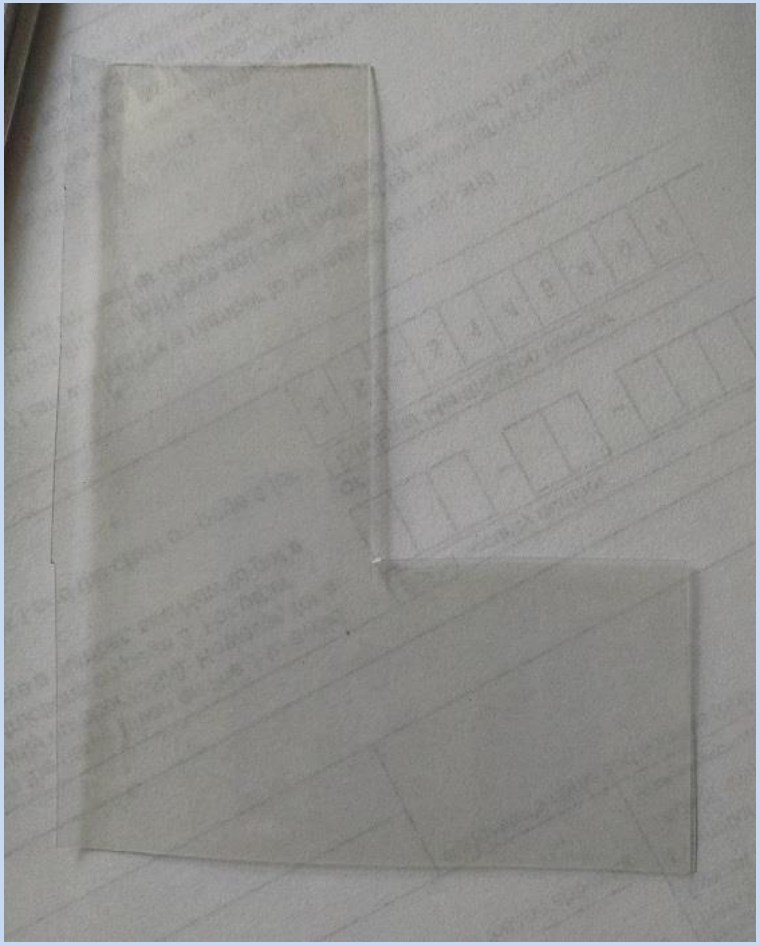




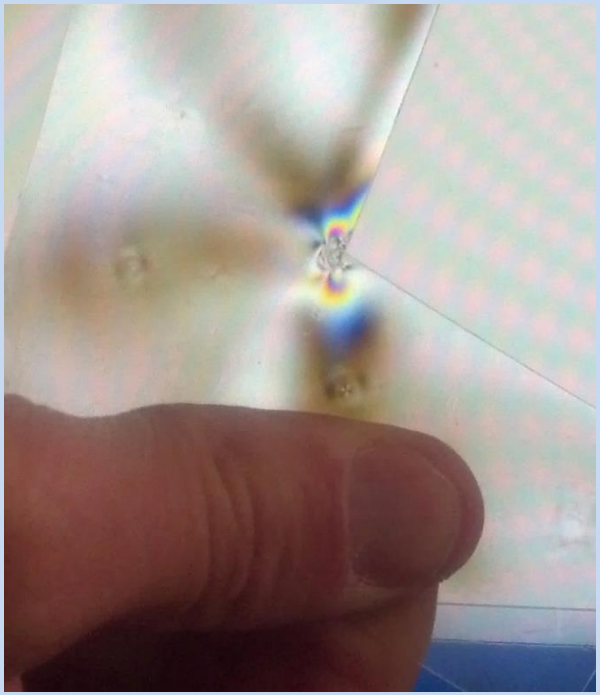
Make a material “notch” in your plastic





Put some tension on the sample. What do you notice about the strain?

Where does the stress concentrate?



The infamous “notch stress”!

What happened?

Sam Stier

Sam Stier

E. Smyrou & İhsan E. BAL

What’s going on here?

Olivier Cleynen

What’s going on here?

Sam Stier

Where do you see notches?

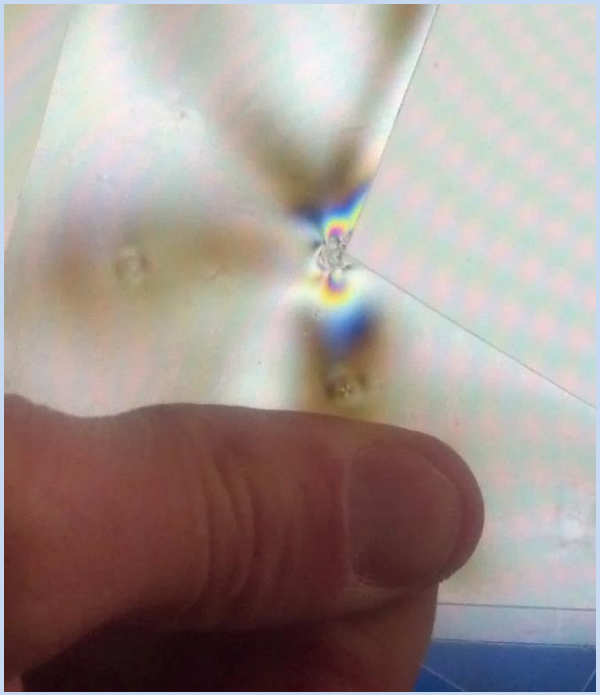
R. Nial Bradshaw

Where do you see notches?

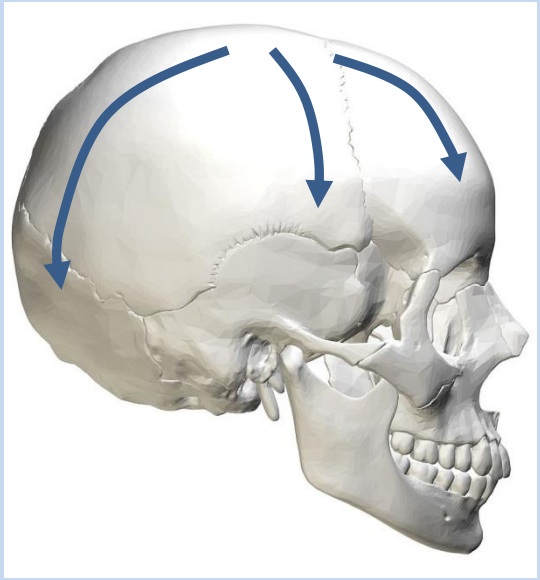
R. Nial Bradshaw

Notch stress was the cause of all of these…

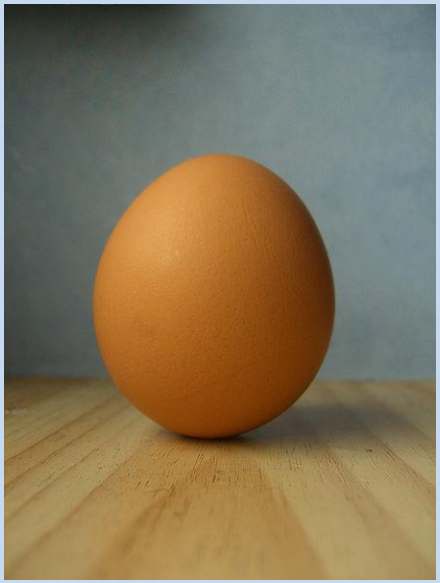
Ask students how they might try to improve the situation, and to model and test it in plastic.



Curved shapes are often used in Nature to help channel impact force, spreading the force out and keeping it away from what's valuable.



Andrewmeyerson CC BY SA 3.0



Kacper "Kangel" Aniołek CC BY SA 3.0

Jeremy Weber CC BY 2.0

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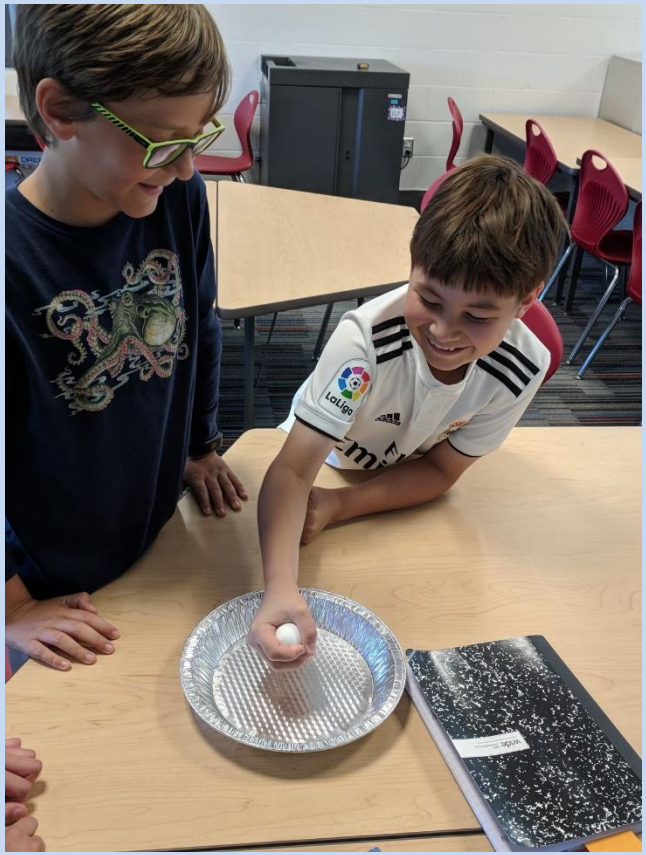
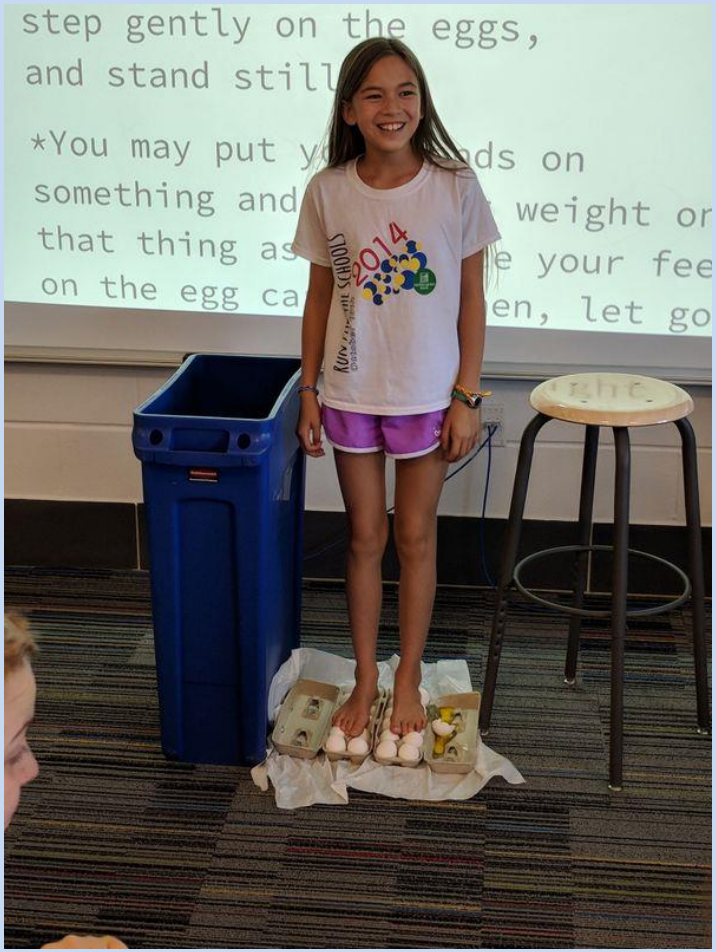
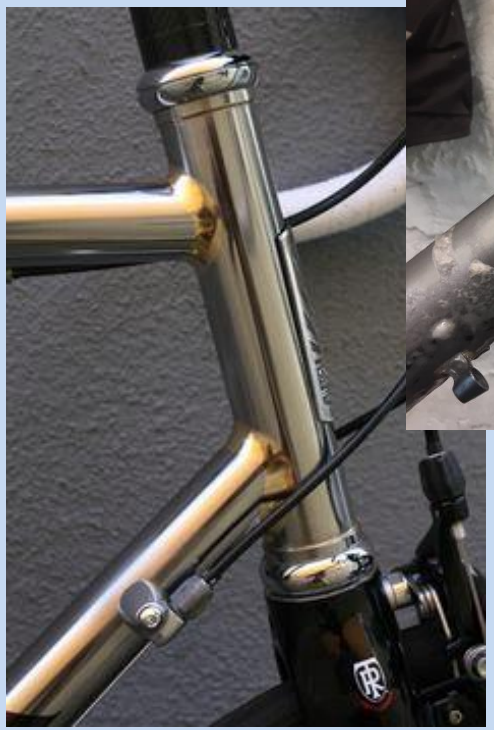
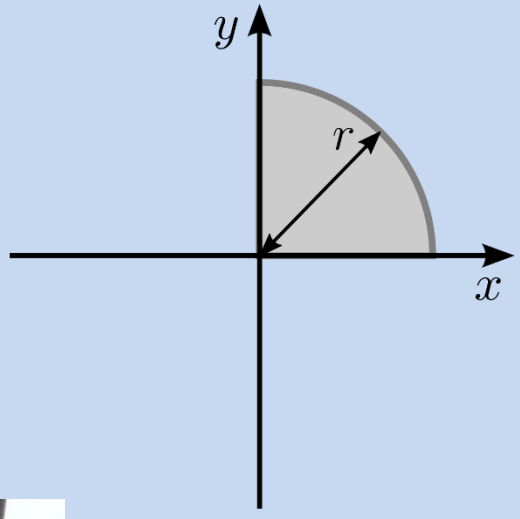
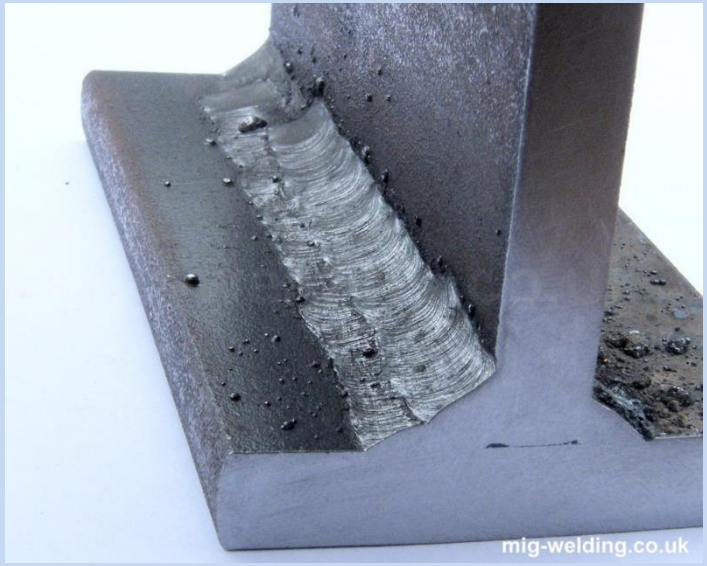


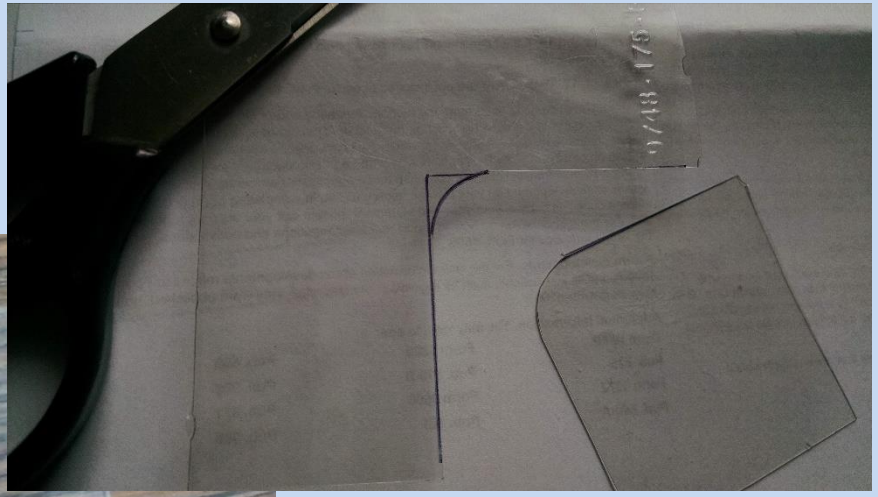


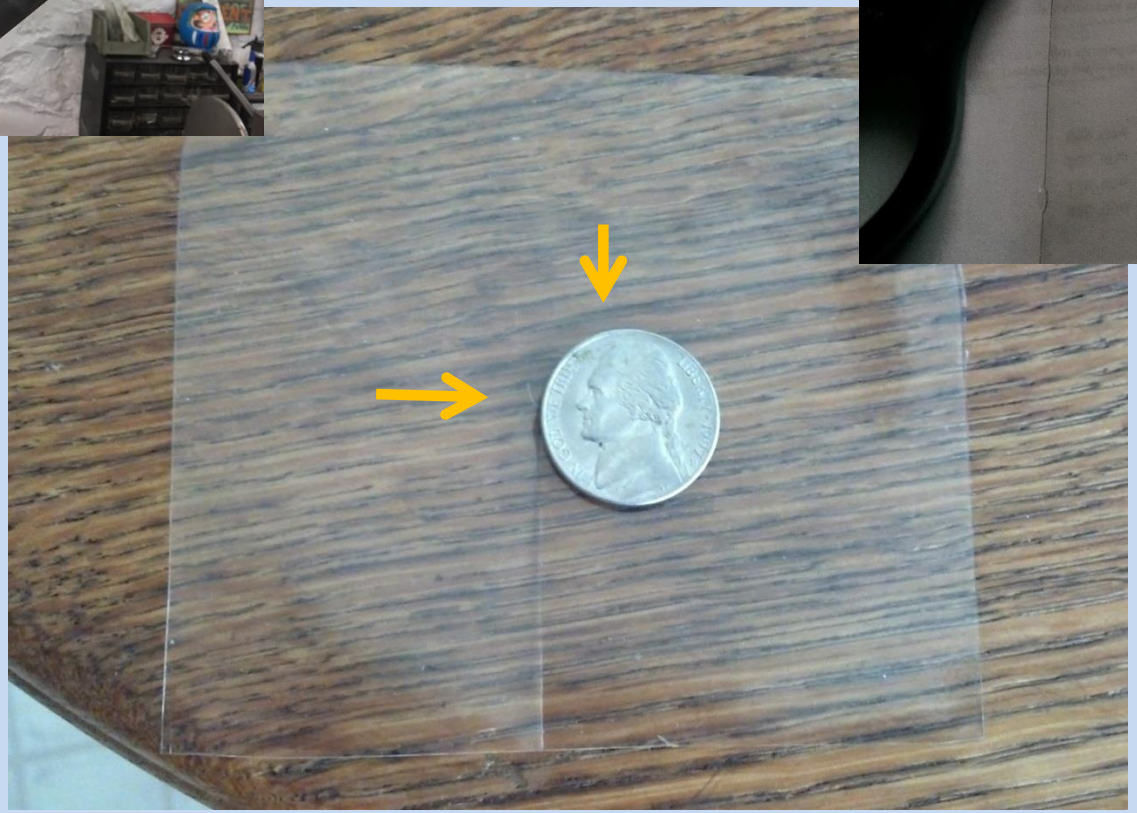
Engineers address the notch problem of notch stress using a “quarter circle fillet”



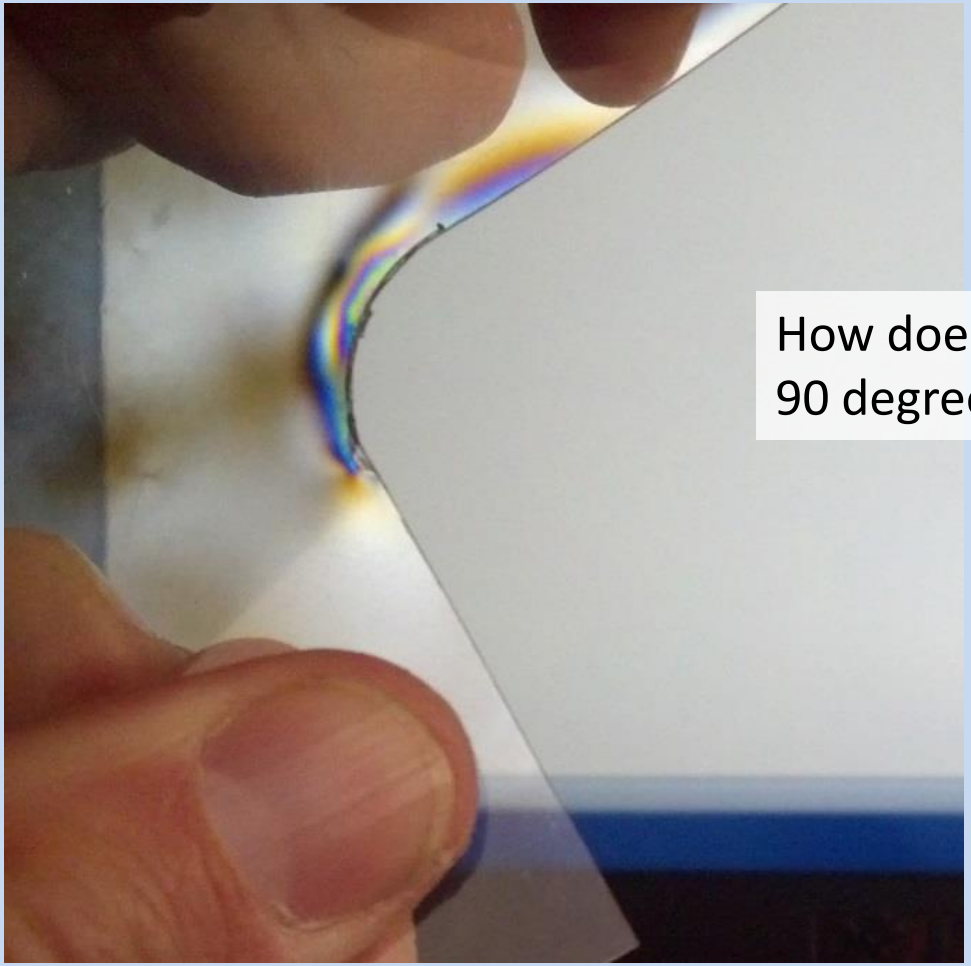






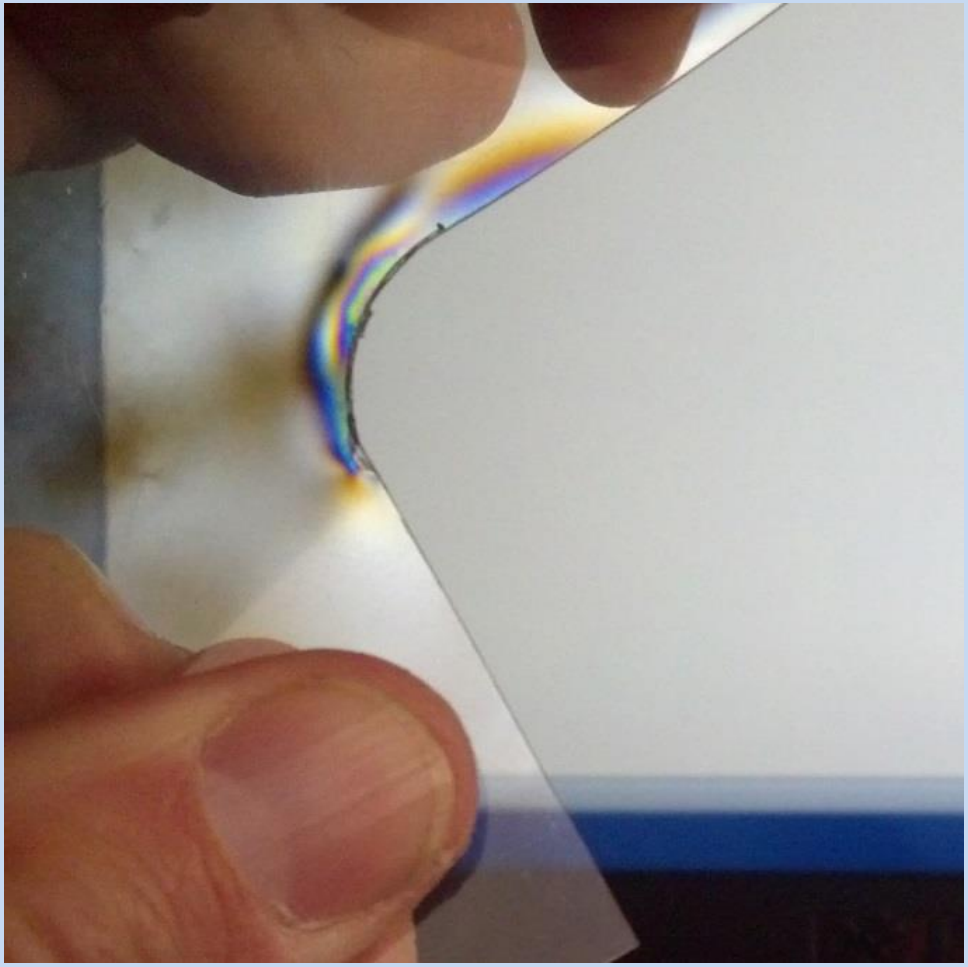


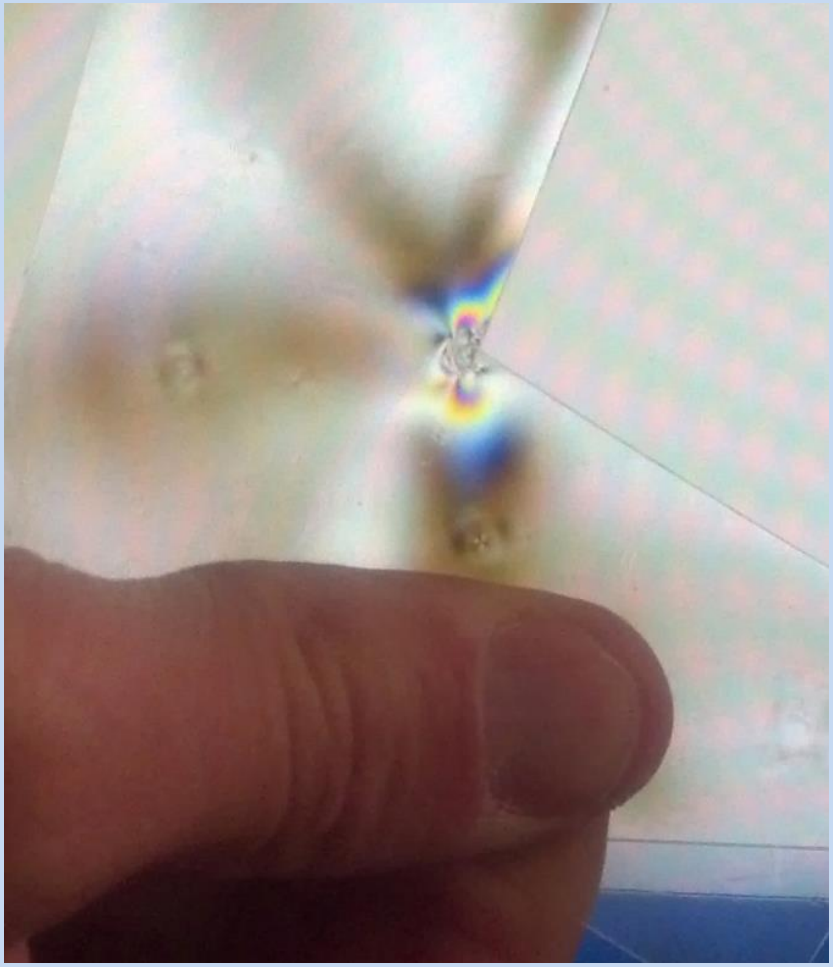
Apply tension as before…what do you notice?



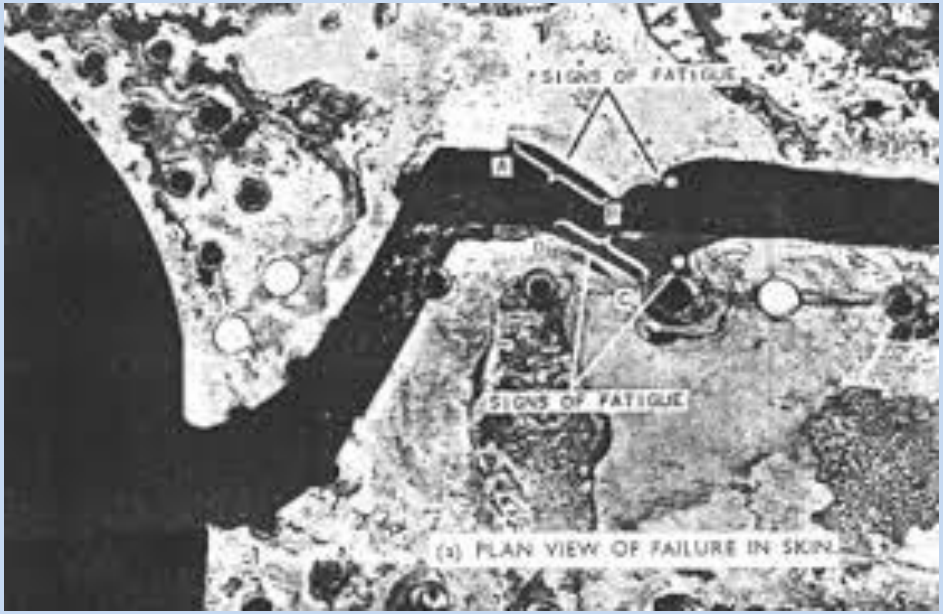
How does tensile force compare between a 90 degree notch and quarter circle notch?

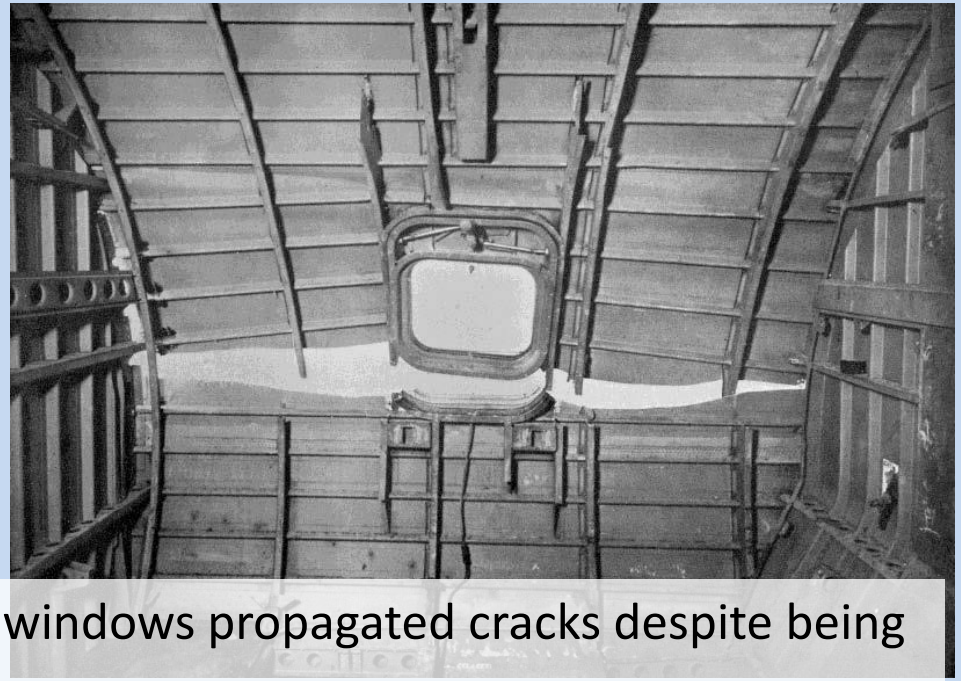
This is why engineers use a quarter circle fillet to manage notch stress concentration





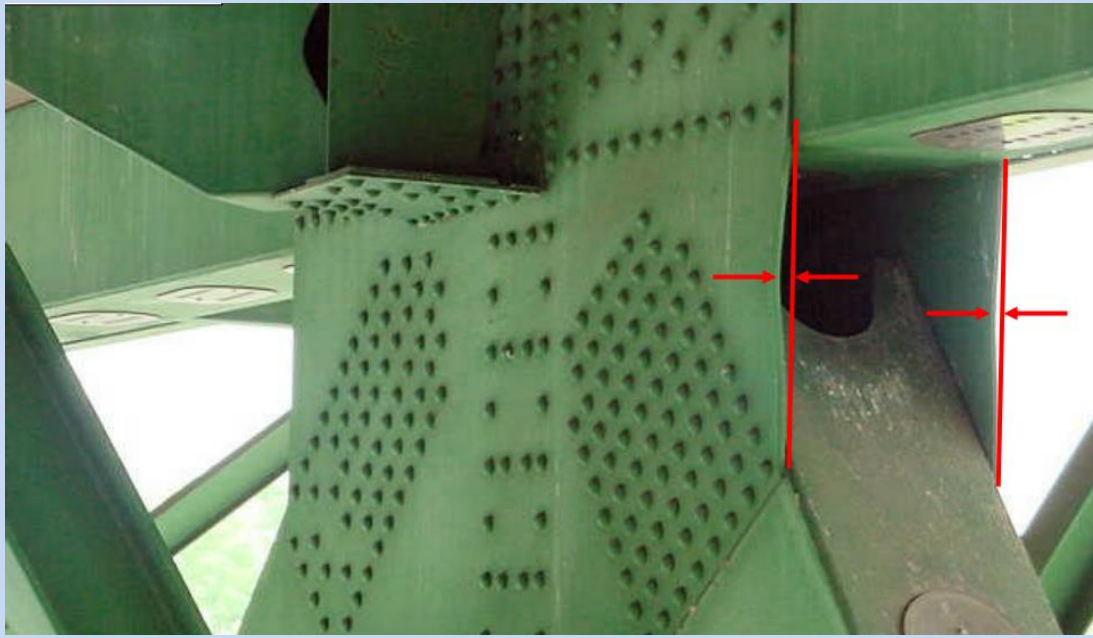
This is why engineers use a quarter circle fillet to manage notch stress concentration!

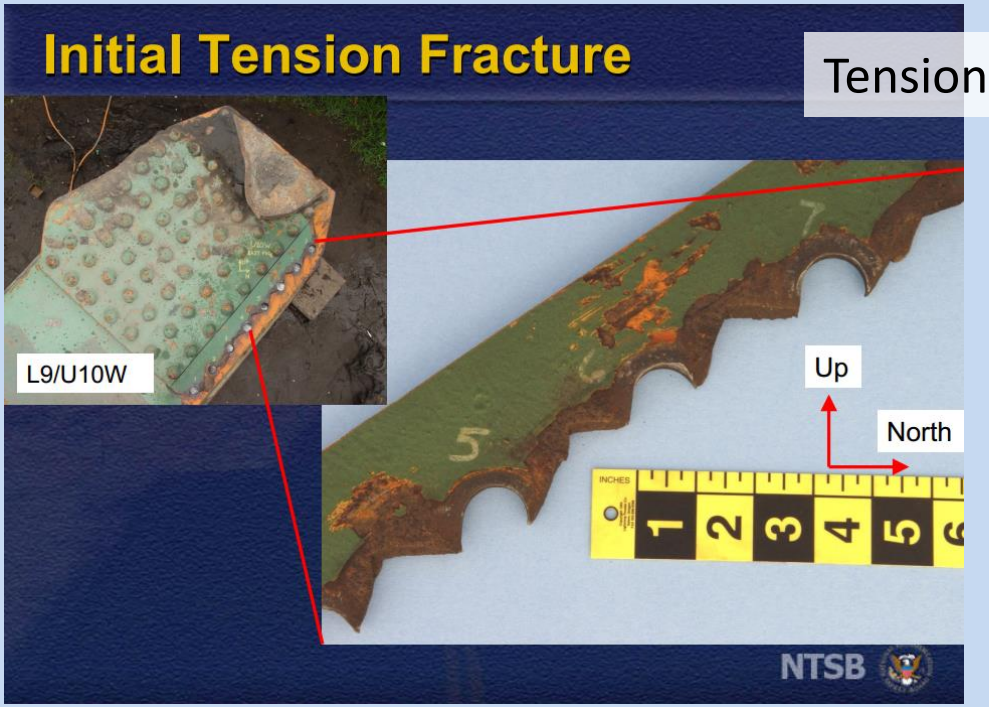




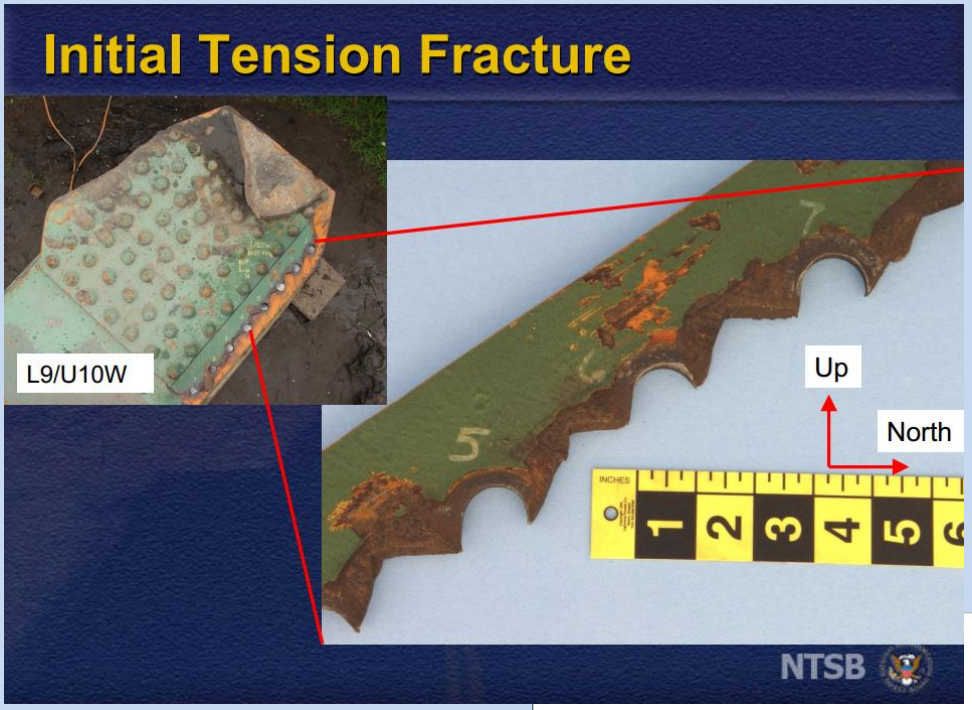
On closer inspection, the Comet airplane windows propagated cracks despite being rounded with a quarter circle fillet.

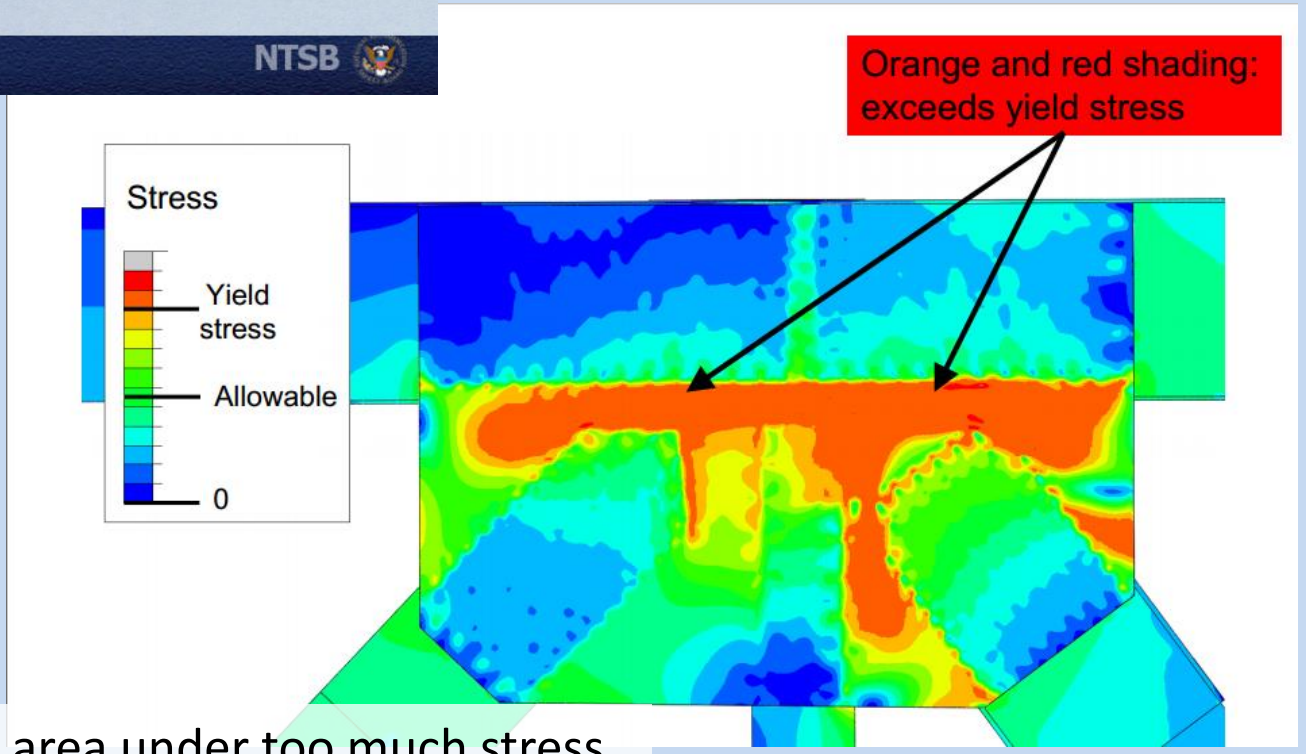
I-35 Bridge collapsed due to the build-up of stress concentration in the joint. The first sign was the plate that bowed under compression.



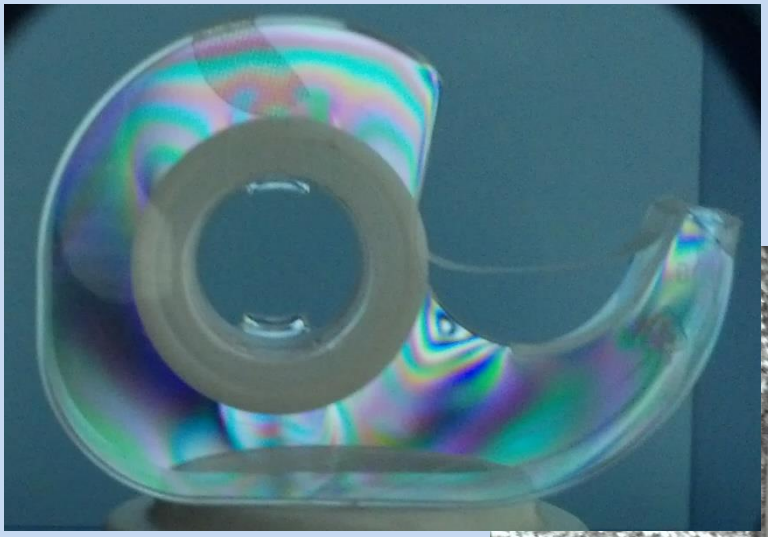


Tension fracture ripped across the rivet holes.





Analysis later showed the area under too much stress.



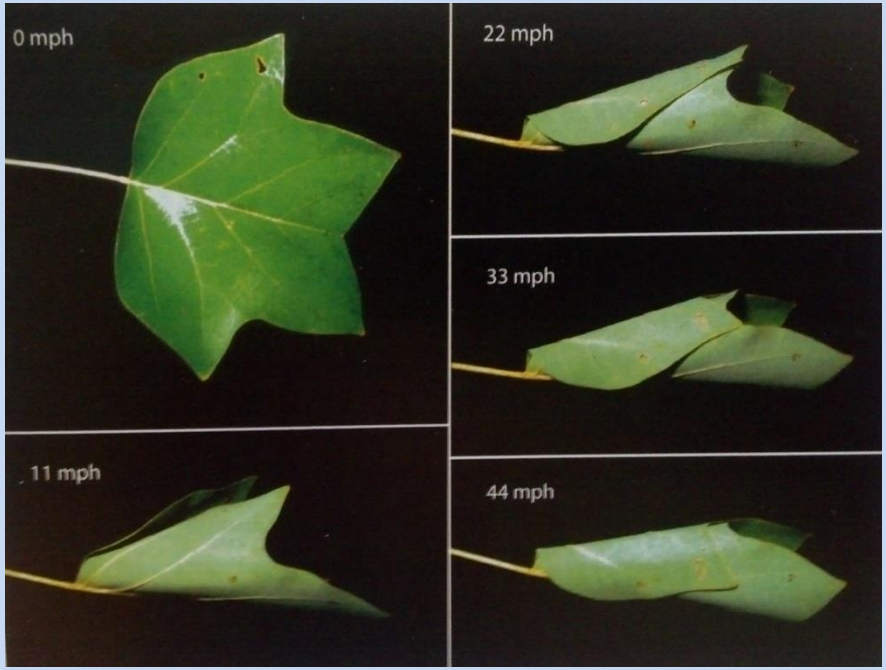
Quarter circle fillets spread stress but don’t eliminate it.

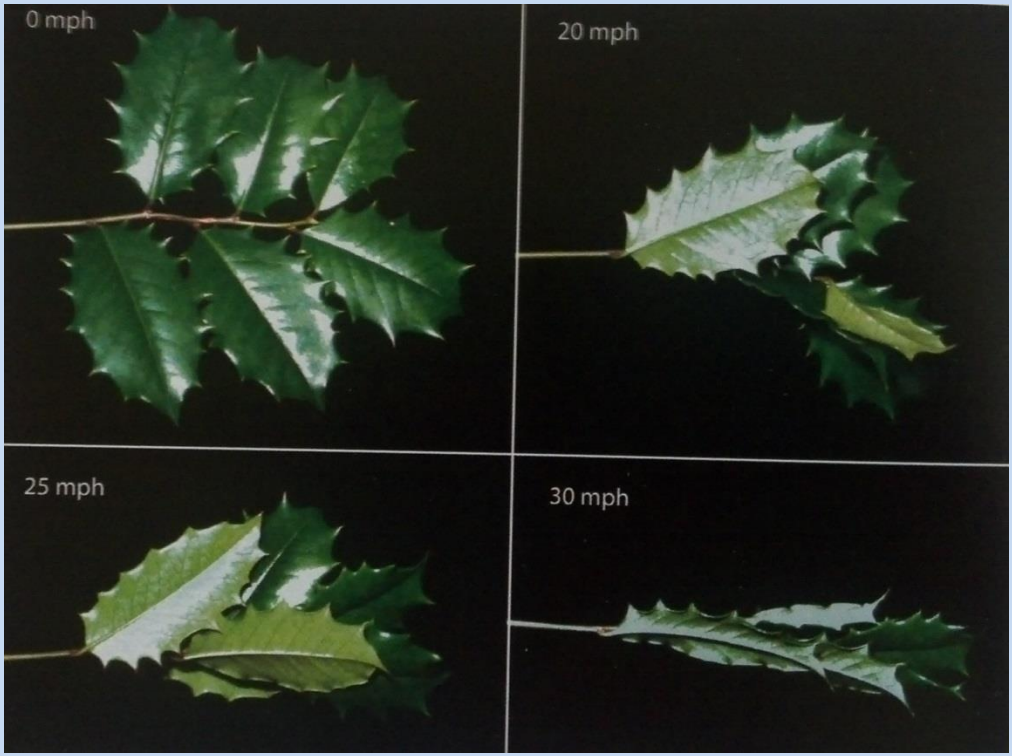
How does Nature manage notch stress?

How does Nature manage notch stress?

How do trees manage to rarely break?

Trees have evolved many ingenious strategies for coping with cracks…

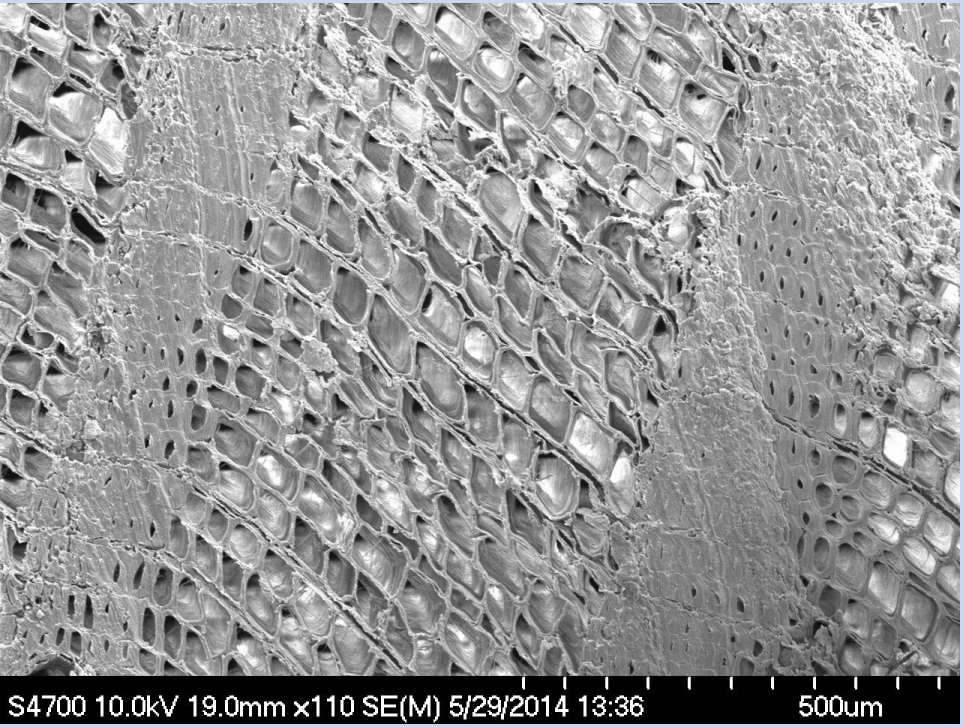




Stephen Vogel

Spring/early wood

Summer/late wood

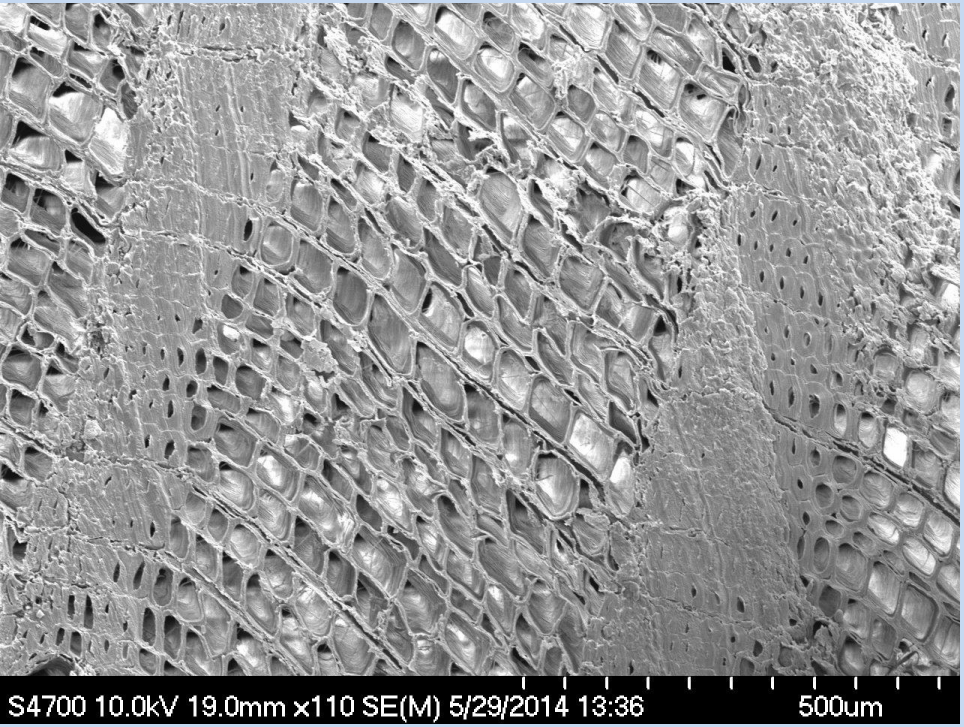


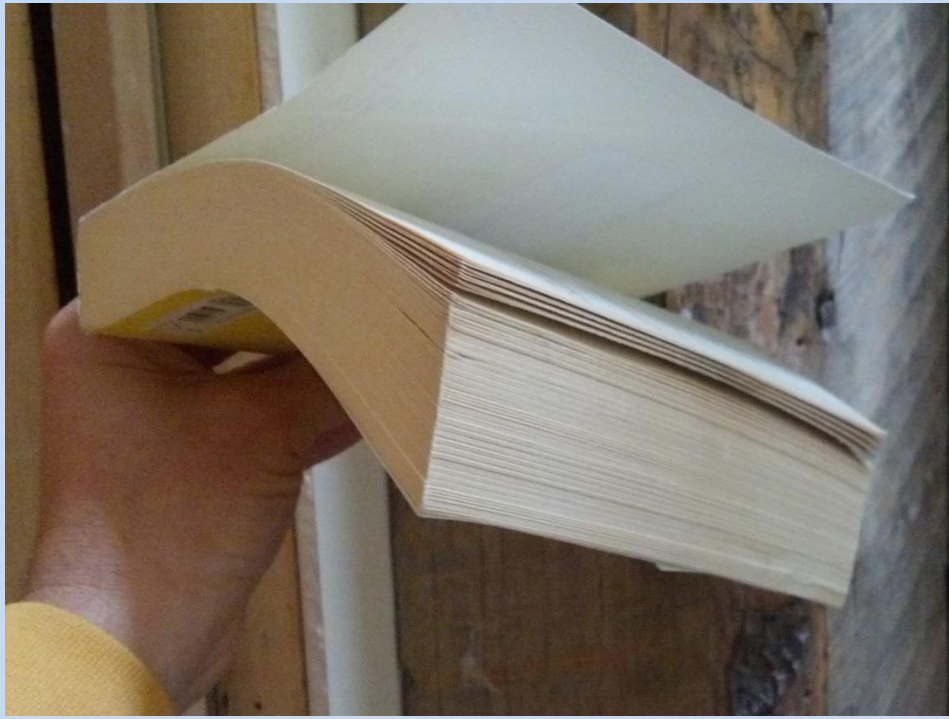
SEM of wood © Sam Stier

crosswise cut

Spring/early wood

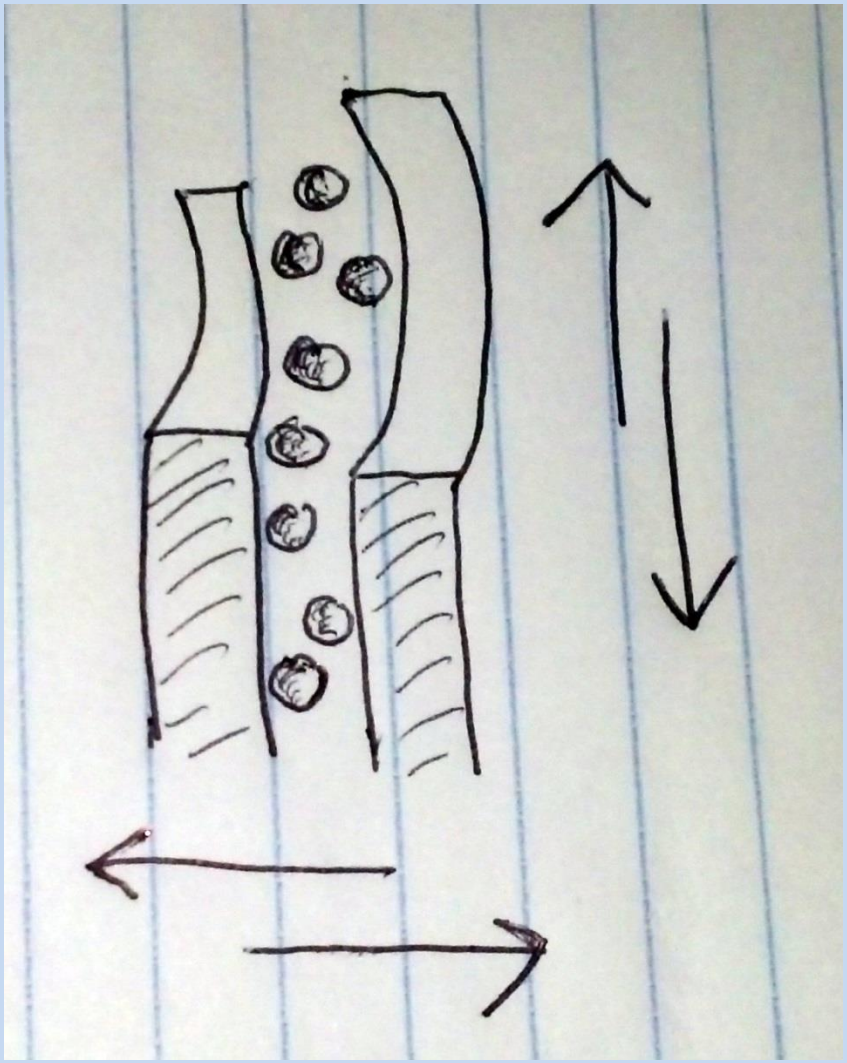
Summer/late wood





SEM of wood © Sam Stier

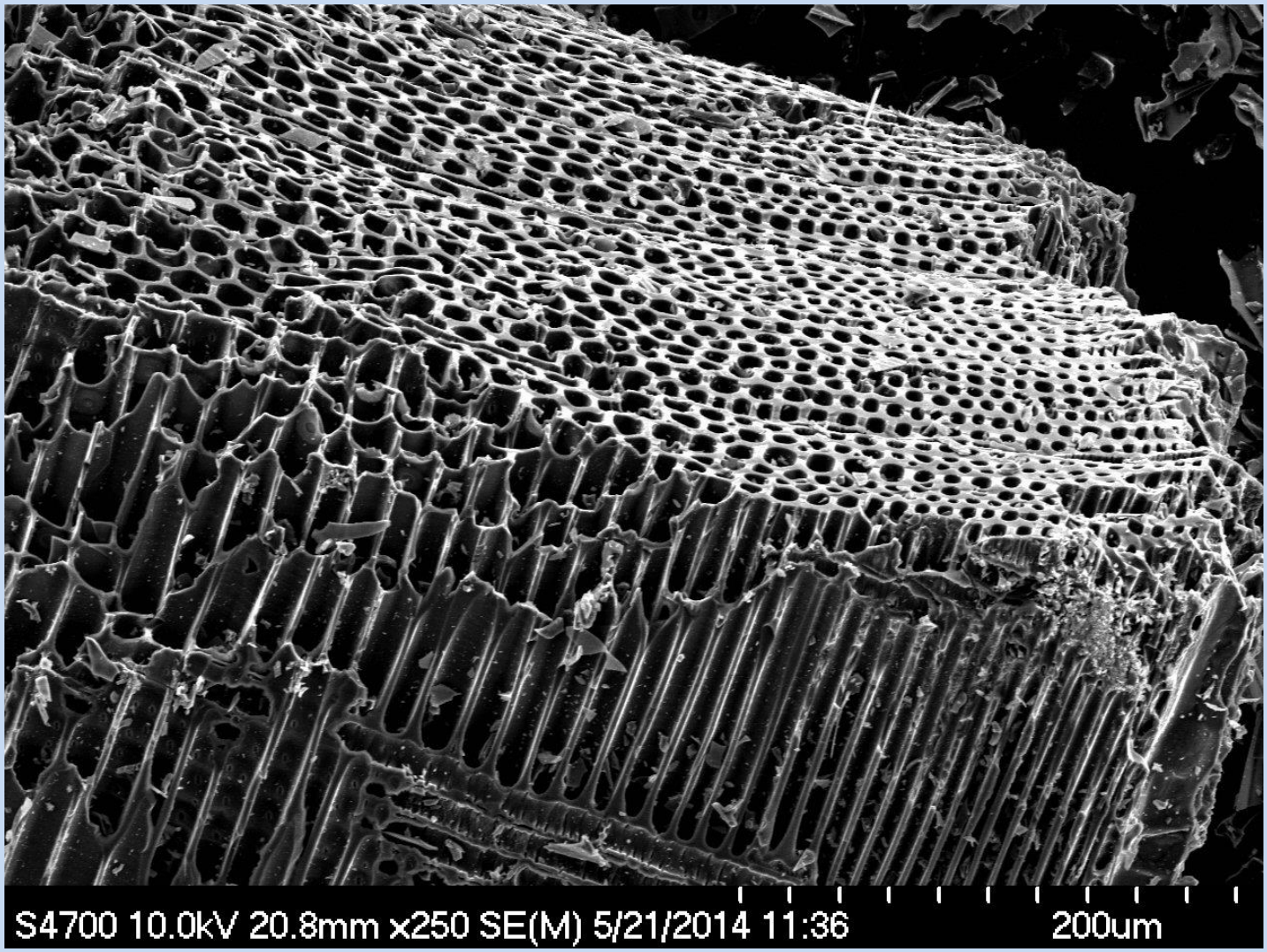
Tree rings serve a function…



…they operate like ball bearings, giving the tree lateral flexibility.

Trees are immensely strong, but…

…their strength doesn't come from being solid. Here's structure of wood:



SEM of wood © Sam Stier

Wood isn't really solid at all.

A little math can help us understand conceptually this crack-stopping strategy…

The stress concentration at the tip of a crack is described as:

$$K = 2\sqrt{(y/R)}$$

Where K = the stress concentration at the crack tip

y = crack length (or yikes!)

and R = is the radius of the crack tip

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The stress concentration at the tip of a crack is described as:

$$K = 2\sqrt{(y/R)}$$

Where K = the stress concentration at the crack tip

y = crack length (or yikes!)

and R = is the radius of the crack tip

The BIGGER R gets (radius of the crack tip), the SMALLER K becomes (the smaller the stress concentration gets).

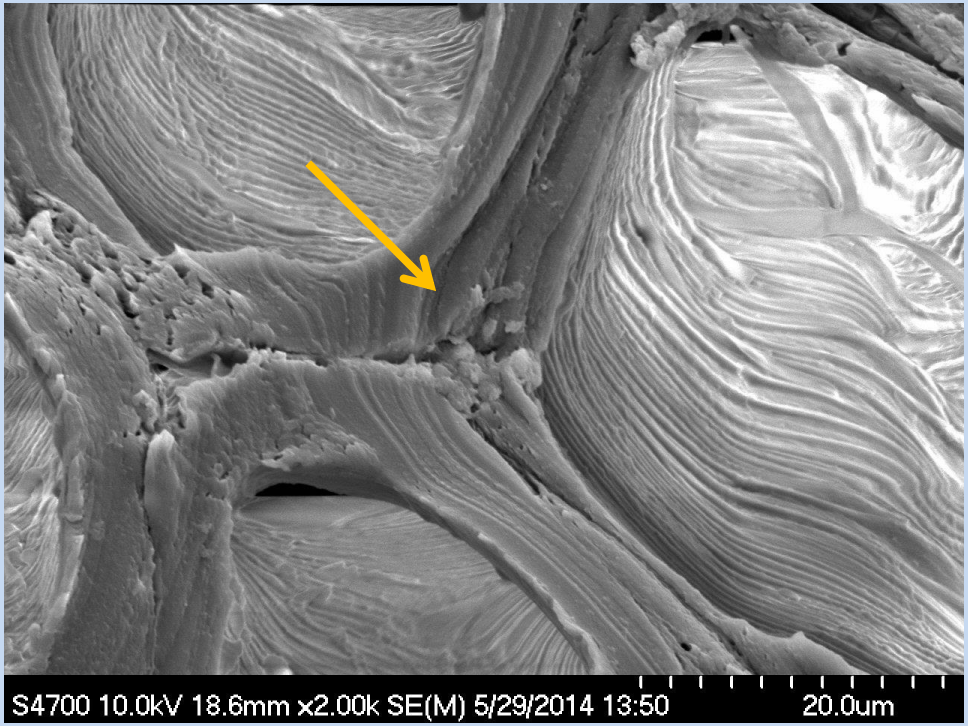
The stress concentration at the tip of a crack is described as:

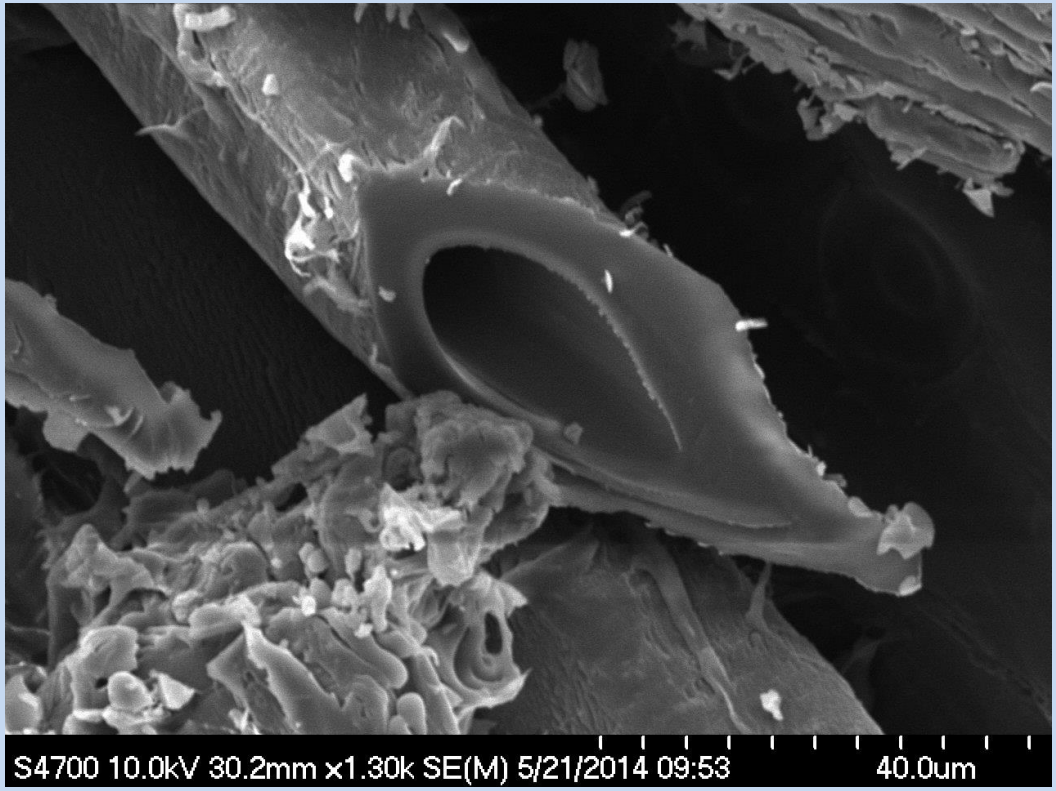
$$K = 2\sqrt{(y/R)}$$

Where K = the stress concentration at the crack tip

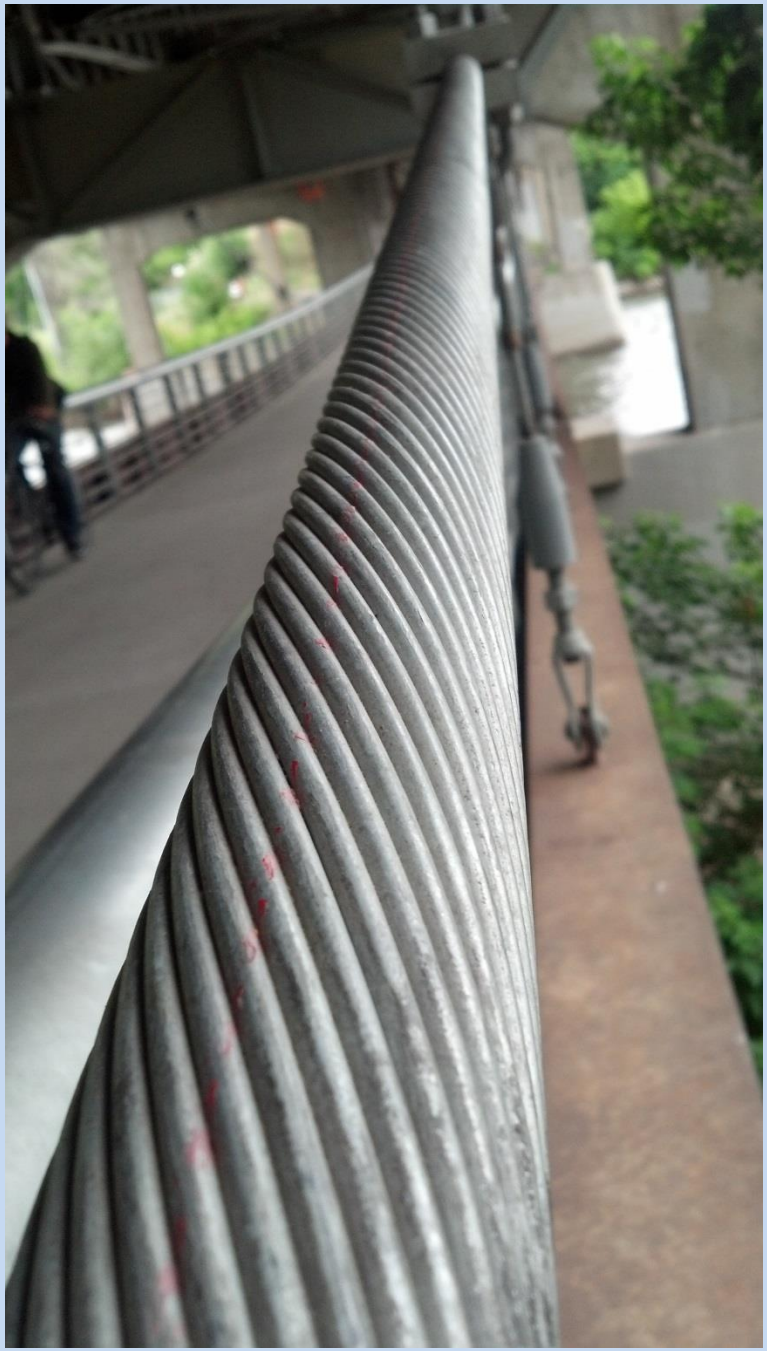
y = crack length (or yikes!)

and R = is the radius of the crack tip

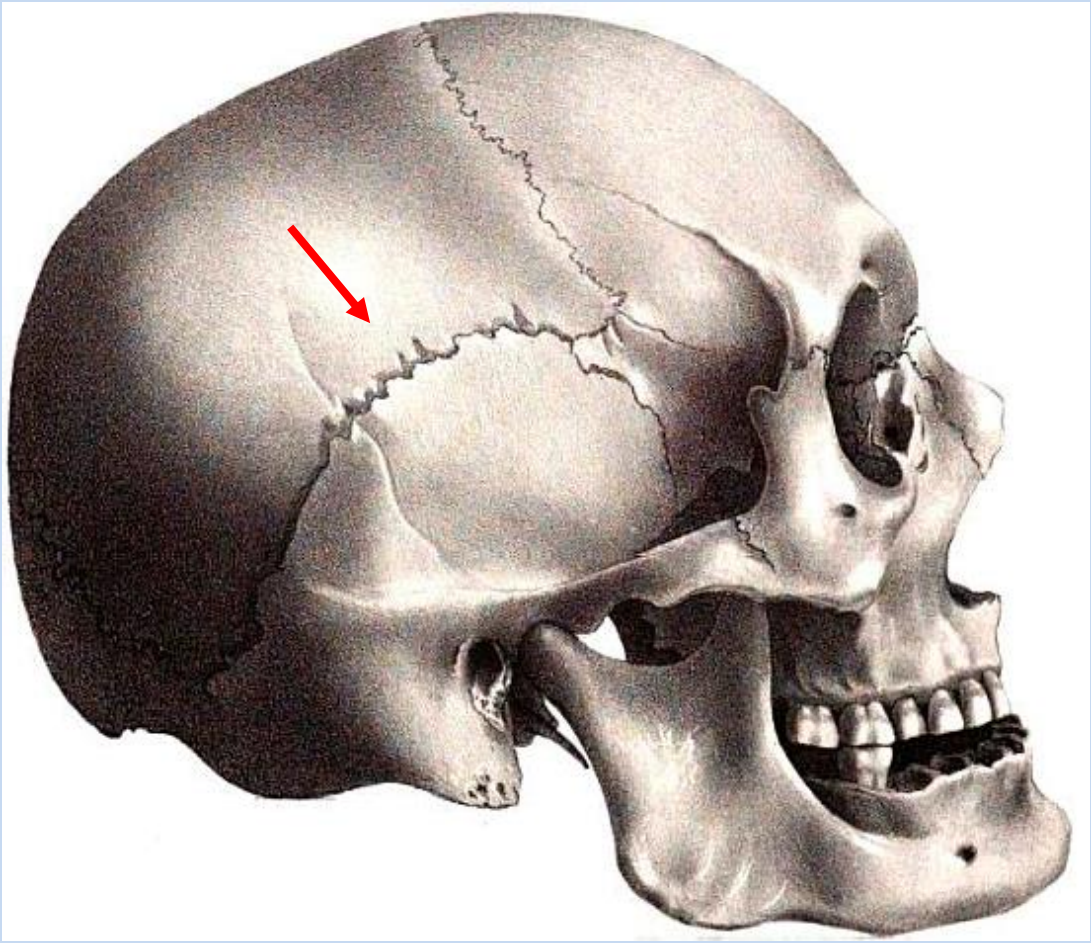




Single conduit from ruptured Douglas fir



Crack-stopping strategies are everywhere in Nature…

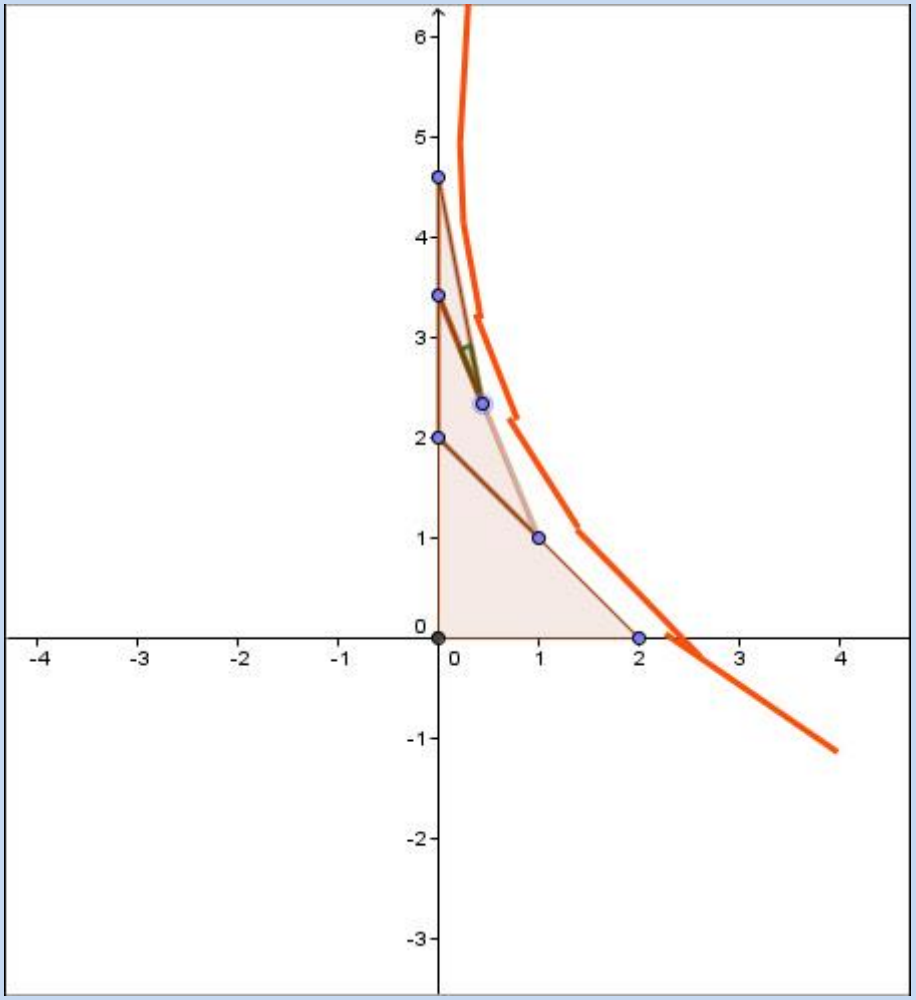


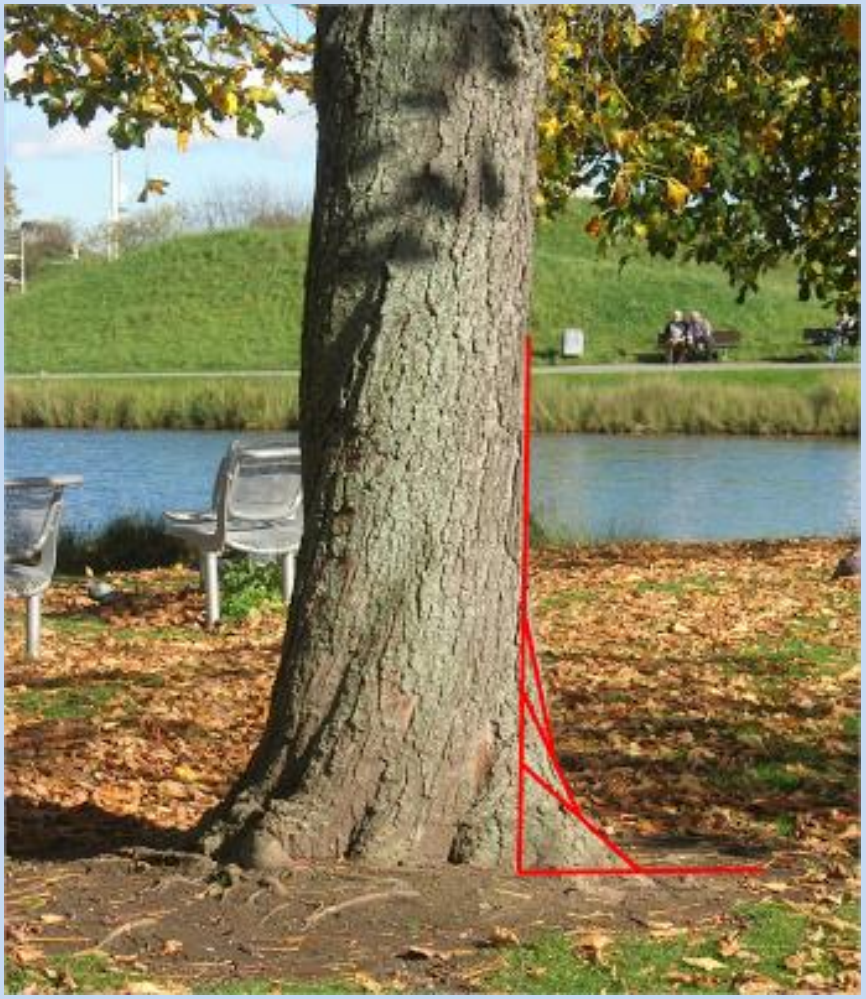
Paradoxically, materials are stronger by being (strategically) broken already…


• Tree curves
• Discovered by Dr. Claus Mattheck, Karlsruhe University, Germany

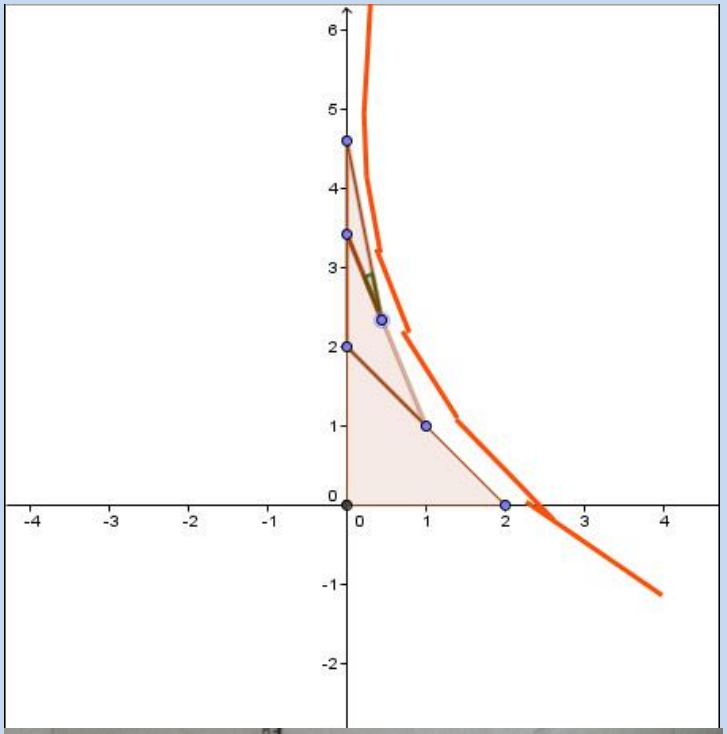

Quarter circle

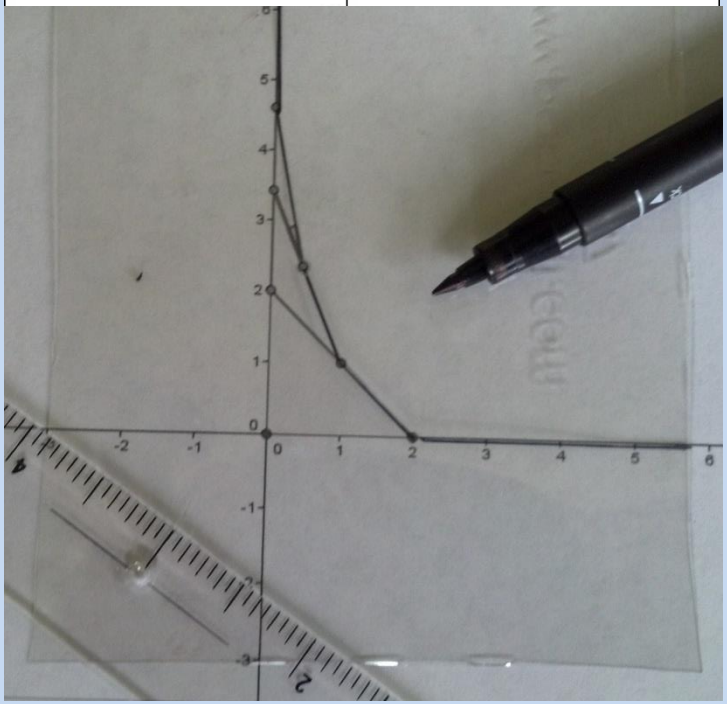

Tree curve





What kind of curve is it?



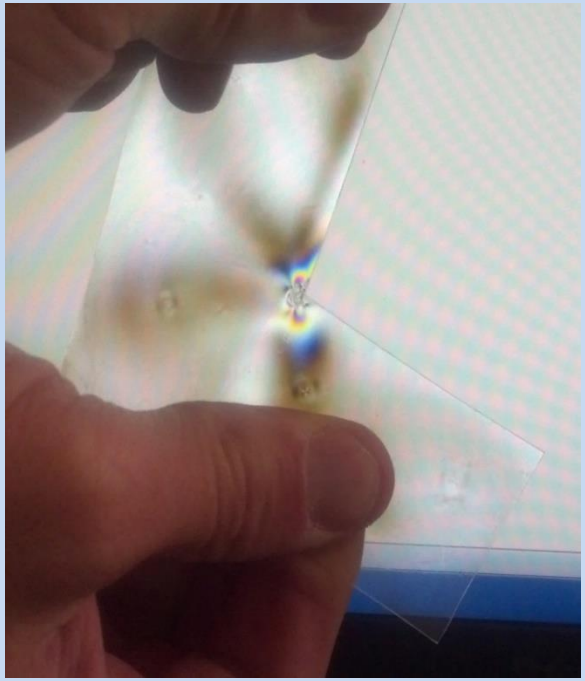


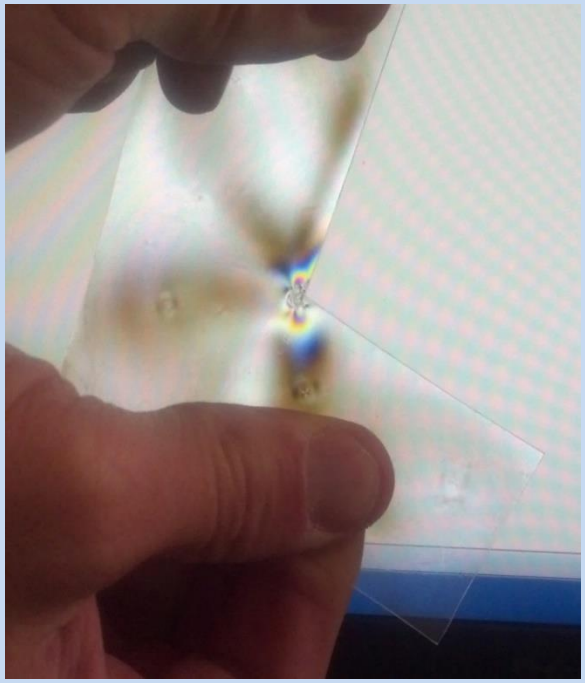
Draw a 45° equilateral triangle in the notch, as large as possible (within other design constraints).

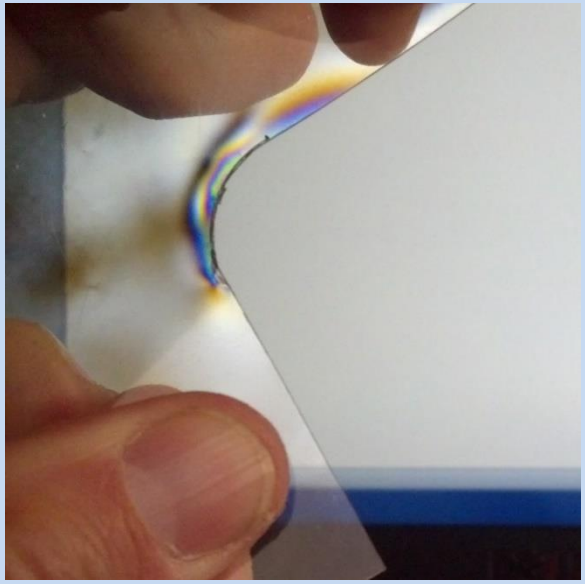
From the mid-point of the first triangle's diagonal, make another equilateral triangle by making a diagonal to the vertical, at an angle of 22.5°.

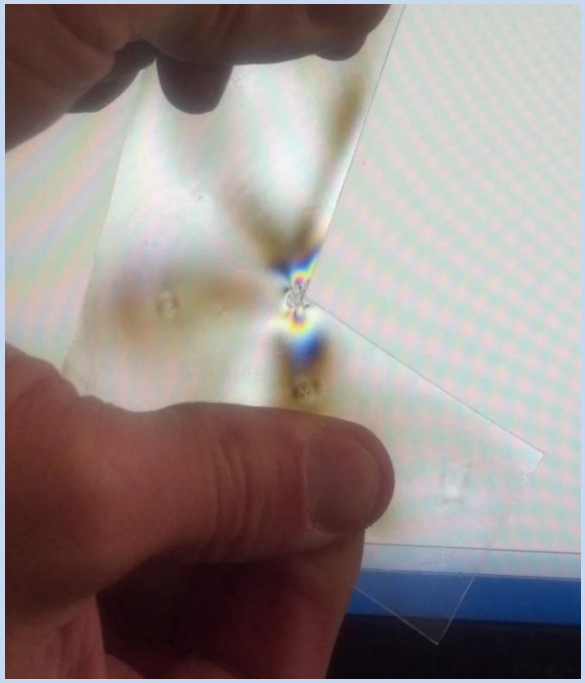
From the mid-point of the second triangle's diagonal, make a final equilateral triangle by making another diagonal to the vertical, at an angle of 11.25°.

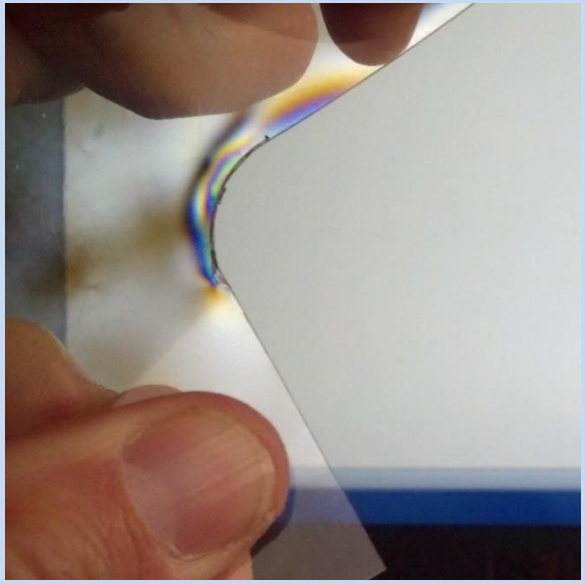
Compare the 3 structural solutions to notches





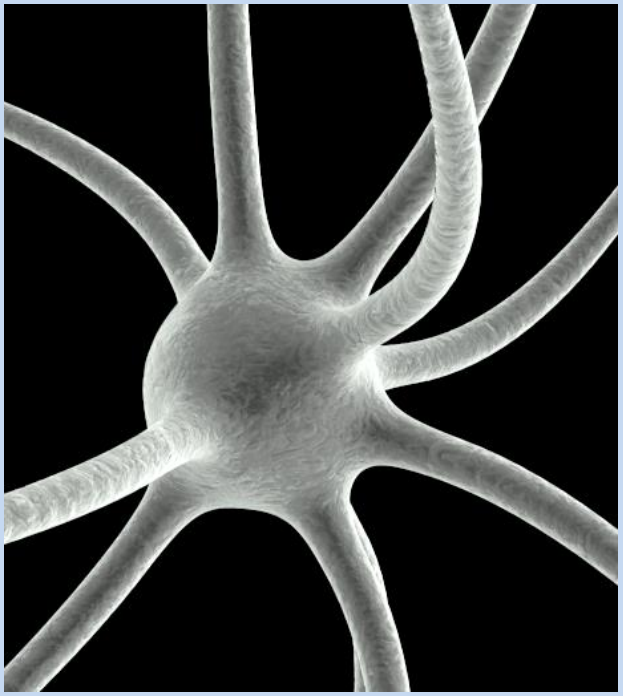






Tree curve model under 20kg of tensile stress

Tree-curve fillets in notches reduces stress concentrations over quarter-circle fillets by a whopping **57%!**



Neuron

Moose antler

Leaf

There are notches everywhere, in everything humans make!

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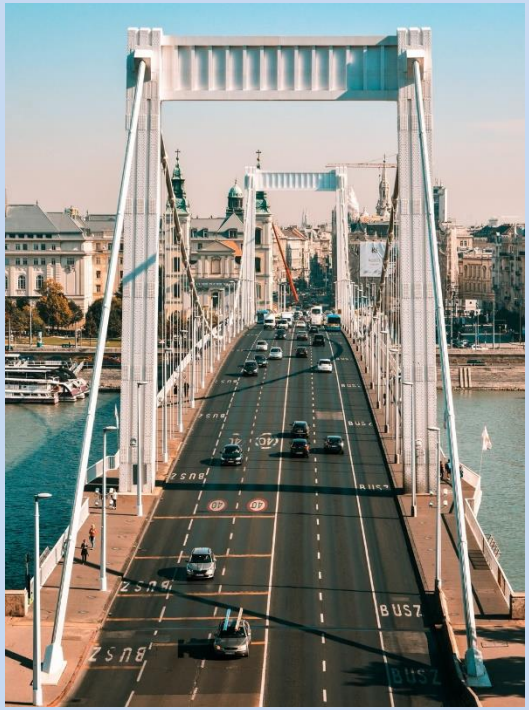
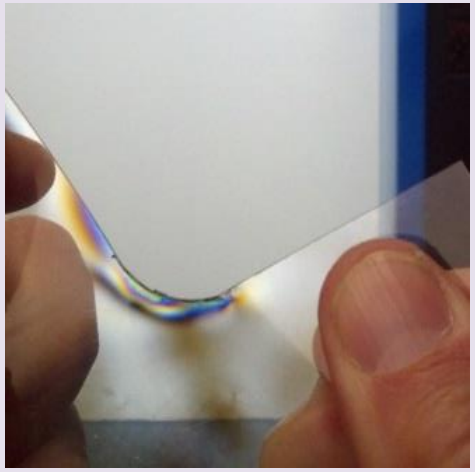


On Measurement

- Graphic “pictorial” measurement is intuitive and instantaneous
- Can also numerically quantify the differences in different ways (counting dark lines, measuring area with graph paper)
- Can standardize force applied using a fish scale



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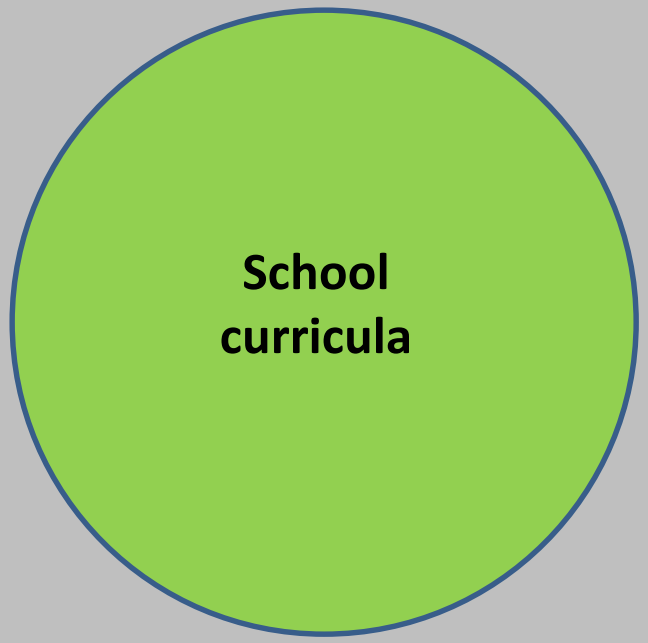
- We've learned about core physical forces and principles structural engineers use in their work.
- We've used these principles to understand a variety of everyday phenomena, from cracks in the sidewalk to human-made structures to how trees in the schoolyard work.
- Students have experienced first-hand how organisms like trees can teach us ways to improve the safety of our buildings, bridges, etc.


Imagine feeling like this…


….while doing this.

Schools



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- ✓ **Conveys the process of bio-inspired innovation** to students, by providing examples of how the natural world can inspire innovative solutions to human challenges

- ✓ Covers fundamental STEM content and meets educational standards, facilitating **the integration of environmental education**, sustainability, and design innovation **into everyday school learning.**

That’s how we transform the world through education!

Sam Stier
Director, The Center for Learning With Nature
samstier@gmail.com
www.LearningWithNature.org

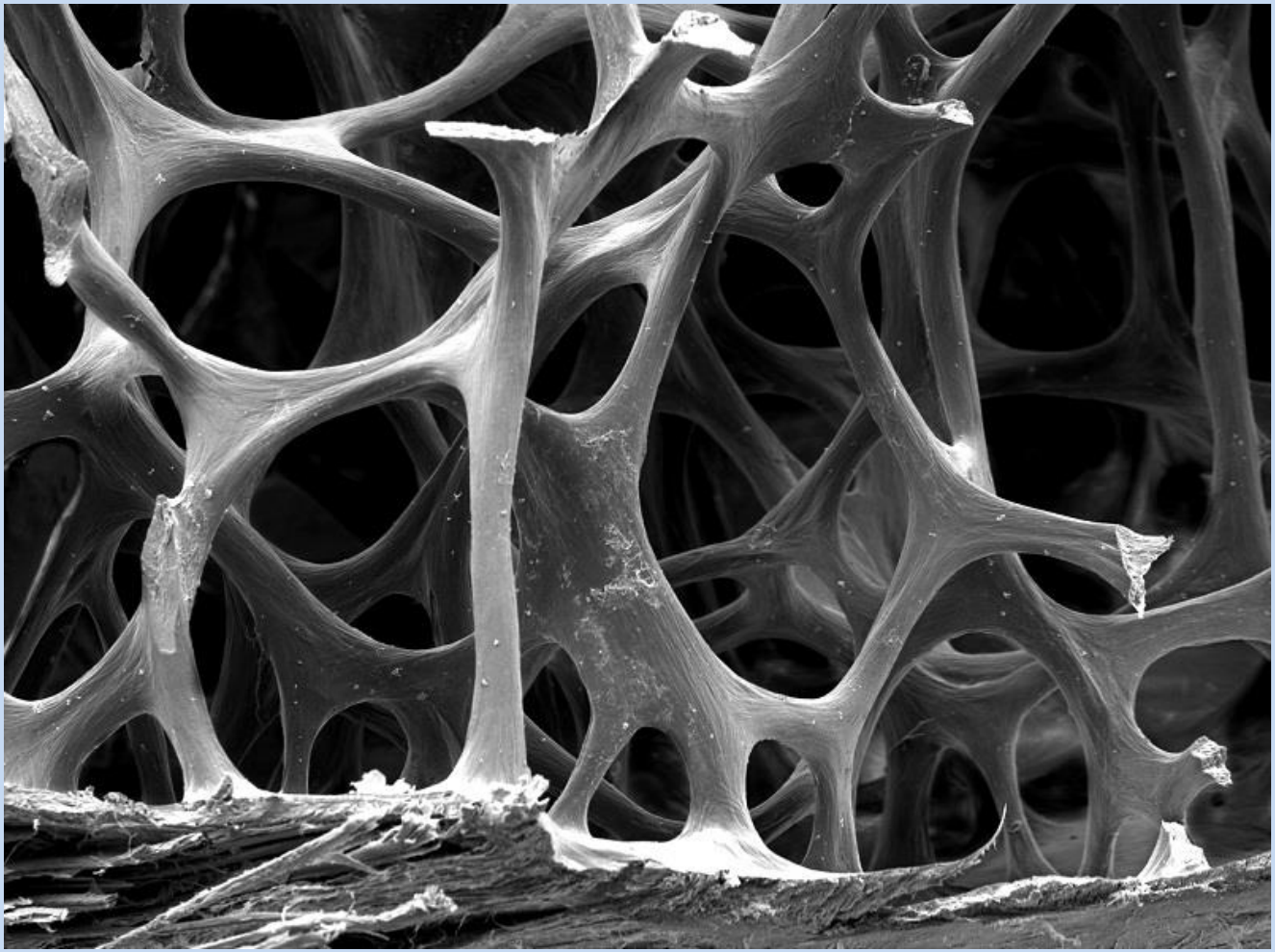
The drama continues…

Trees add material where stress occurs

Bones also add material where stress occurs

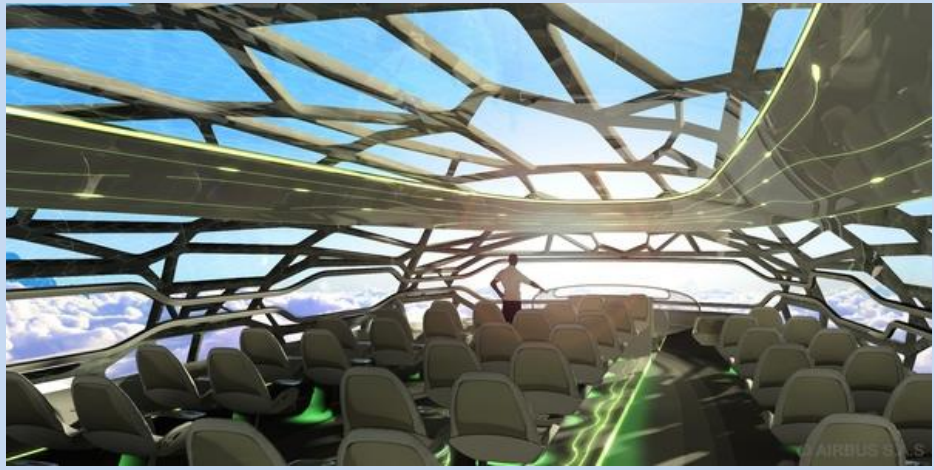
Listen to your bones grow!

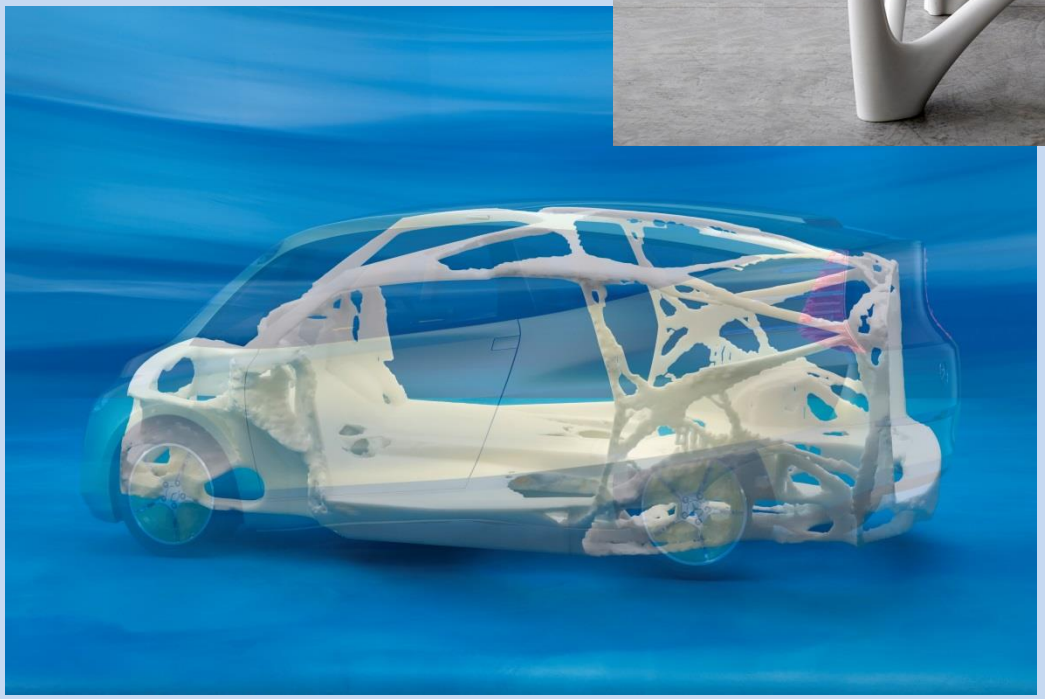
Unnecessary material weight is often poor design in Nature



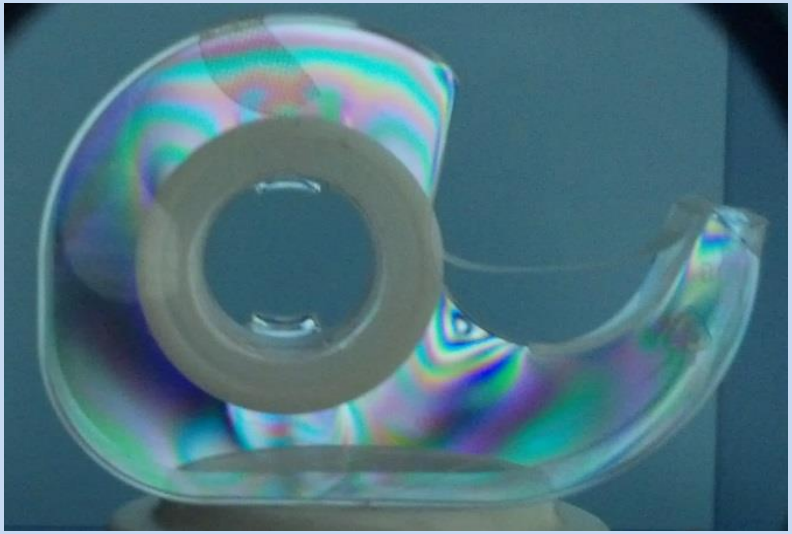
Bones **remove** material where stress is relatively slight

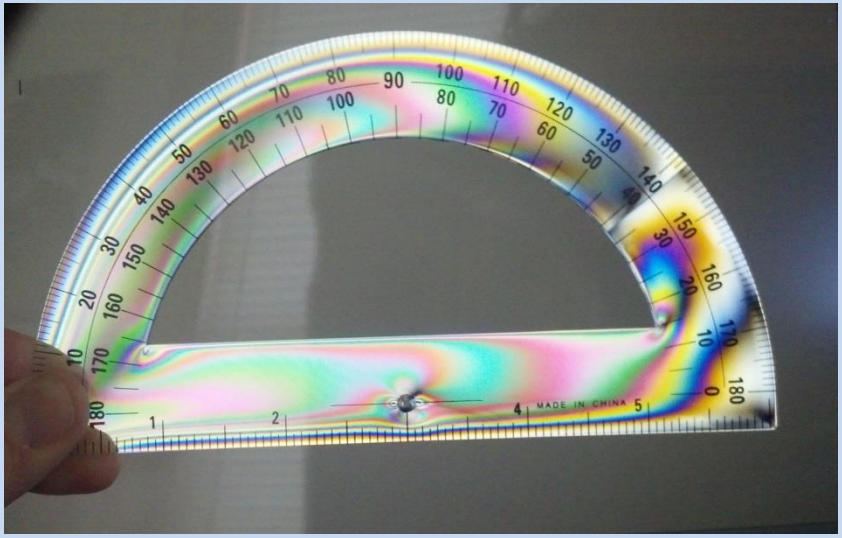
Material use in our designs is an issue too, for many reasons

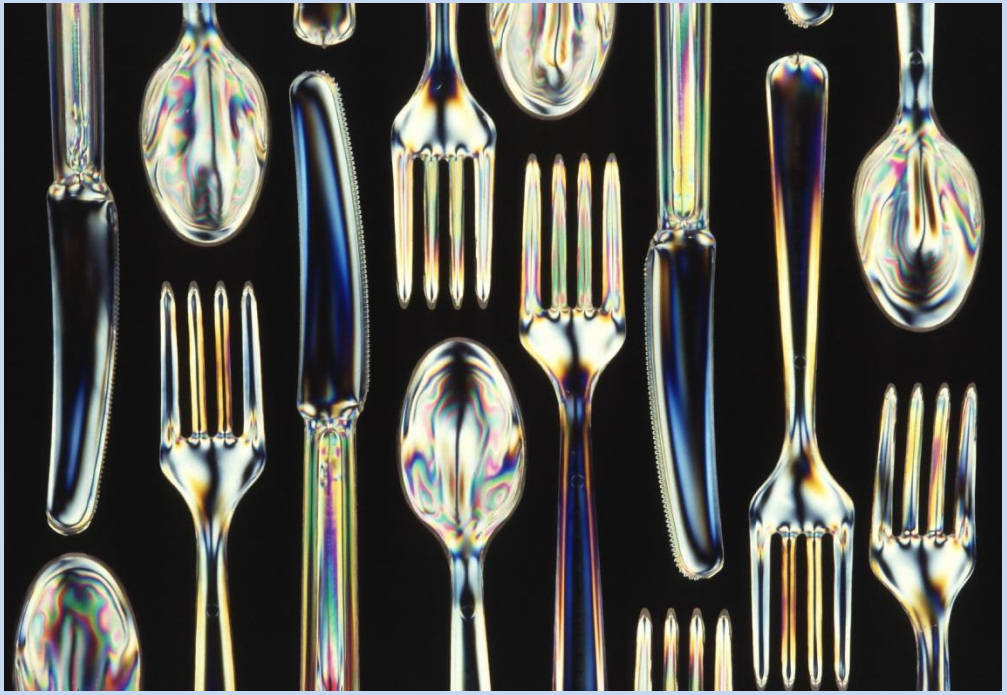


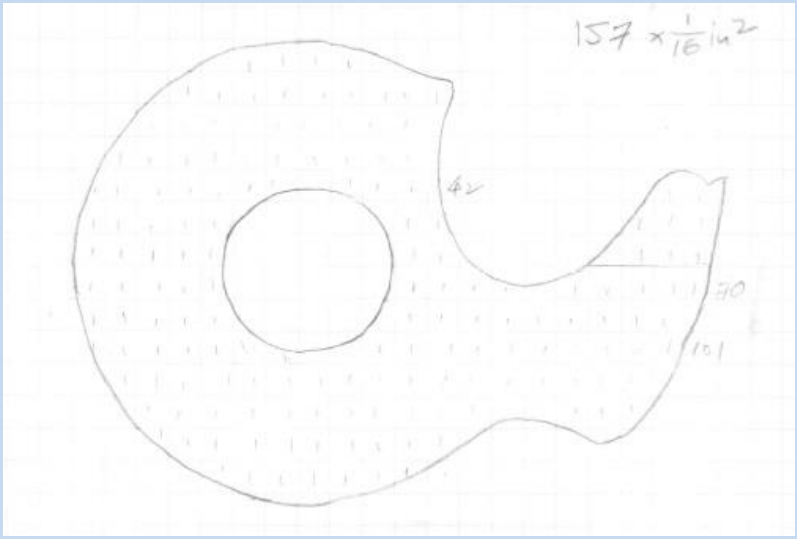


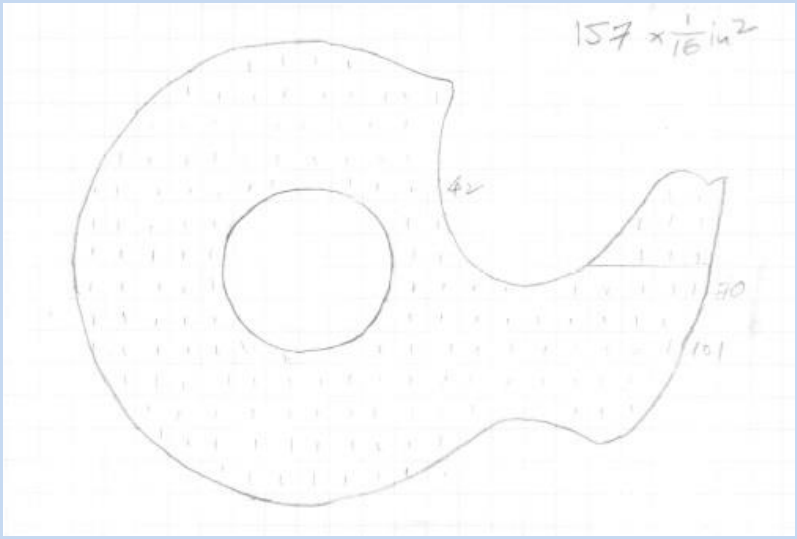
Altair

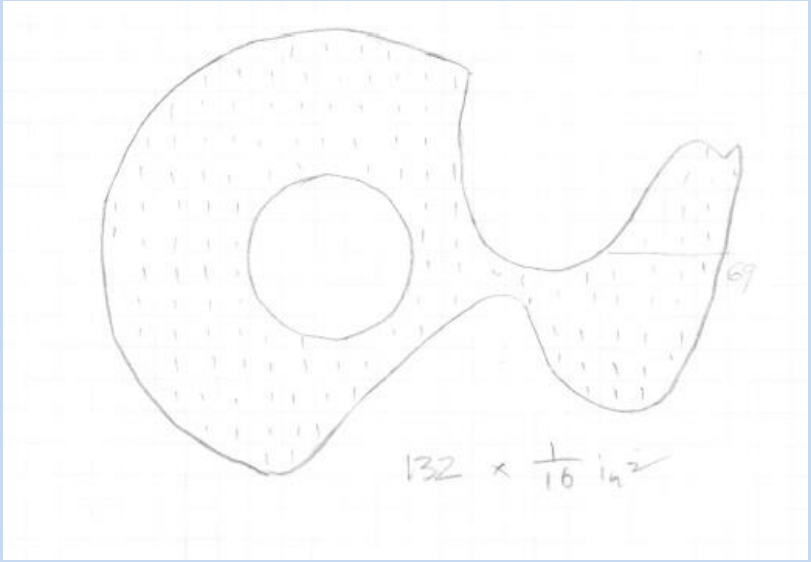



MADE IN CHINA




157 × 1/16 in²
4 in
10
10.1


157 × 1/16 in²
4.2
7.0
10.1


6.9
132 × 1/10 in²