The Concord Consortium

InfraMation 2012

The Largest Infrared Camera-Users Conference in the World

# Teaching Science with IR Imaging

Charles Xie

Infrared YouTube, http://energy.concord.org/ir

Sponsored by: itc INFRARED TRAINING CENTER, FLIR, NSF National Science Foundation WHERE DISCOVERIES BEGIN

# Outline

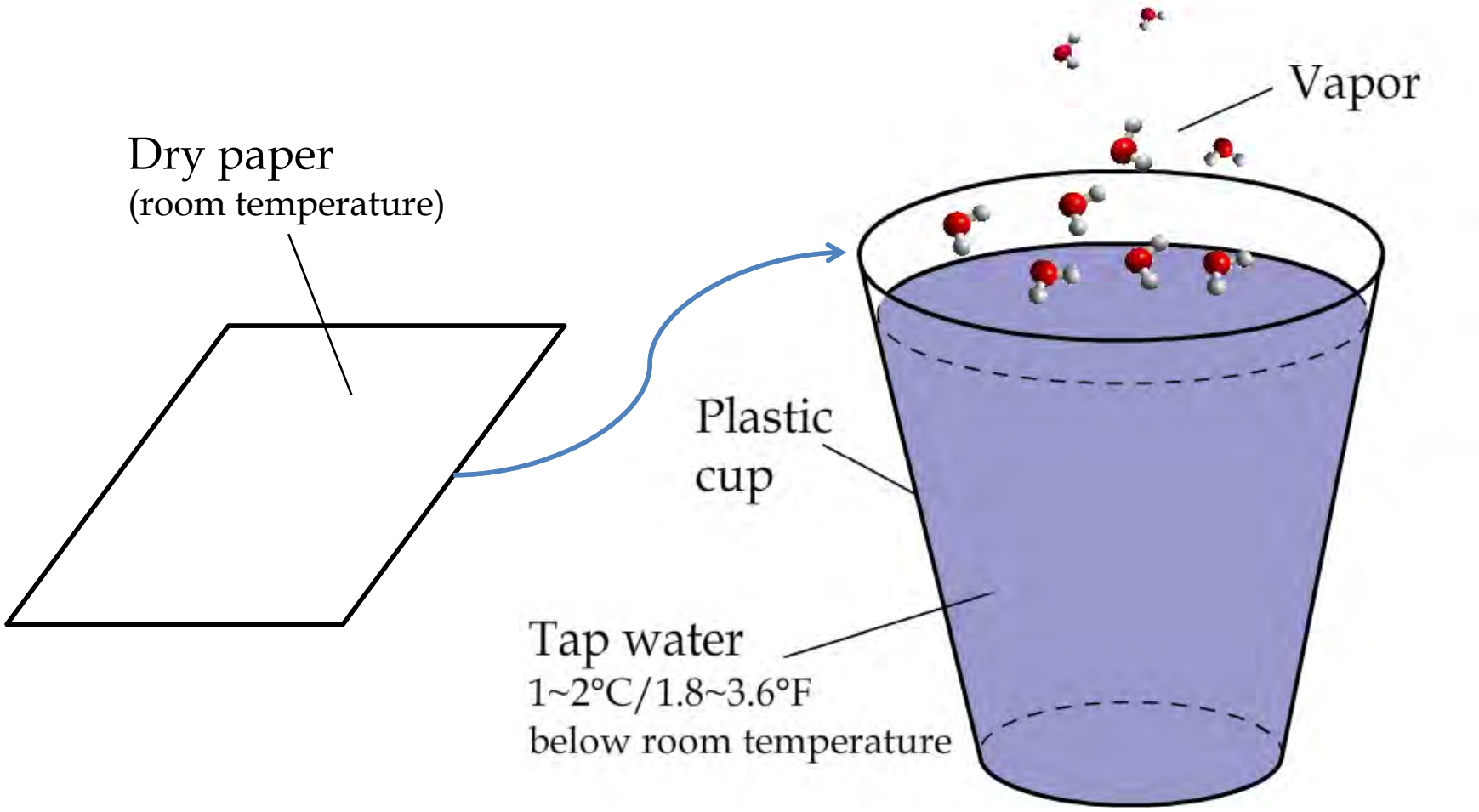
I. Science on a piece of paper
II. An education perspective of IR imaging
III. A science perspective of educational imaging
IV. More science experiments
V. People's reactions
VI. An education market for IR cameras?
VII. Opportunities for actions
VIII. Acknowledgments

The Concord Consortium

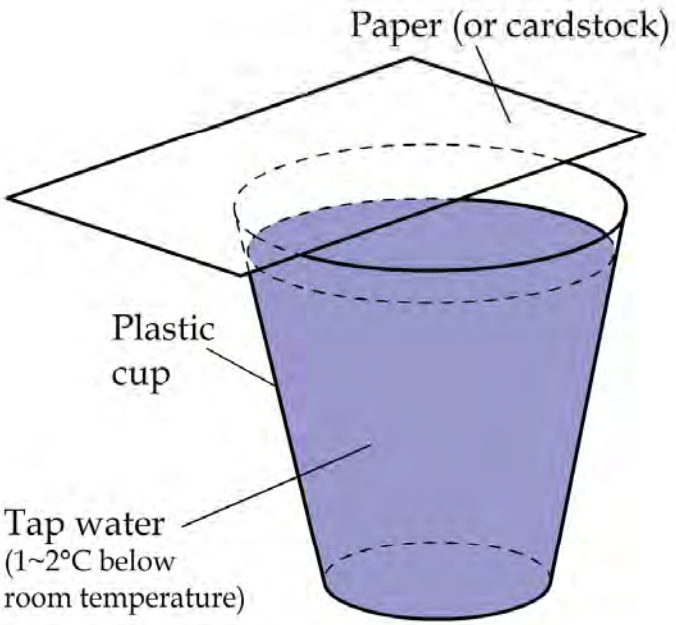
A non-profit organization realizing the educational promise of technology

http://concord.org

# Science on a piece of paper



# Put paper on top of water…

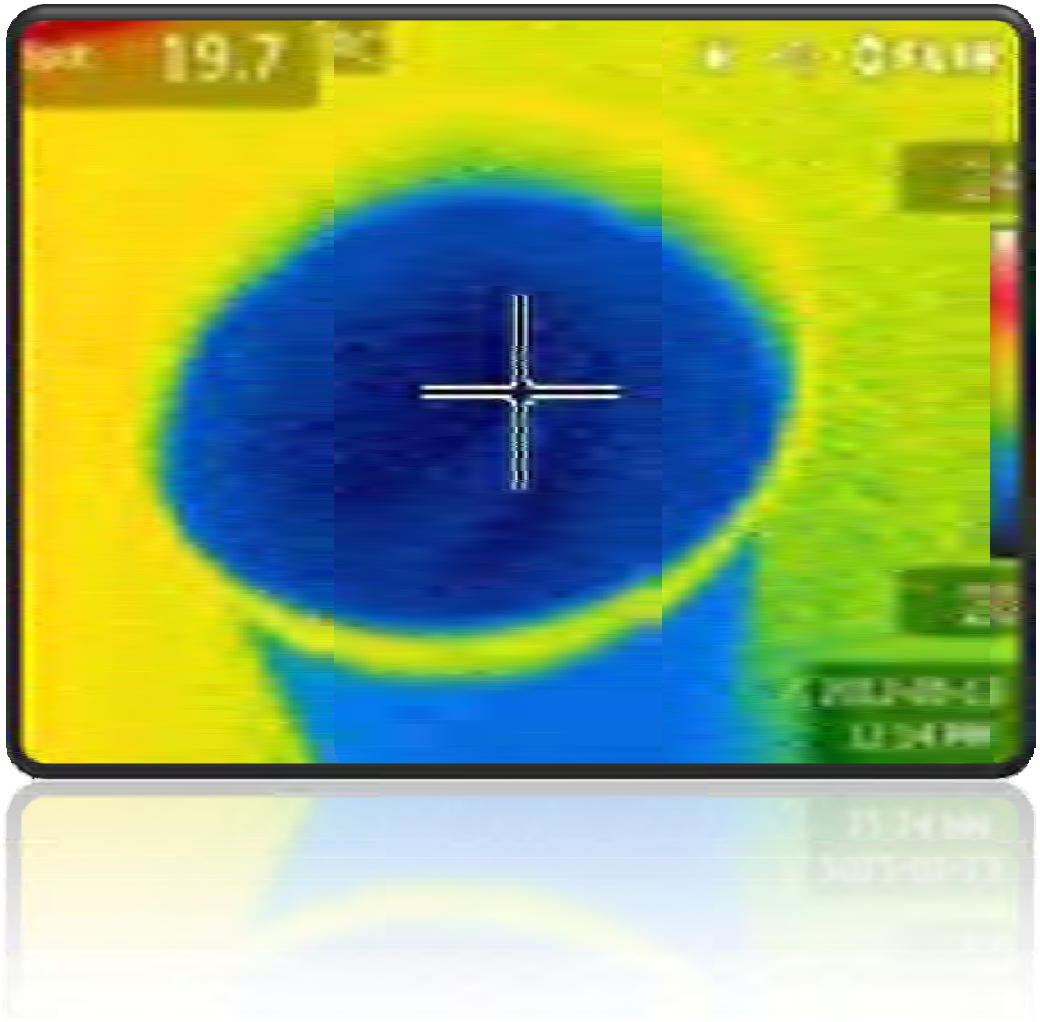



# What an IR camera sees

Camera:
FLIR E30bx

Emissivity:
0.95

Auto rescaling:
On



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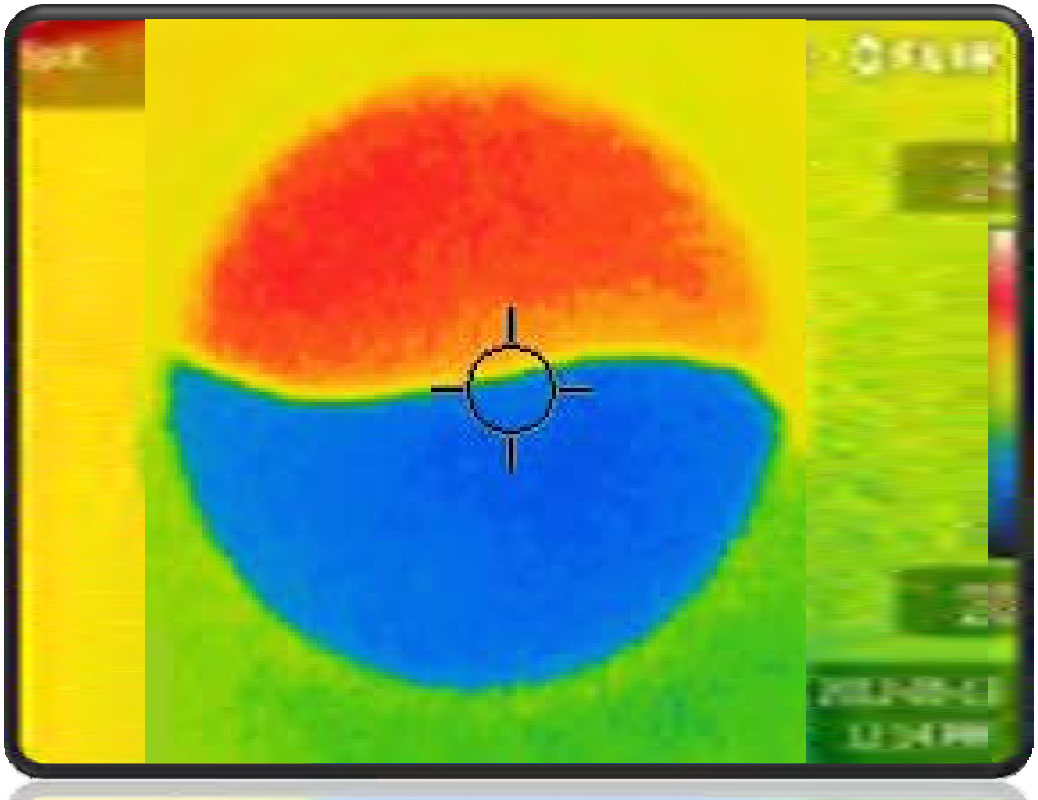
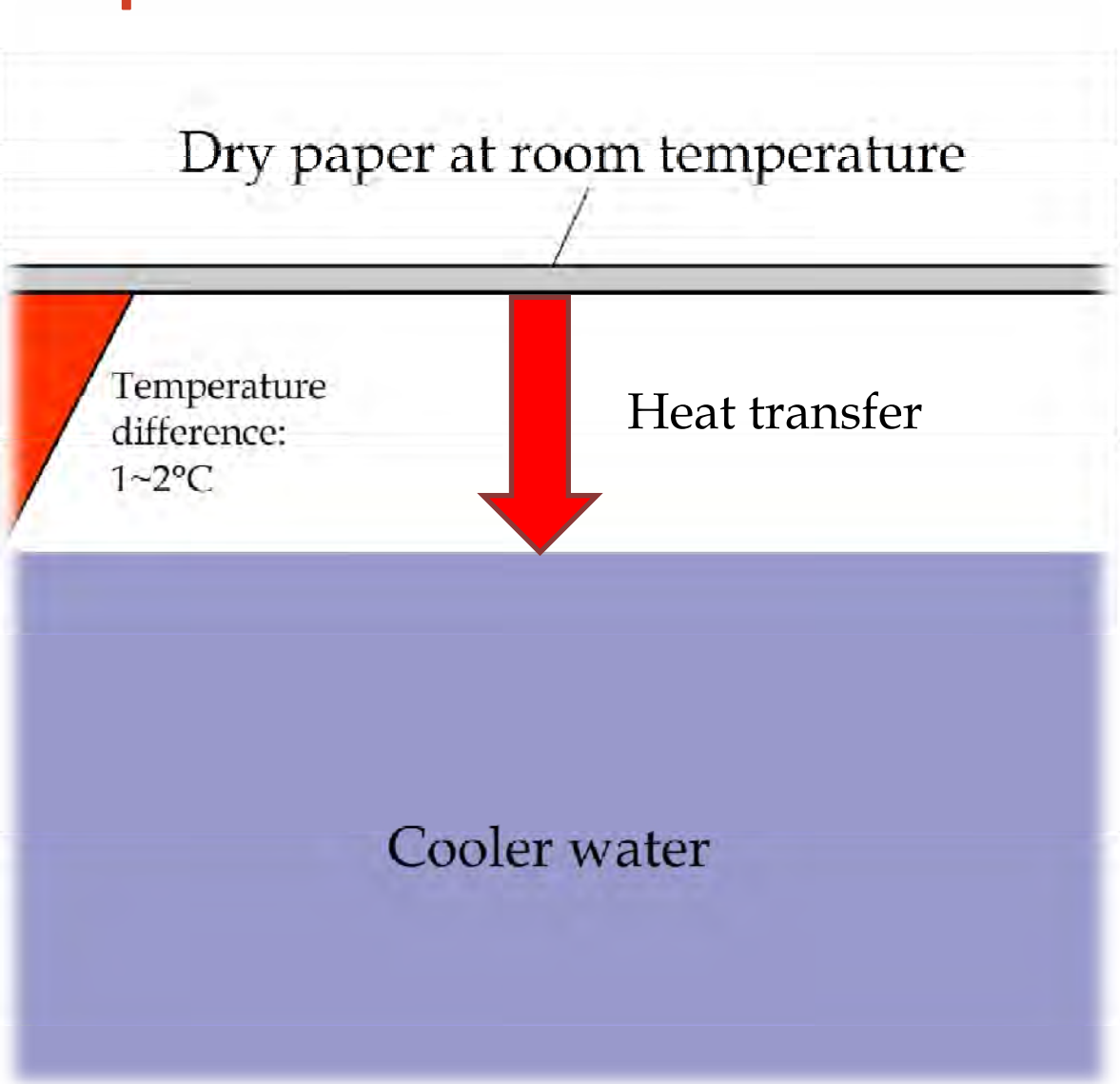
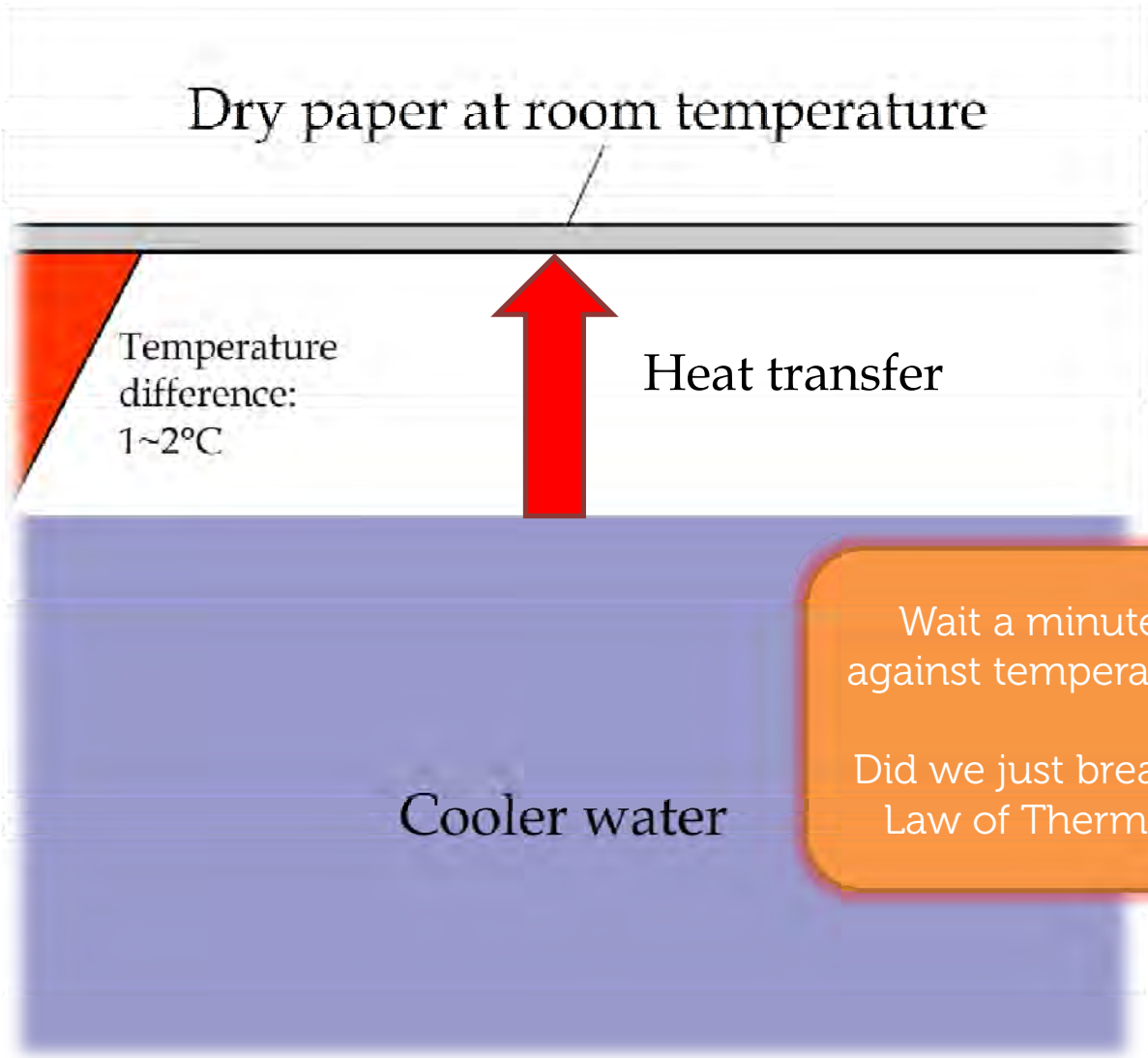


See the PEPSI logo from a cup of PEPSI drink through an IR camera!

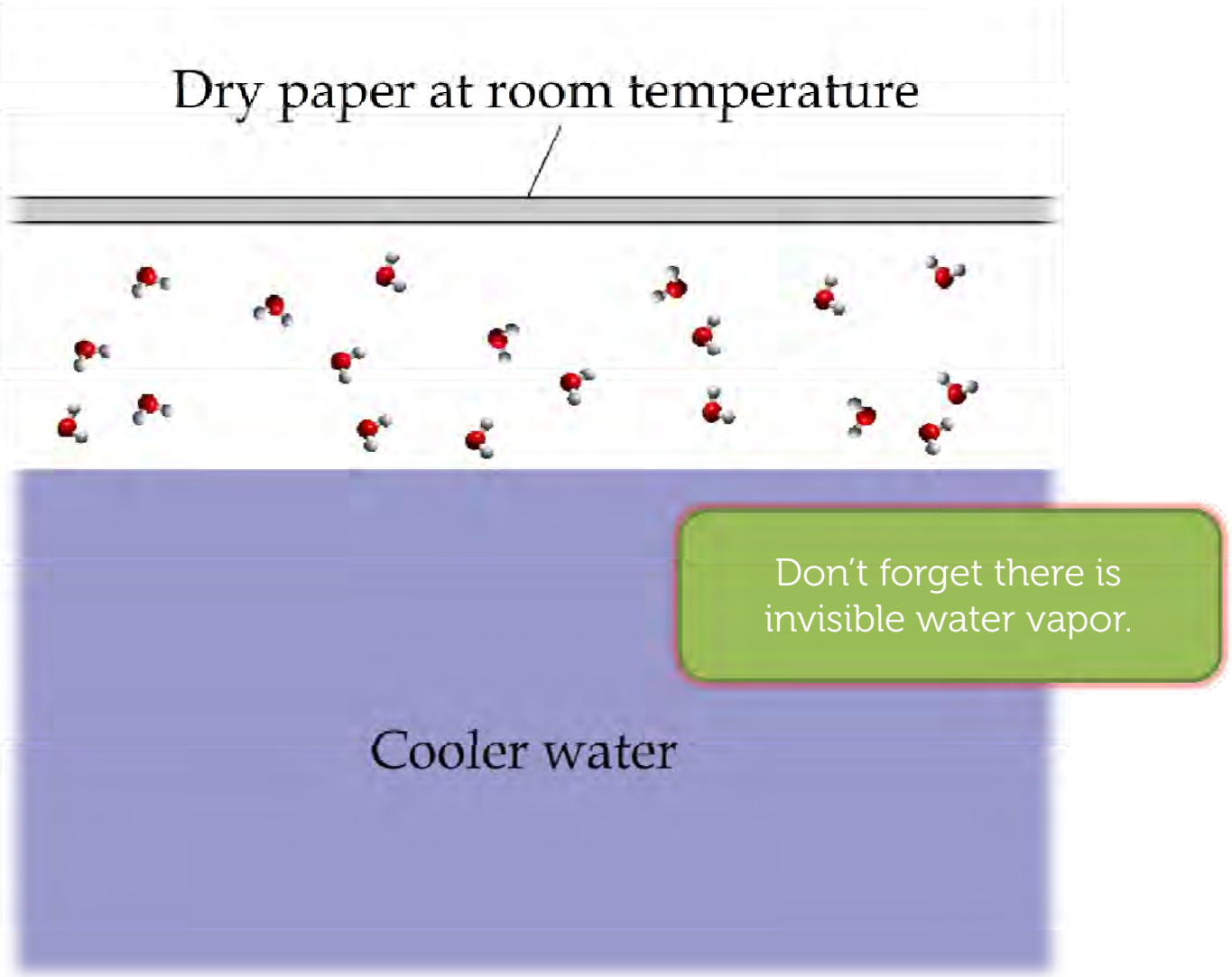
# What I expected…



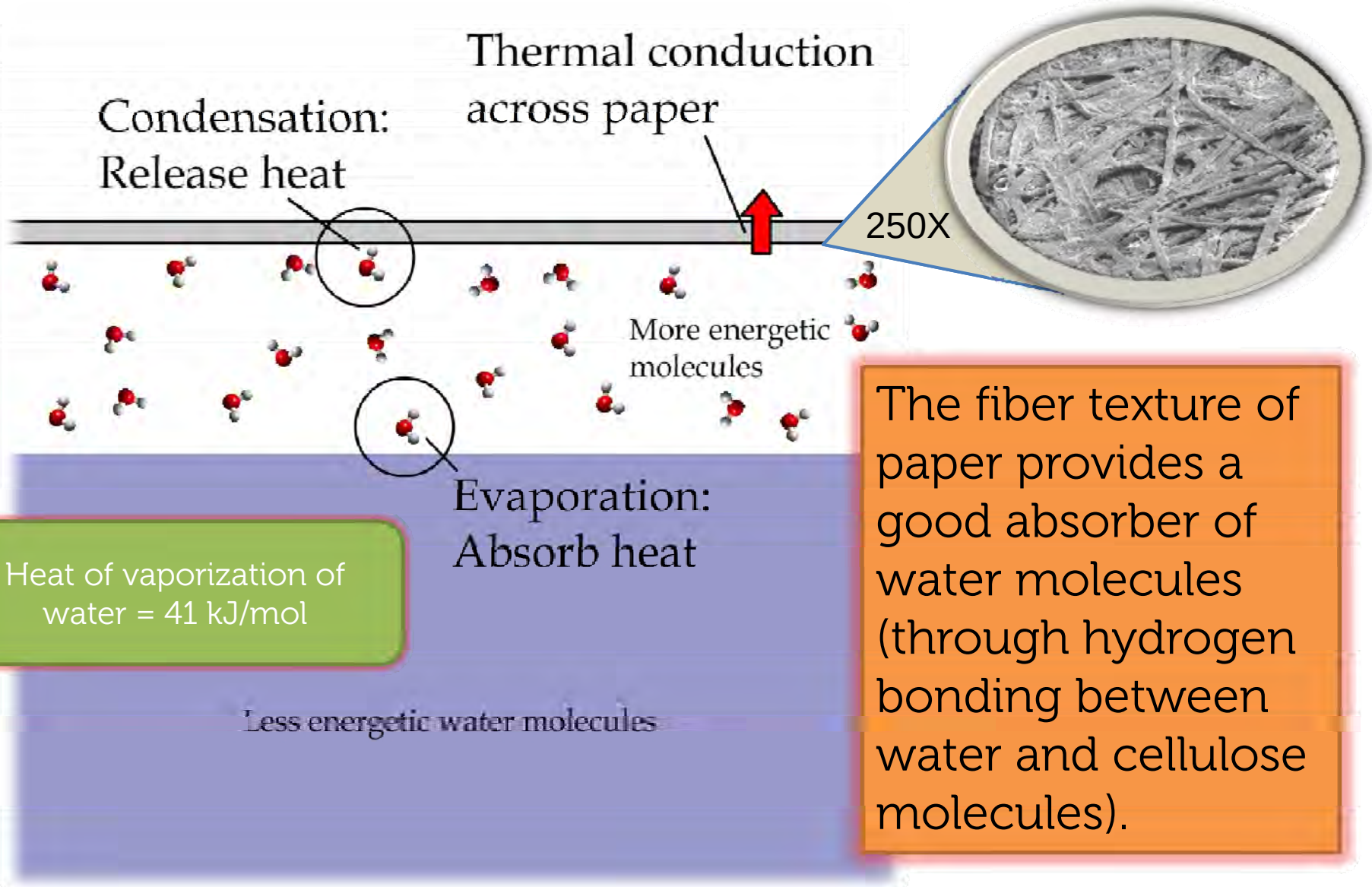
# What actually happened…



# What's going on?



# Heat released in water absorption



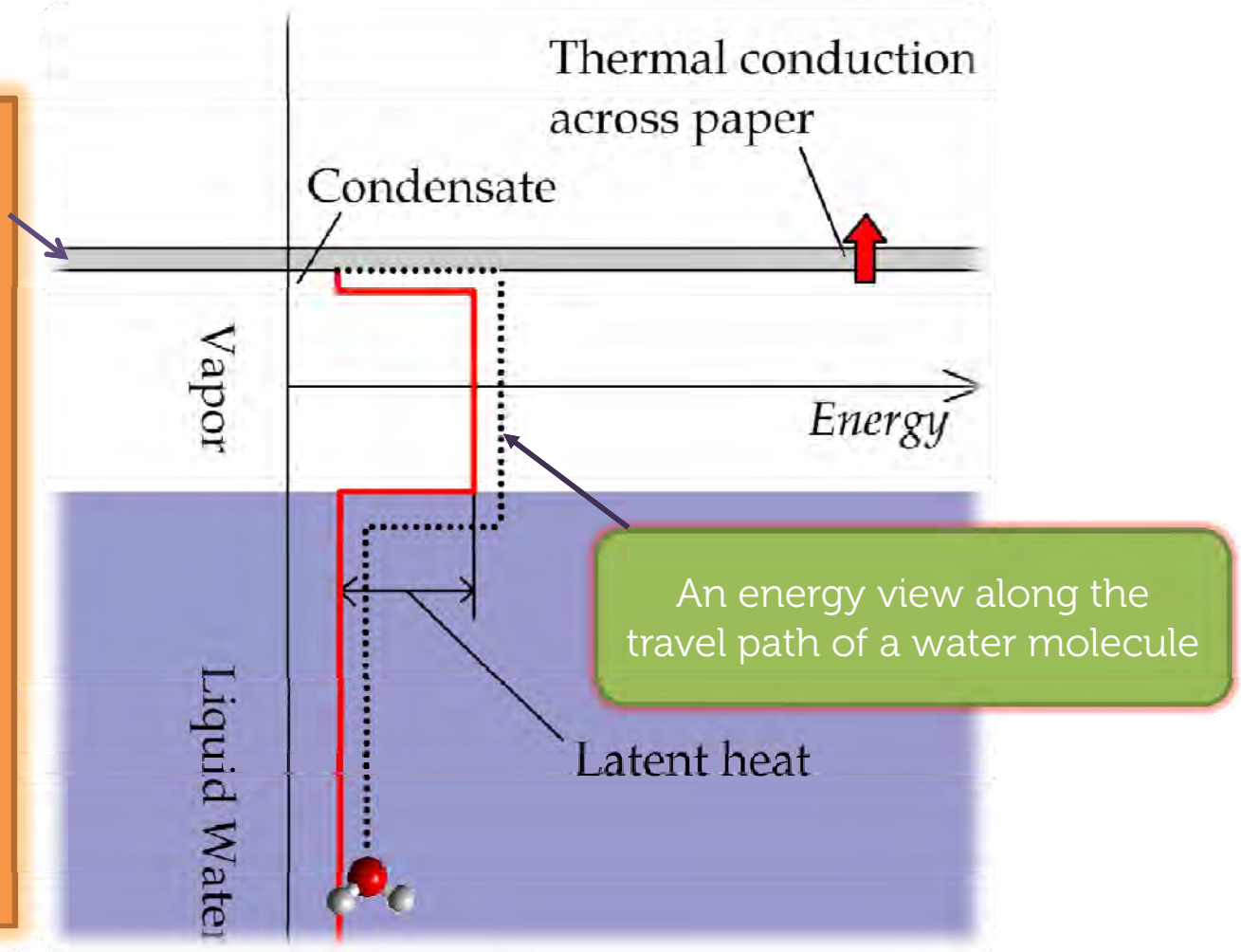

Heat of vaporization of water = 41 kJ/mol

The fiber texture of paper provides a good absorber of water molecules (through hydrogen bonding between water and cellulose molecules).

# Heat transfer through two phase changes occurring at different places

The paper recovers the heat lost in evaporation.

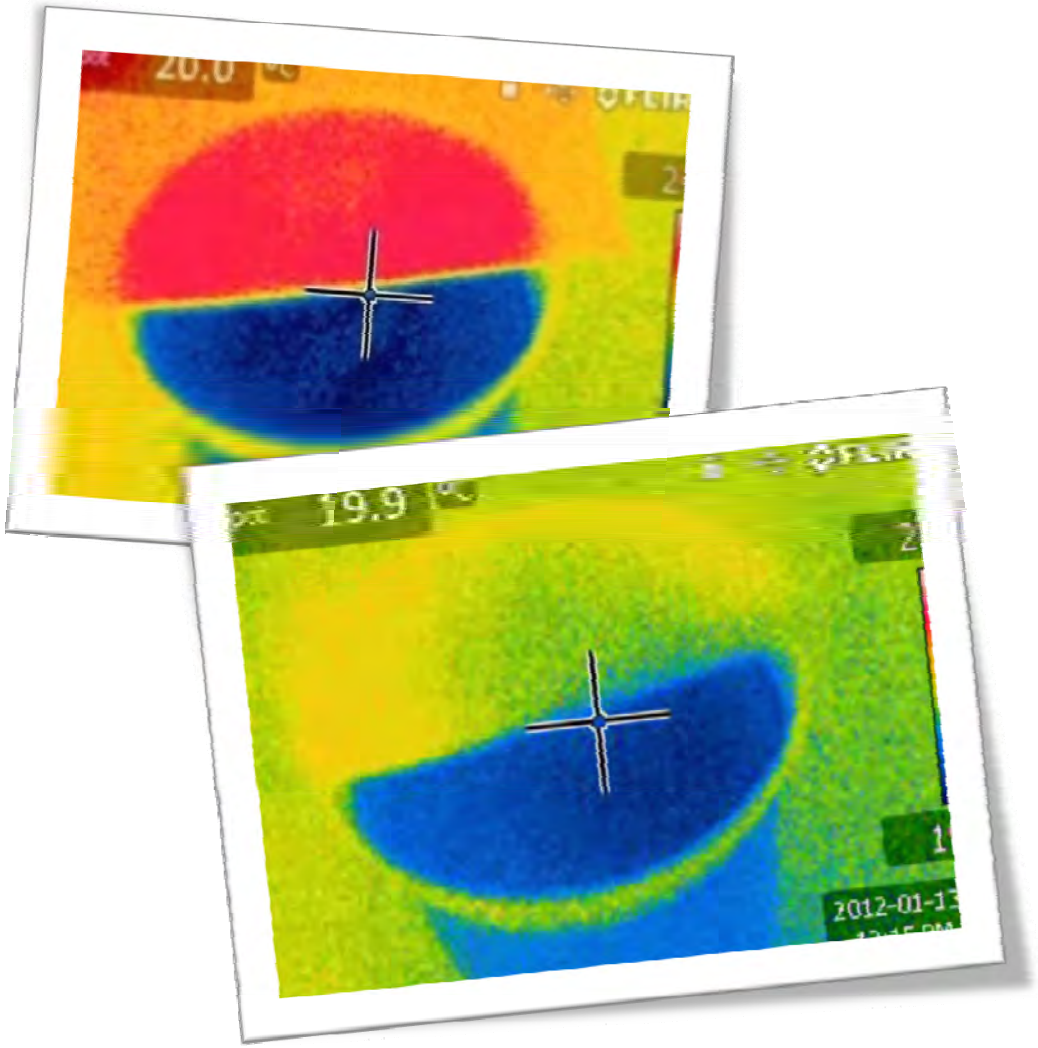
$H_2O$ acts like an energy carrier to transfer heat from water to paper.



# A cute story, isn't it? But wait!

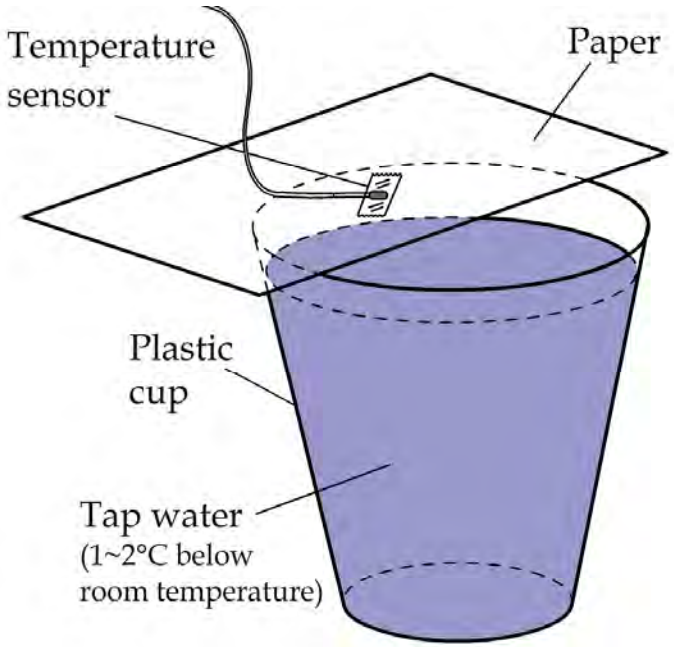
A new mystery?

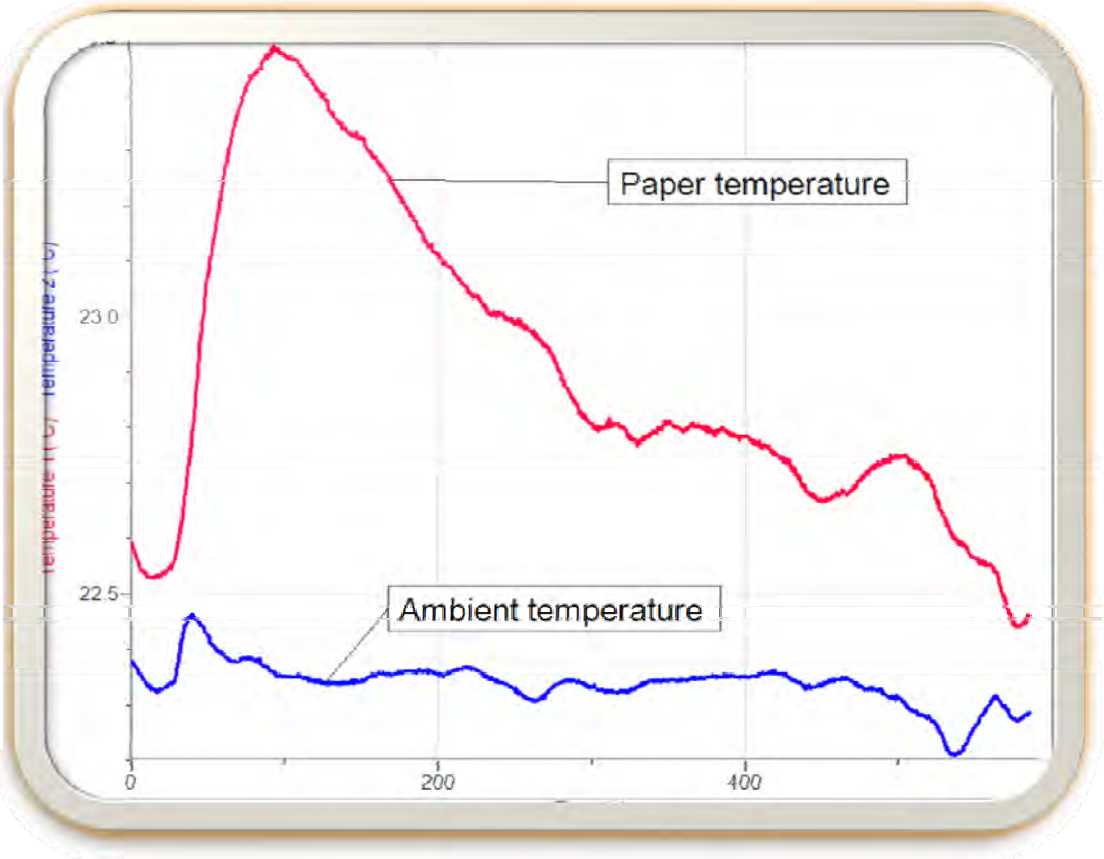
Why did the condensation heating diminish in the video?



# Results from a data logger using a temperature sensor

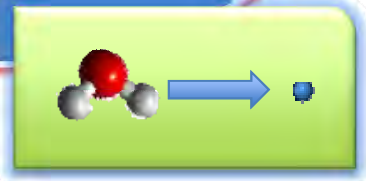
Recorded on 10/22/2012



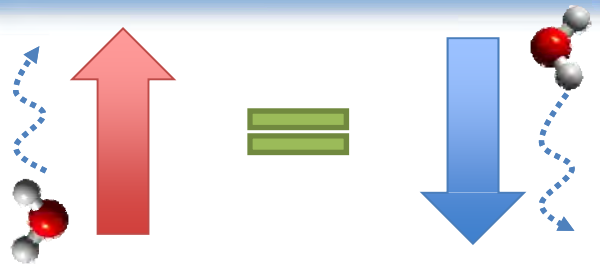



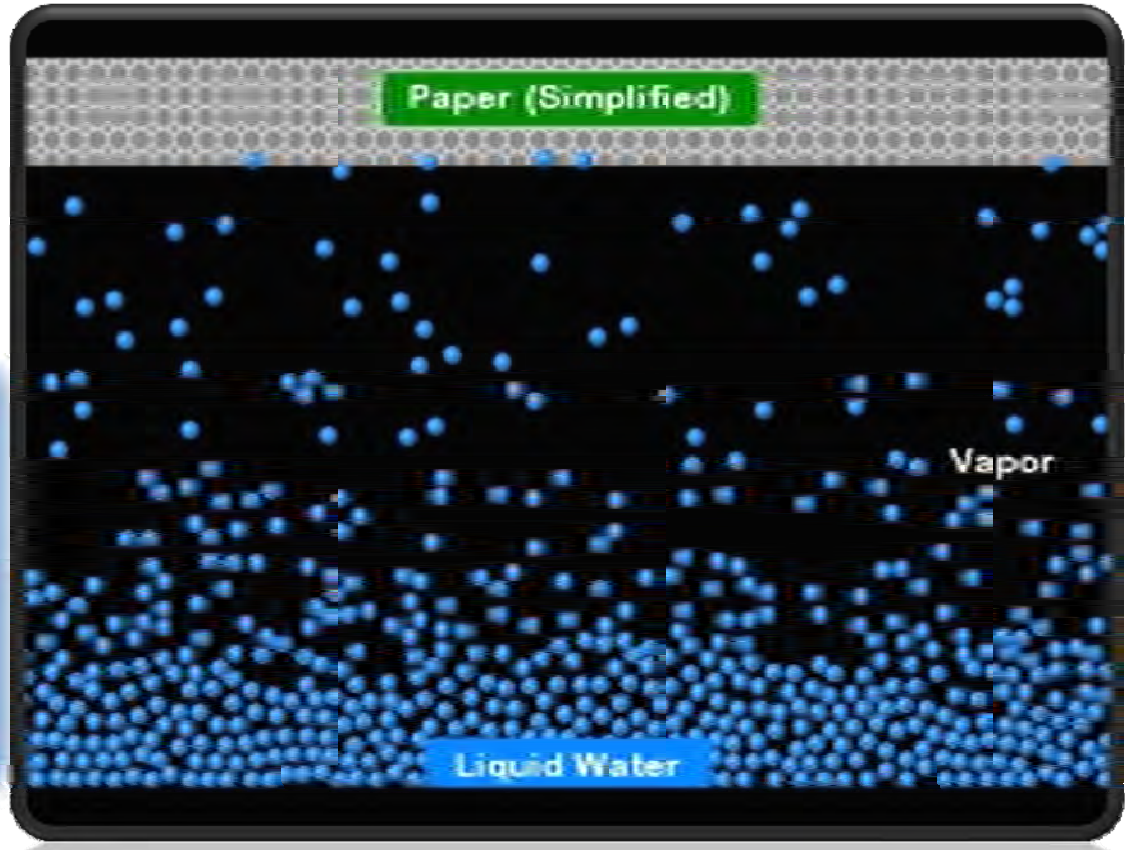
# Dynamic equilibrium

Molecular simulation



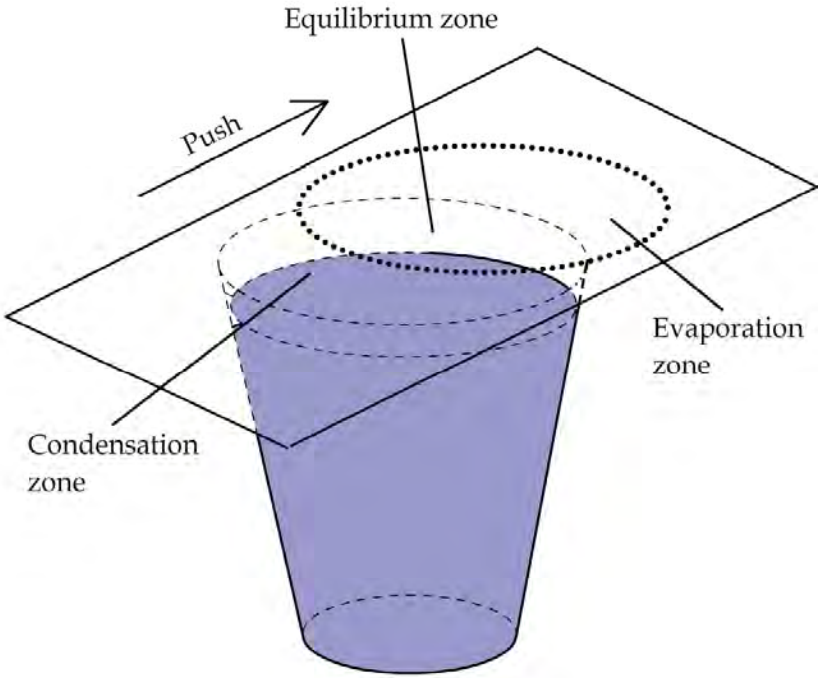
When the rate of condensation onto the paper equals the rate of evaporation from the paper…

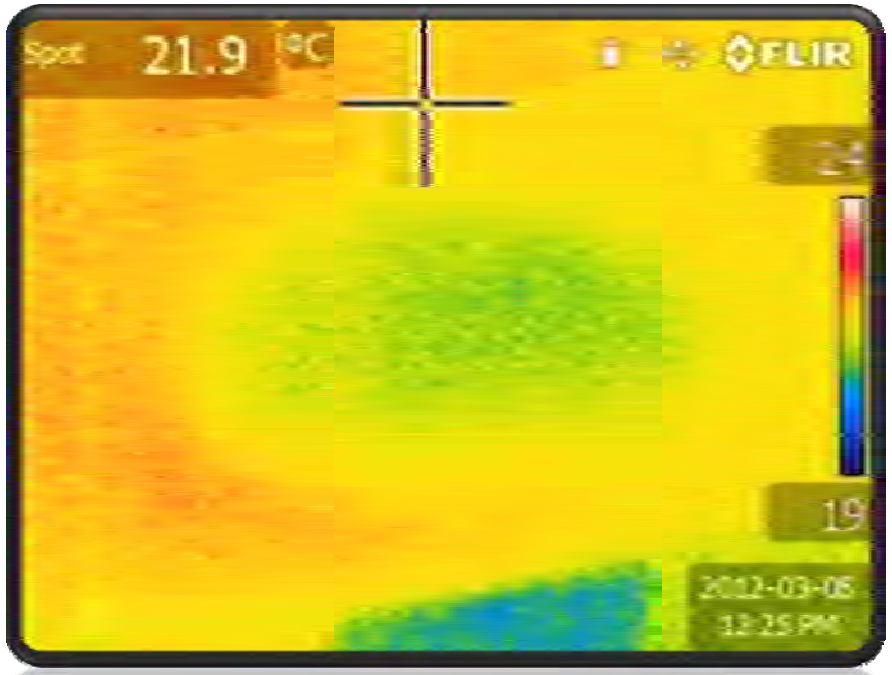




# Breaking dynamic equilibrium

How can we be so sure that there is a dynamic equilibrium? Because we can break it – all you need to do is to push the paper a bit.

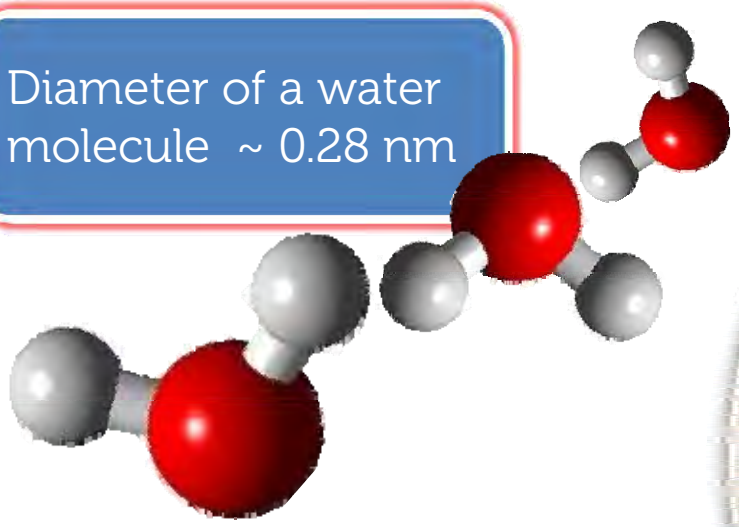


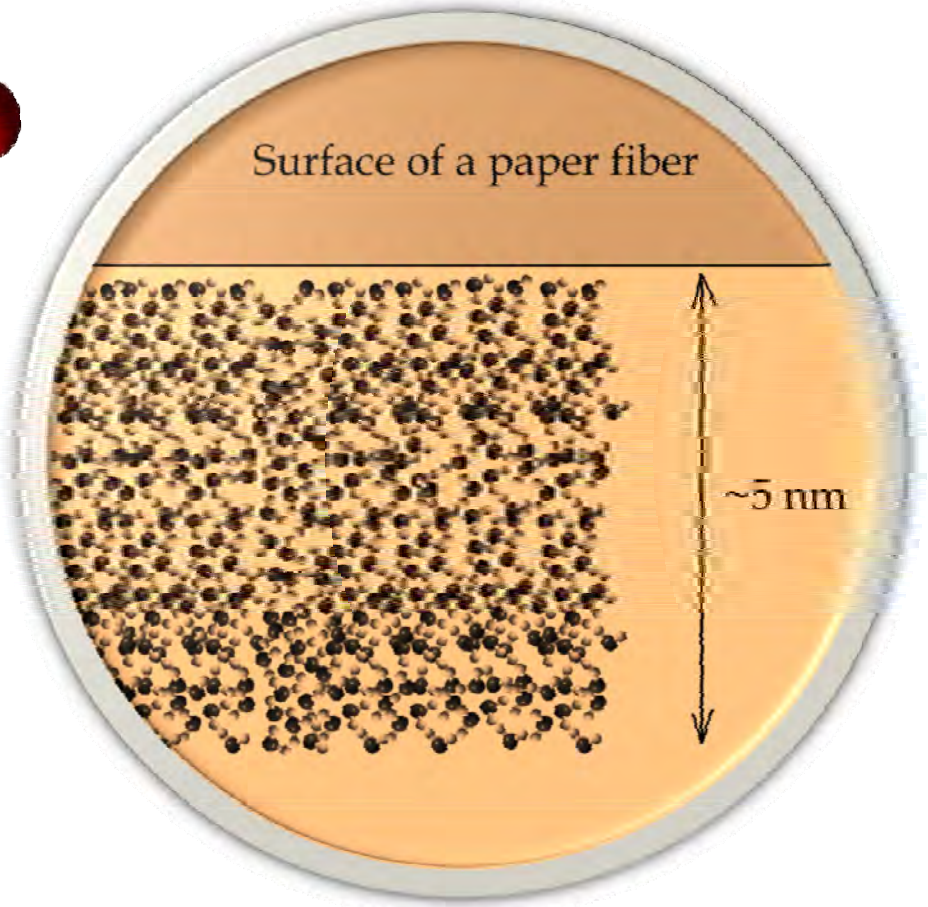




Evaporative cooling and condensation heating take place simultaneously on the same piece of paper.

# A signal from the nanoscale world

Diameter of a water molecule ~ 0.28 nm



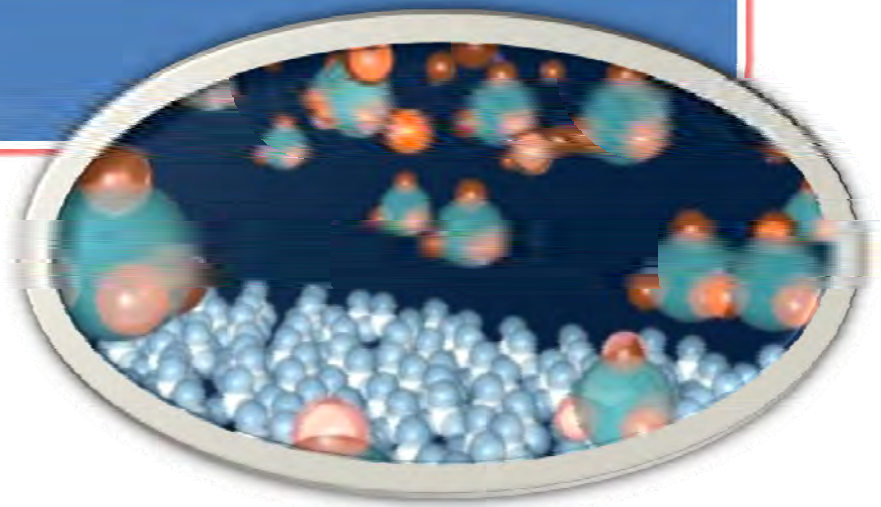



Deposition rate <5 nm/second, i.e., about 15 layers of $H_2O$ molecules per second is responsible for this heating effect!

How small is a nanometer? A human hair is about 50,000 nanometers in diameter.

# An atomic layer deposition demo that anyone can do

Atomic layer deposition:
The technique to grow microchips, *atom by atom*, for your next computers or phones.



The Centura ALD system, Applied Materials

# Think about what all these things mean

The power in your hand may be greater than you think!

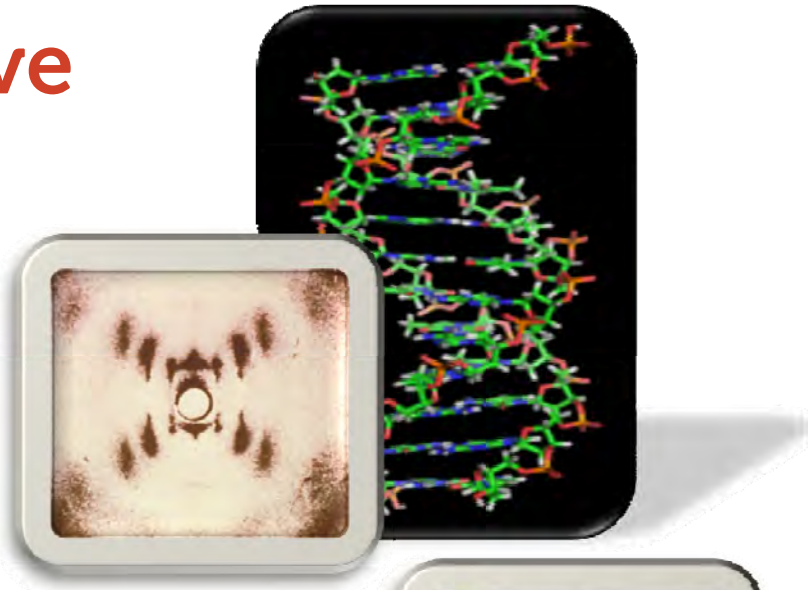
# Think about what all these things mean

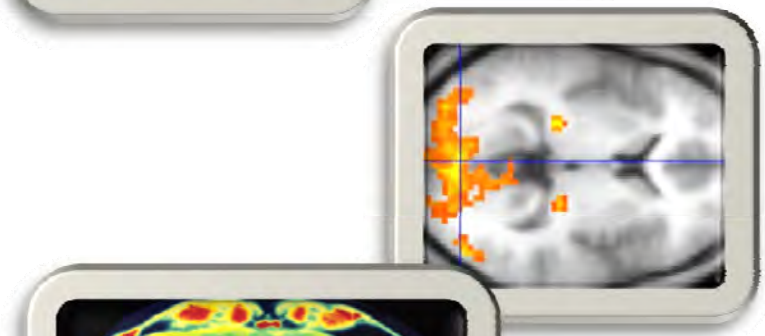
This is an incredibly powerful scientific imaging tool anyone — even children — can use!

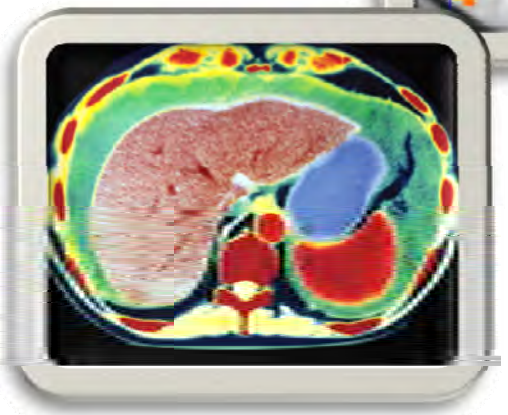
# An education perspective

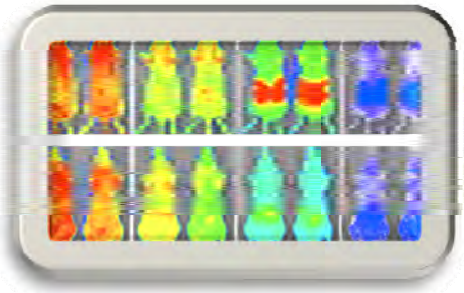
Scientific imaging is central in science.

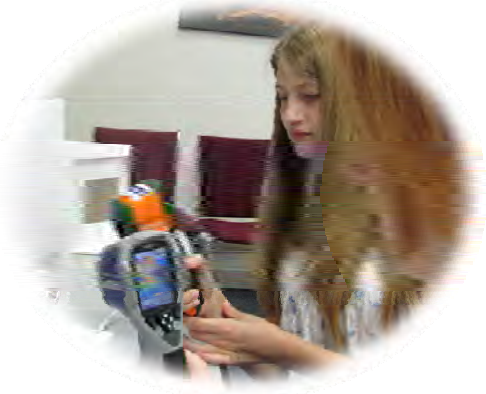
It is important for students to see the REAL thing, not just printed or programmed graphics, because scientific discoveries come from carefully observing the real world.











# A science perspective of educational imaging

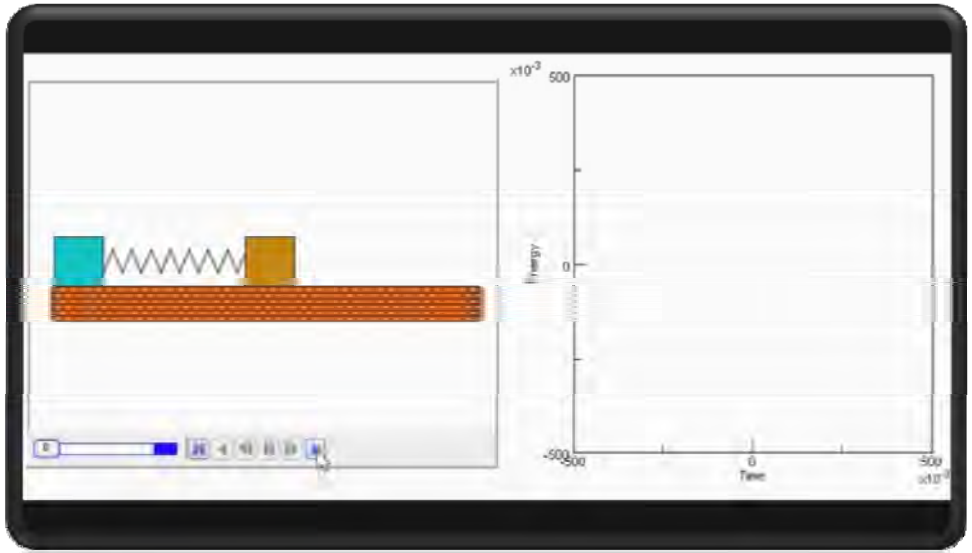
## Desktop remote sensing

Anything that leaves a trace of heat leaves a trace of itself under an IR camera.

Many invisible physical, chemical, and biological processes that absorb or release heat can be visualized, discovered, and investigated.

# Not just seeing thermal energy

Recall a little physics

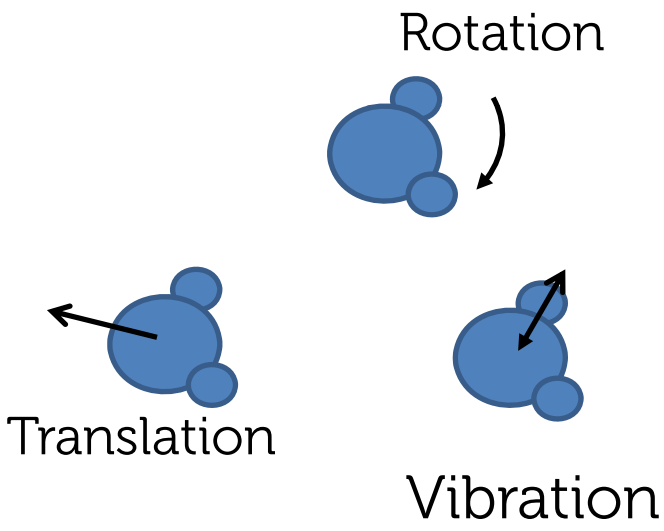


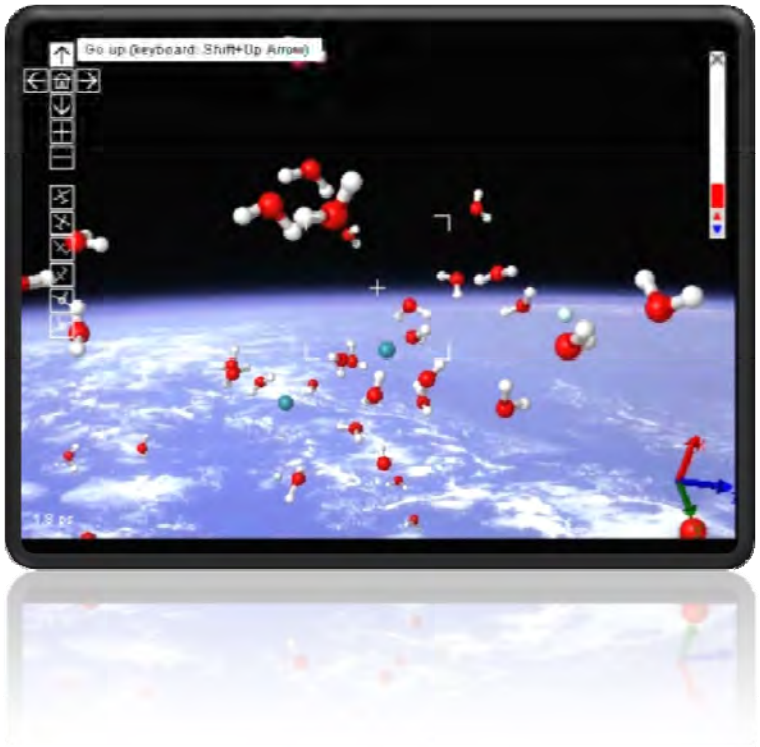
Kinetic Energy + Potential Energy = Total Energy (Constant)

Kinetic energy is a "mirror" of potential energy (as per the Law of Conservation of Energy)

# What really is thermal energy?

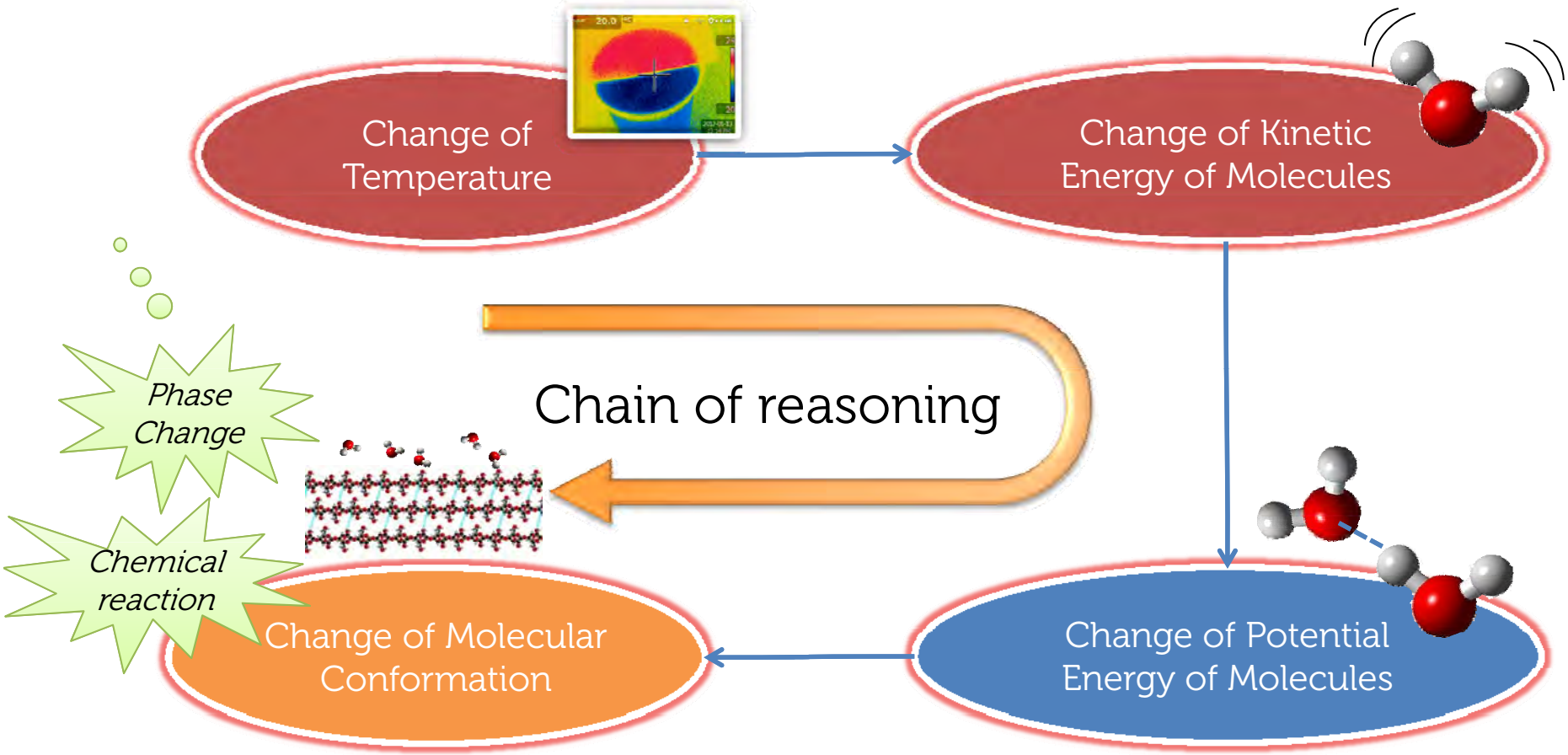
Thermal Energy = Kinetic Energy of Molecules



Thermal energy is a "mirror" of molecular potential energy.

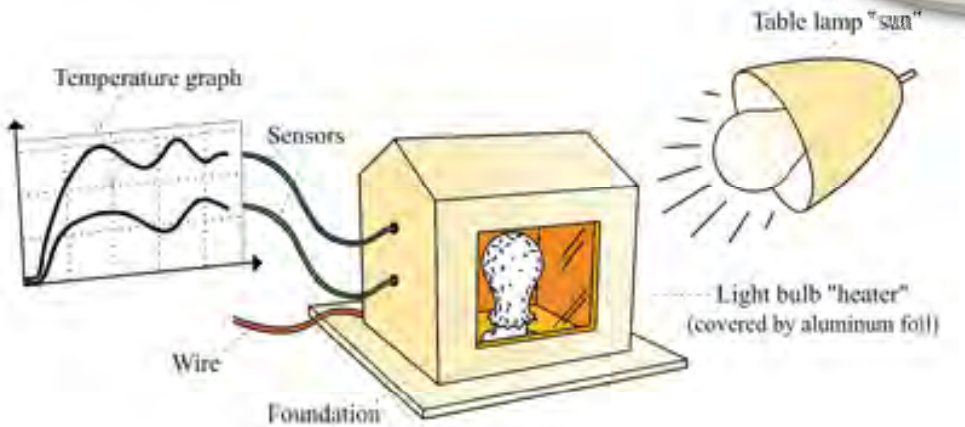
# What is in a thermal image?




Anything that leaves a trace of heat
leaves a trace of itself under an IR camera.

# Why is IR imaging good for education?

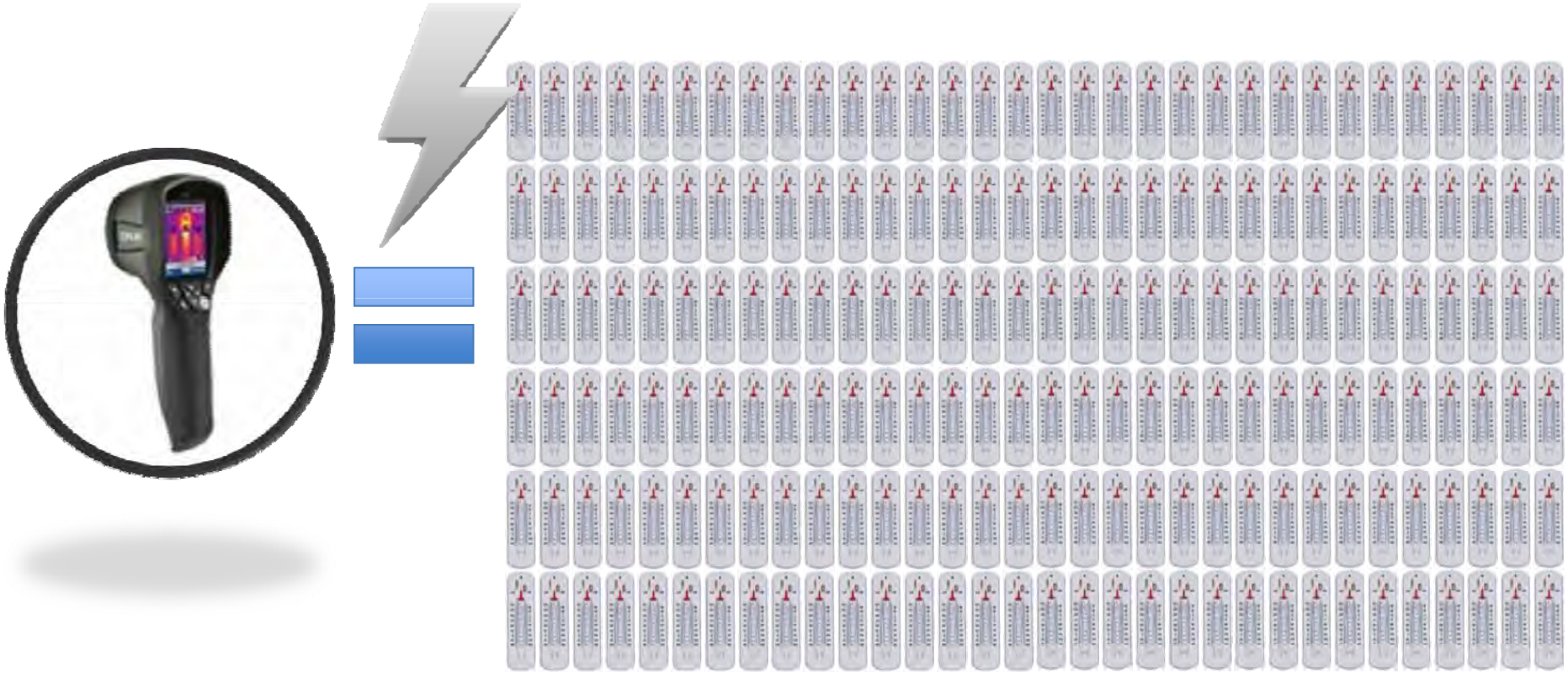
Millions of students have used sensors to learn science through hands-on experiments.



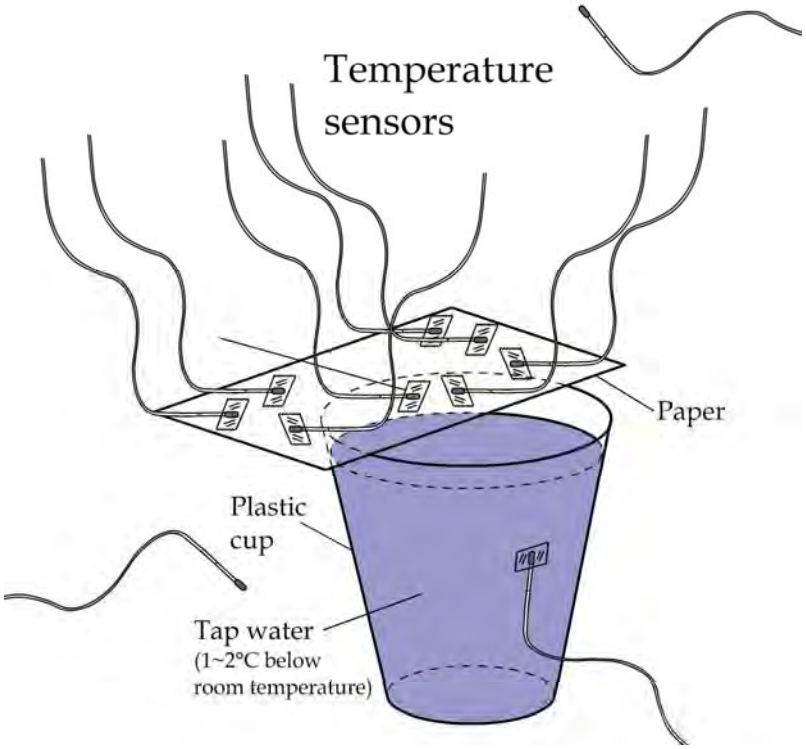

# Why is IR imaging good for education?

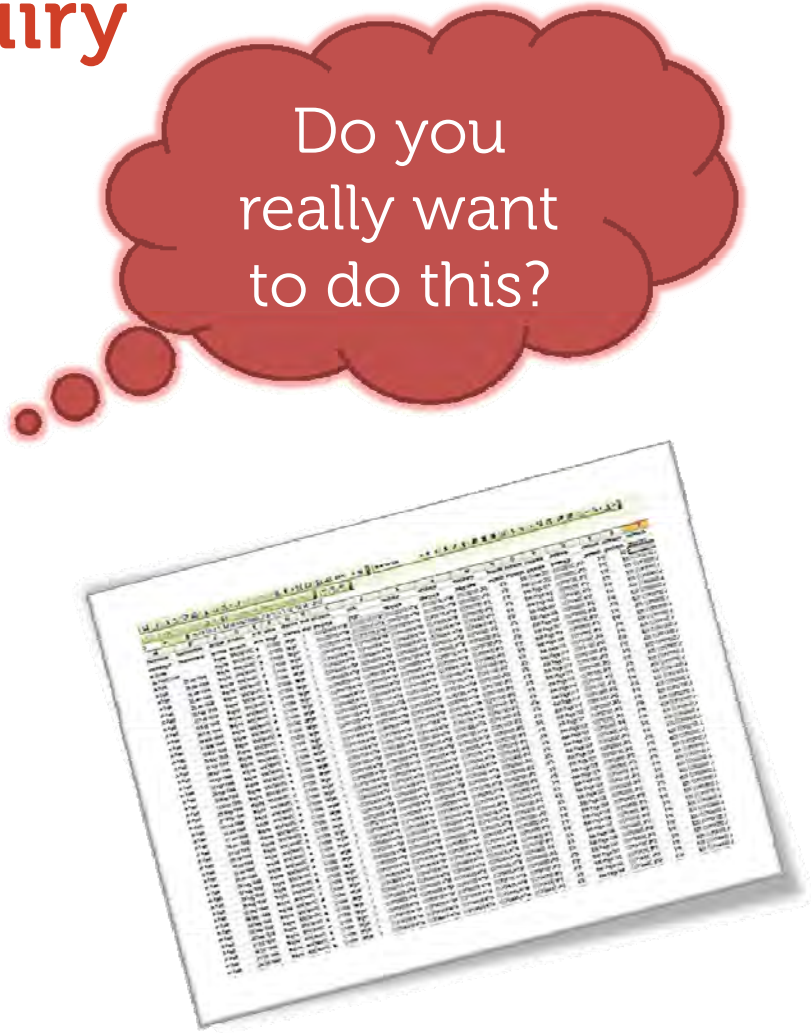
The power of many and parallelism — from one sensor at a time to thousands of sensors at a time

Information acquisition at the speed of light



# Instant scientific inquiry



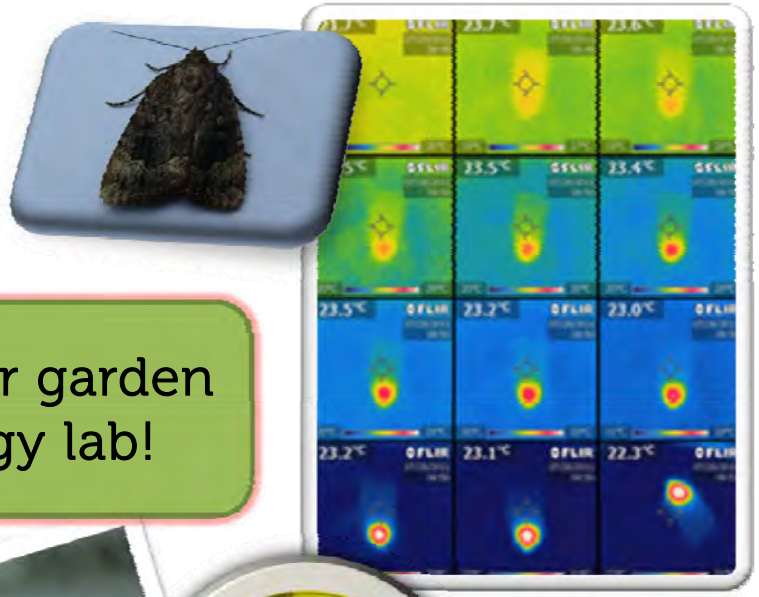

Free students from tedious work, focus them on the fun part of science

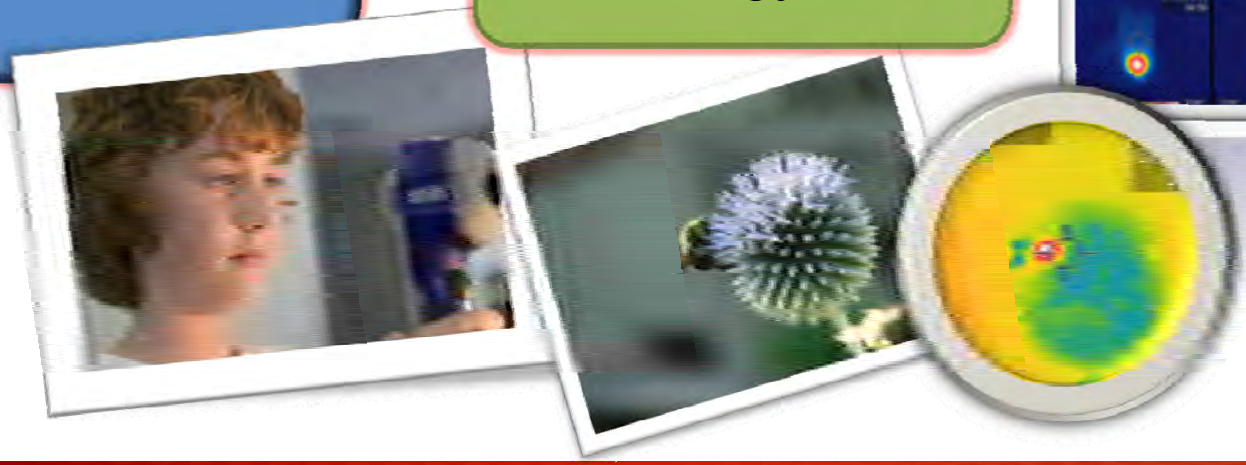
# A true discovery tool

If you tell students where they should position the sensors, you may be giving away the answer and killing the fun!

IR cameras: Just aim and discover!

Make your garden a biology lab!





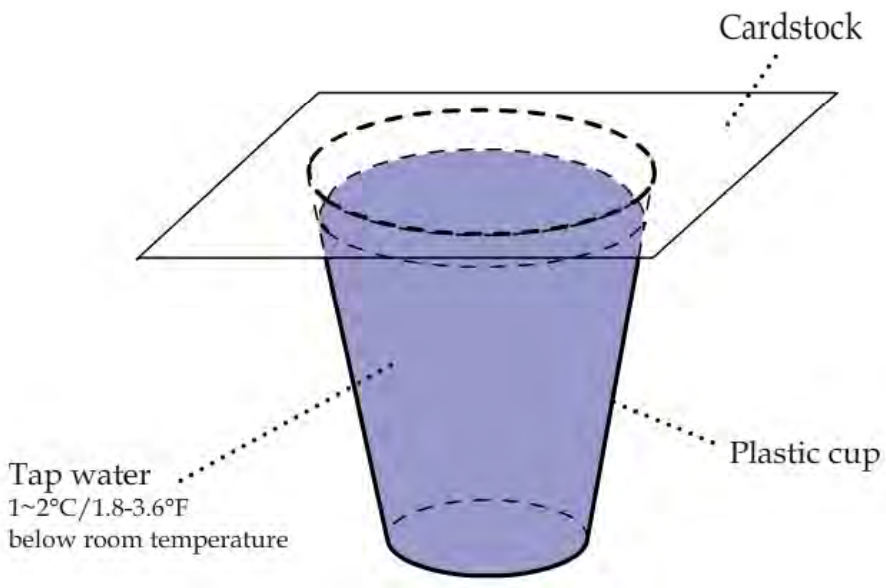
# More science experiments

1. Extensions of science on a piece of paper
2. Ask your IR camera: IR answers to common questions
3. Finale: A science puzzle for everyone

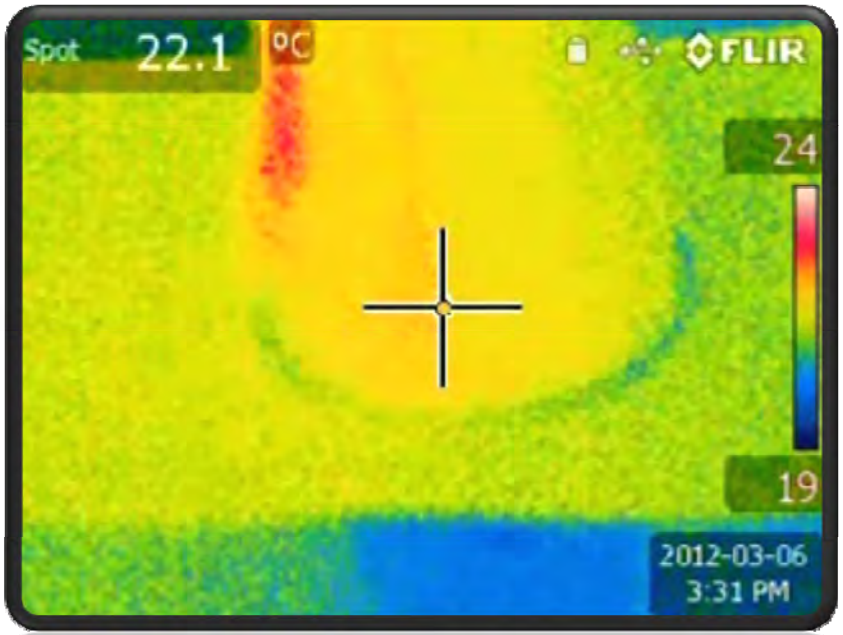
Dig into deep science in ten minutes with your children or grandchildren!

## Science on a piece of paper

# A new surprise?




What if the paper has been atop the water for a long time?



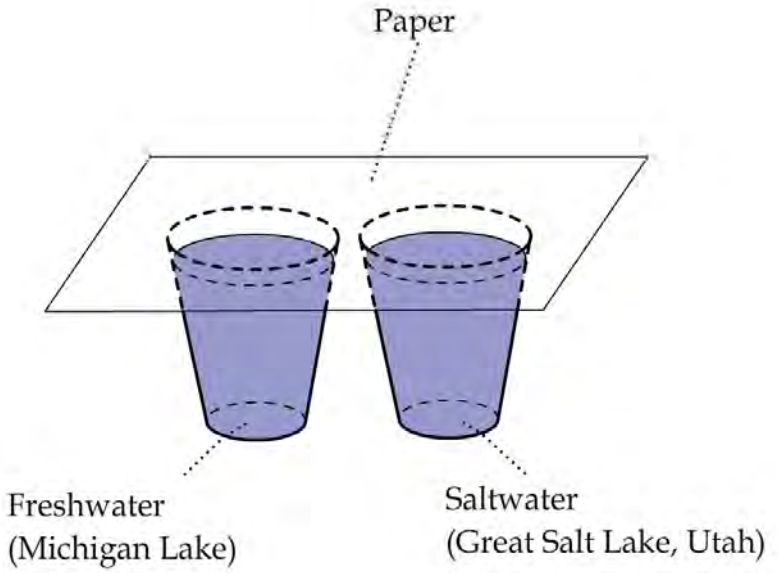

Moisture transport: Water molecules diffuse through the porous structure of paper and evaporate from the other side.

*What Causes Warm Edges on the Boundary of Moist Areas*?

Profs. Vollmer & Möllmann, 4:00-4:30 pm, Today

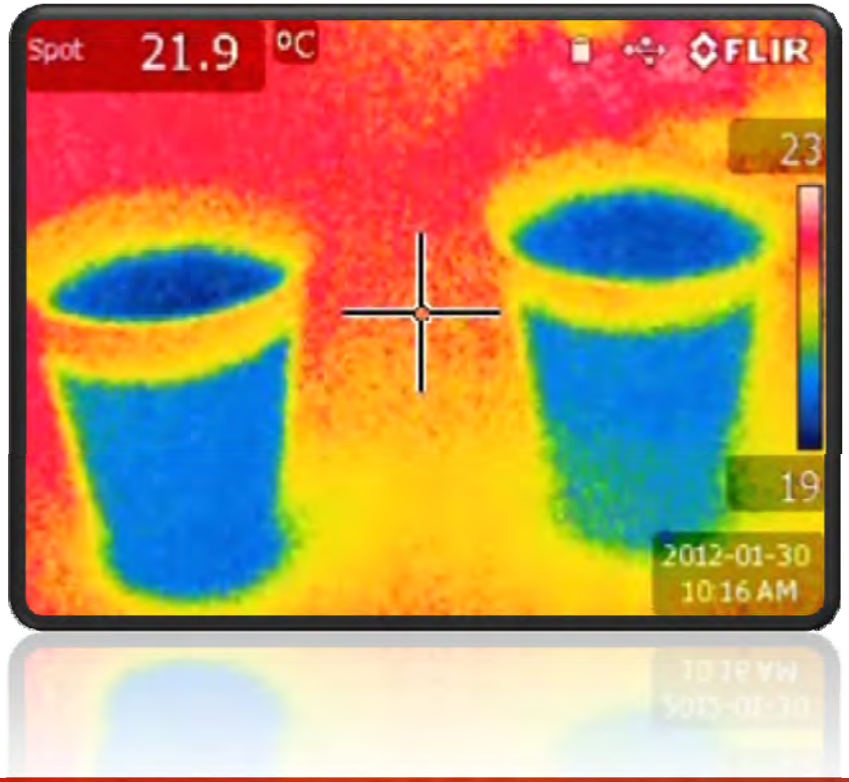
## Science on a piece of paper

# Adding some salt…





Climatology in a cup: Is the lake effect weaker in the Great Salt Lake?

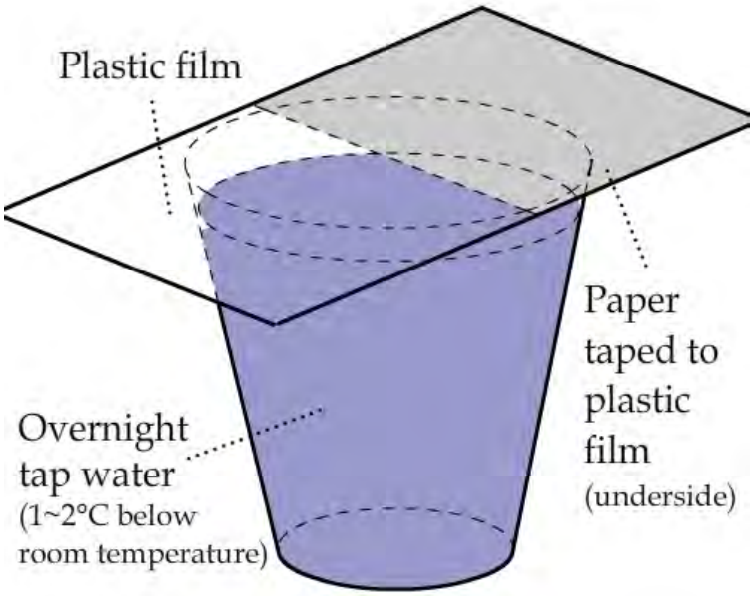



**A direct visualization of vapor pressure depression**: The vapor pressure (proportional to the vapor concentration) above saltwater is lower than that above freshwater.

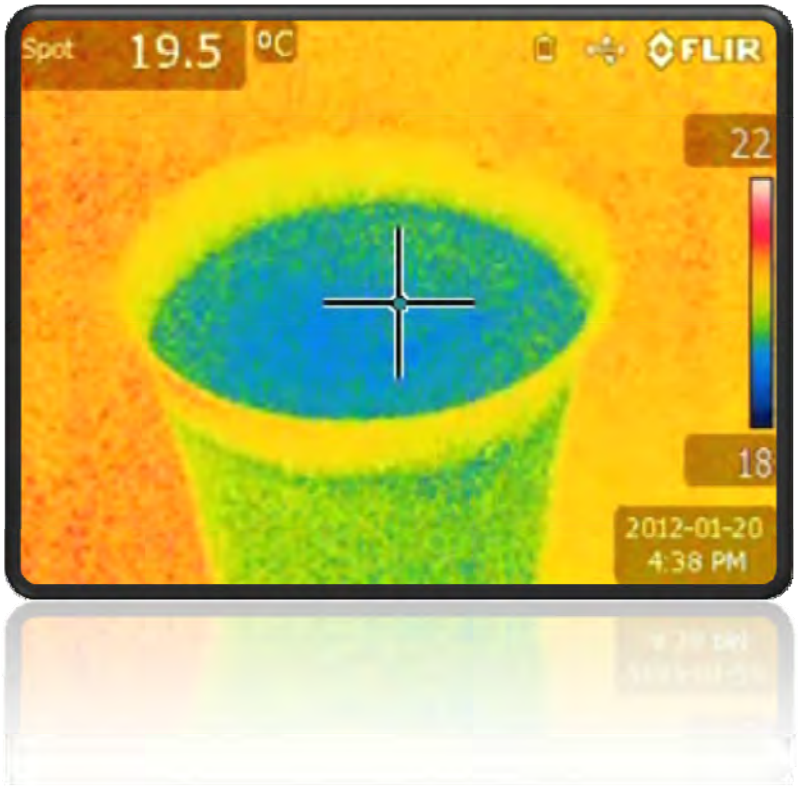
*Dissolved salt ions inhibit water evaporation.*

## Science on a piece of paper

# Paper vs. plastic



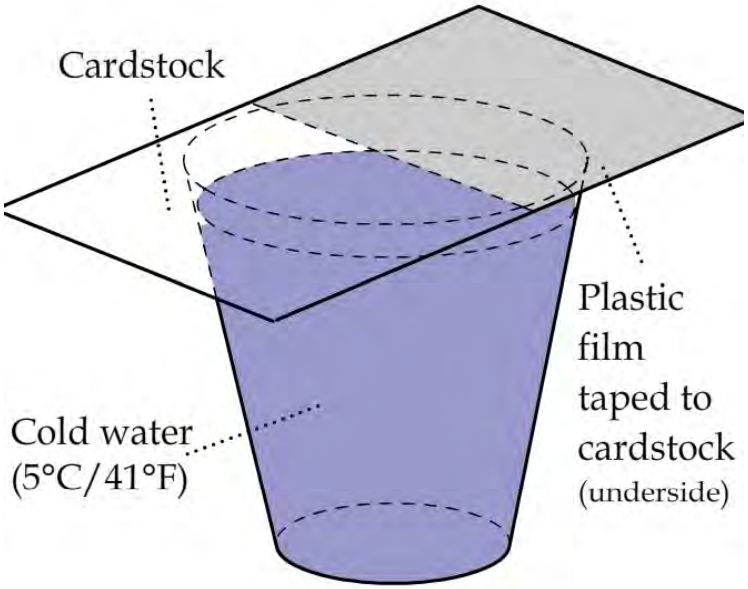

Different materials have "different dew points?"



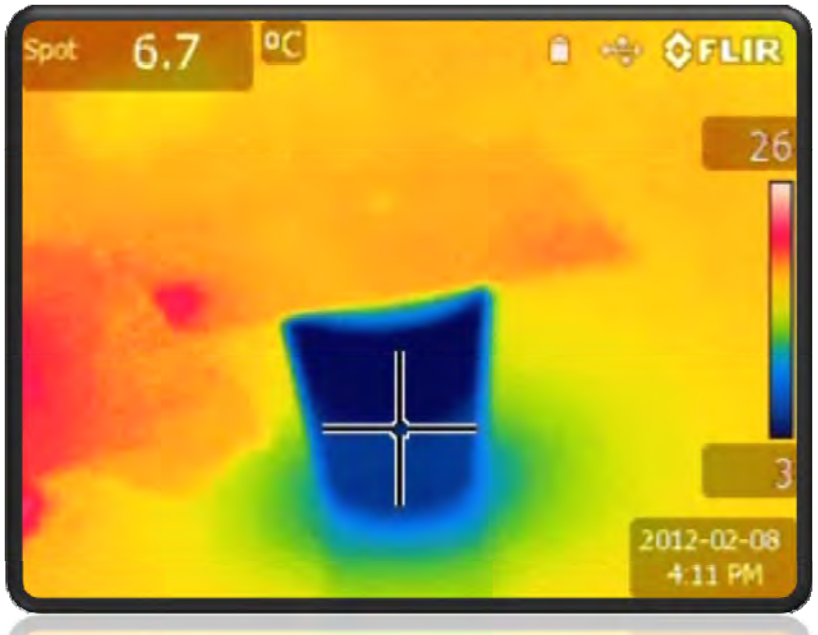

The "attractiveness" of a material to water molecules makes a difference in the condensation of water vapor nearby.

## Science on a piece of paper

# When will the paper be cooled?



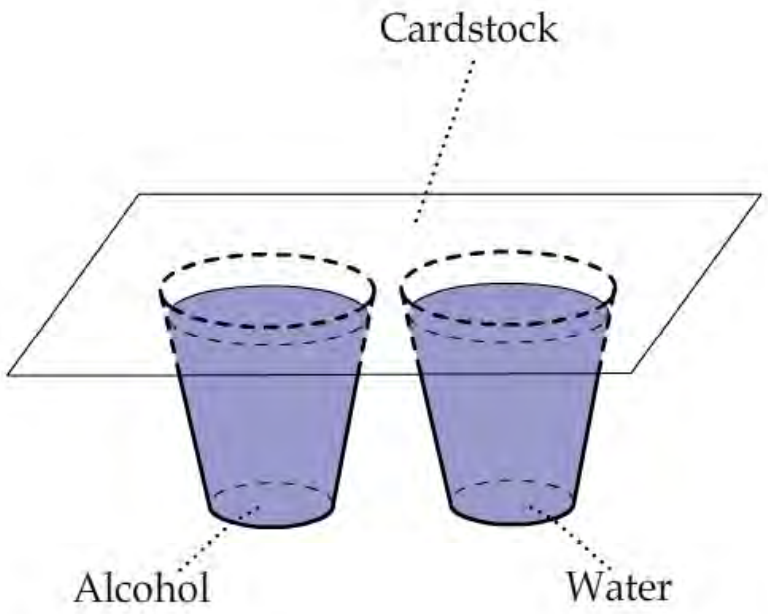

When the temperature gap is large enough (~15°C/27°F)…



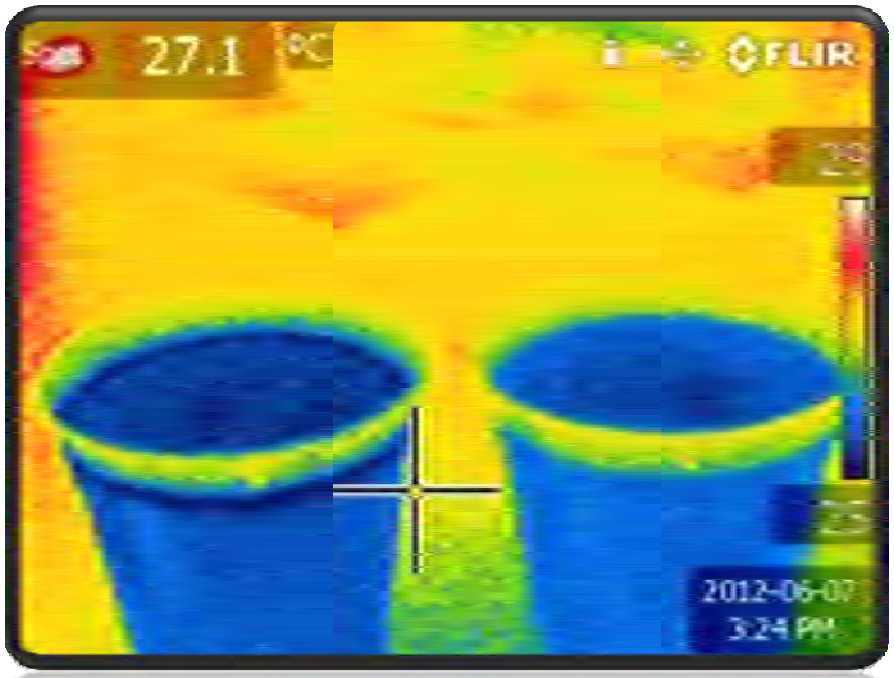

If the water is cold enough, both paper and plastic will be cooled to the same degree.
Condensation heating will be overwhelmed by heat transfer – what I originally hoped to see.

## Science on a piece of paper

# Alcohol vs. water



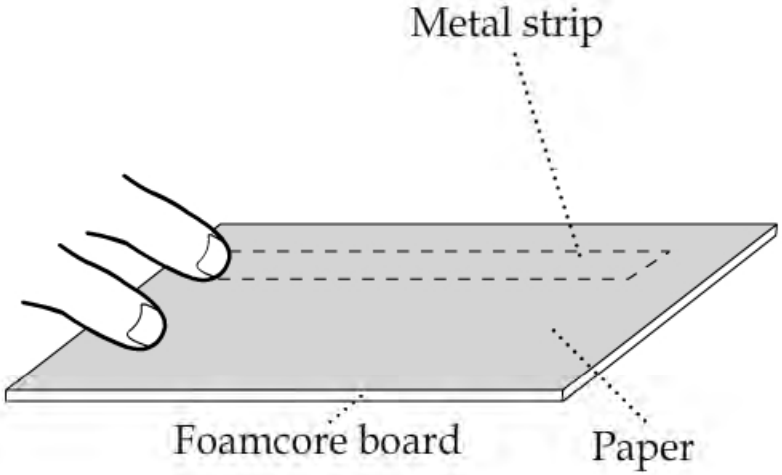

What about alcohol?



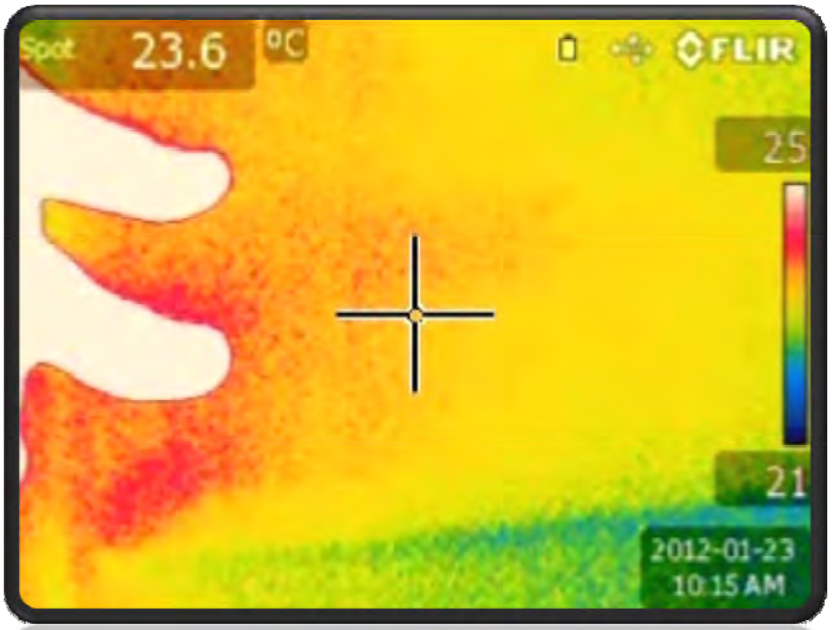

Compare the condensation heating effect of alcohol and water. Why is the warming effect of alcohol weaker?

## Ask your IR camera

# Why do metals feel colder?




Many students believe metals *are* colder than foam. Can this IR experiment change their minds?

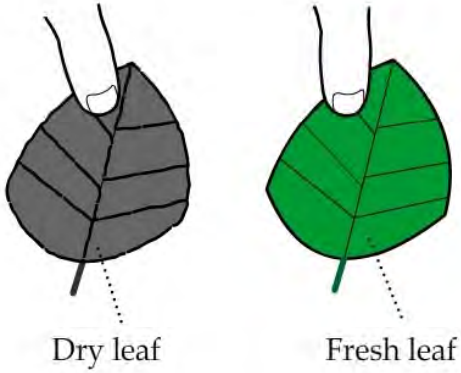



"If pupils were able to 'see' this phenomenon [that metals feel cold] in terms of a transfer of energy from their body to the object, this sort of situation would likely be less of a problem than it seems to be at present."

–Prof. Gaalen Erickson, University of British Columbia, in *Children's Ideas in Science* (p. 59), 1985

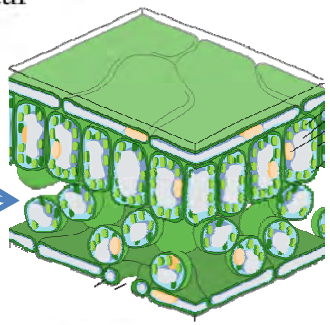
## Ask your IR camera

# Why do fresh leaves feel cooler?

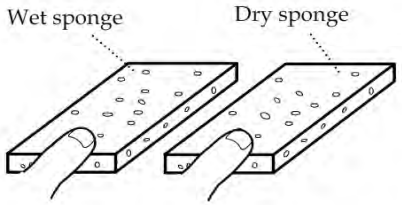



A fresh leaf has higher heat capacity due to the water content.

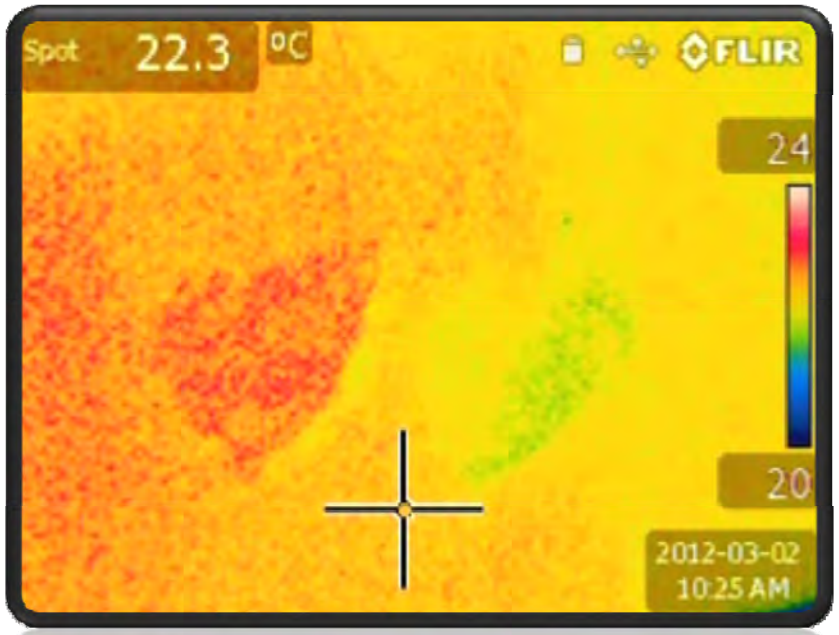
Water storage in the spongy layer



Confirm this with a dry sponge and a wet sponge (wrapped by food wrap) .

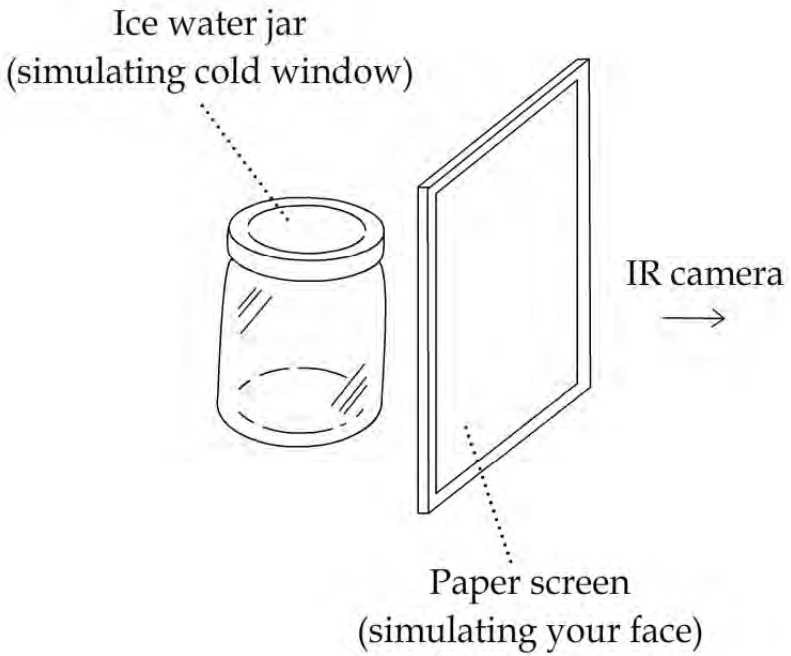



Both sponges are completely wrapped in plastic wrap (not shown).

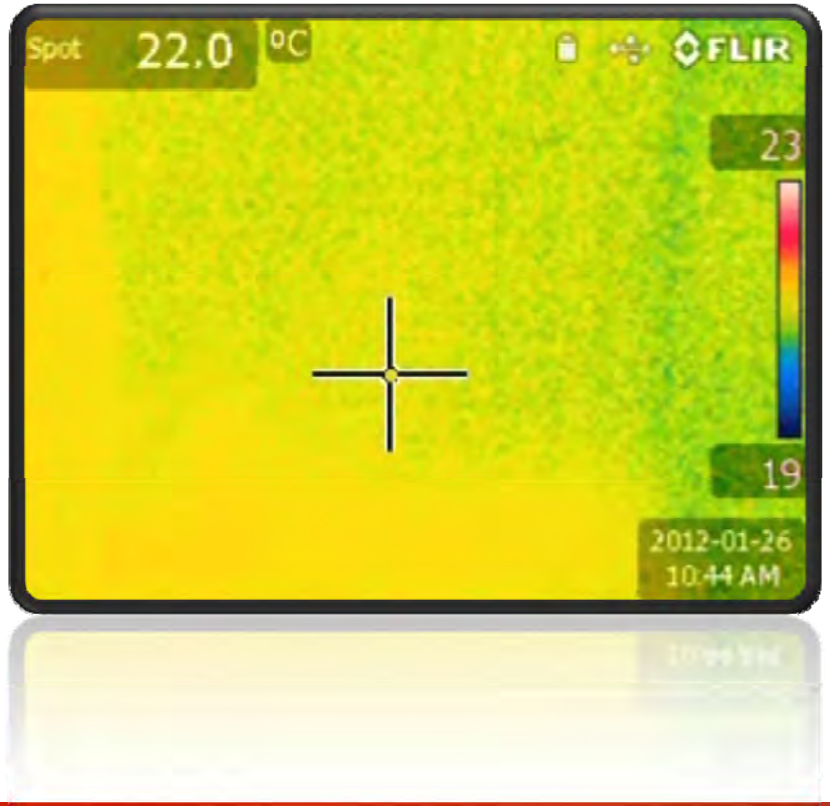


## Ask your IR camera

# Why do we feel cold when facing a closed window in winter?



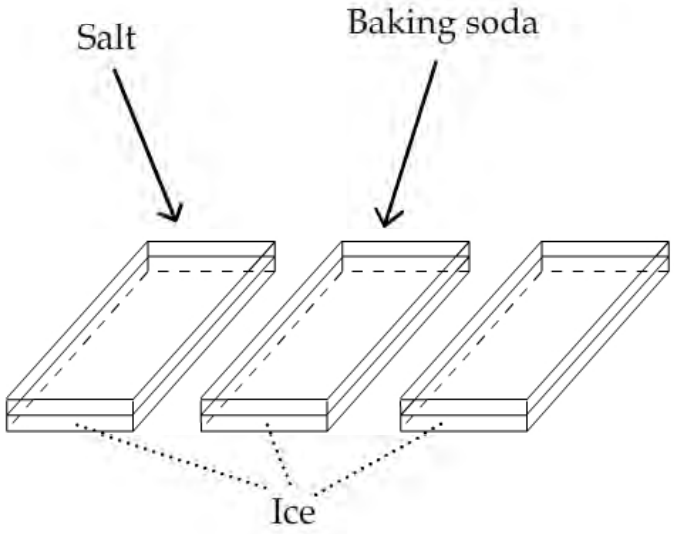

IR cameras are perfect tools for visualizing radiation heat transfer.



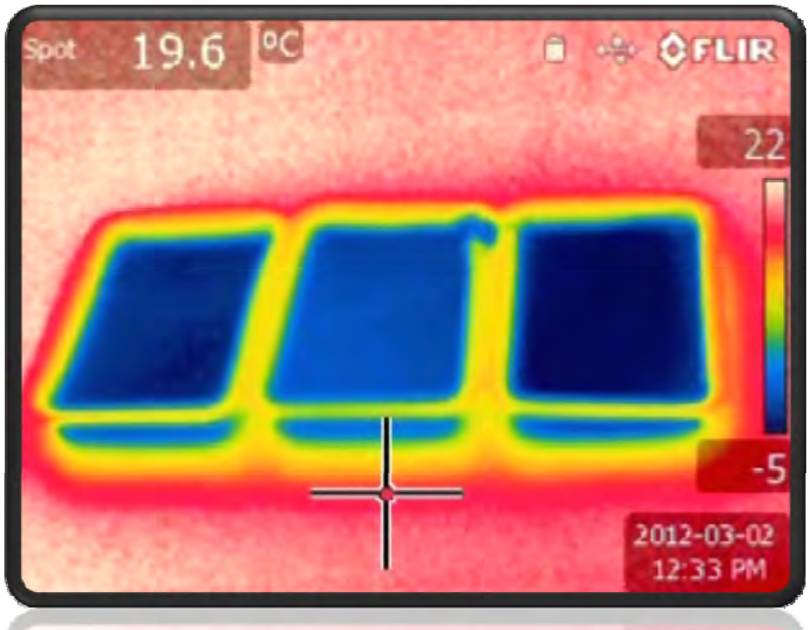

Cold doesn't radiate. Radiation heat transfer happens through the exchange of photons between two objects. The paper screen receives less after the cold jar is placed.

## Ask your IR camera

# Why don't we use baking soda to deice the road?




The deicing process is more visible under an IR camera due to the rapid release of latent heat.



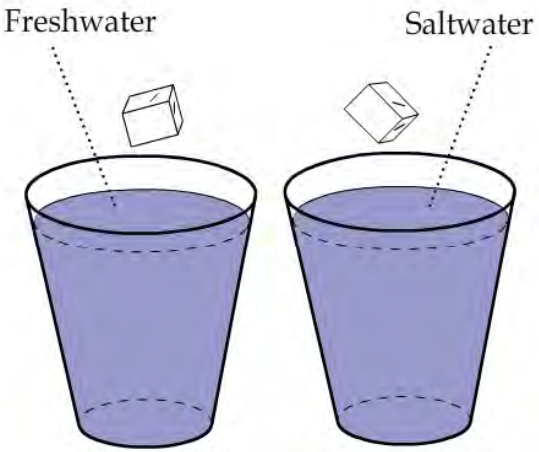

Similar results for sugar.

Melting causes dramatic cooling: Adding salt to ice is the old way to quickly freeze ice cream mixtures.

## Ask your IR camera

# Why does ice melt more slowly in saltwater?

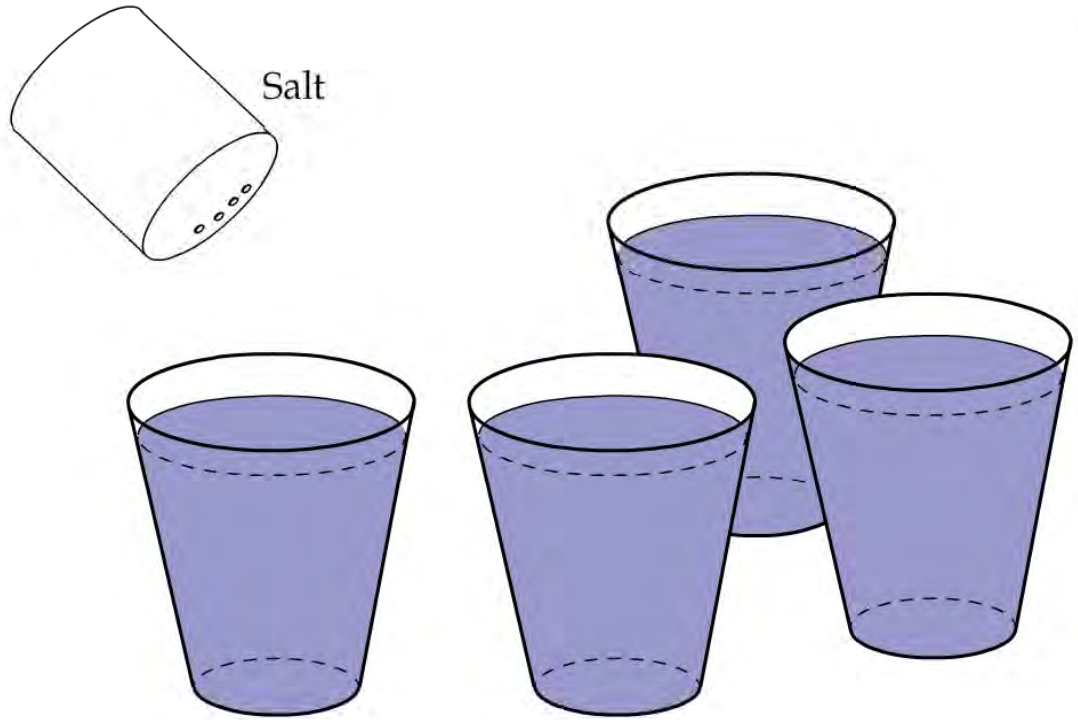
Ocean science in a cup: Thermohaline stratification, global ocean conveyor belt

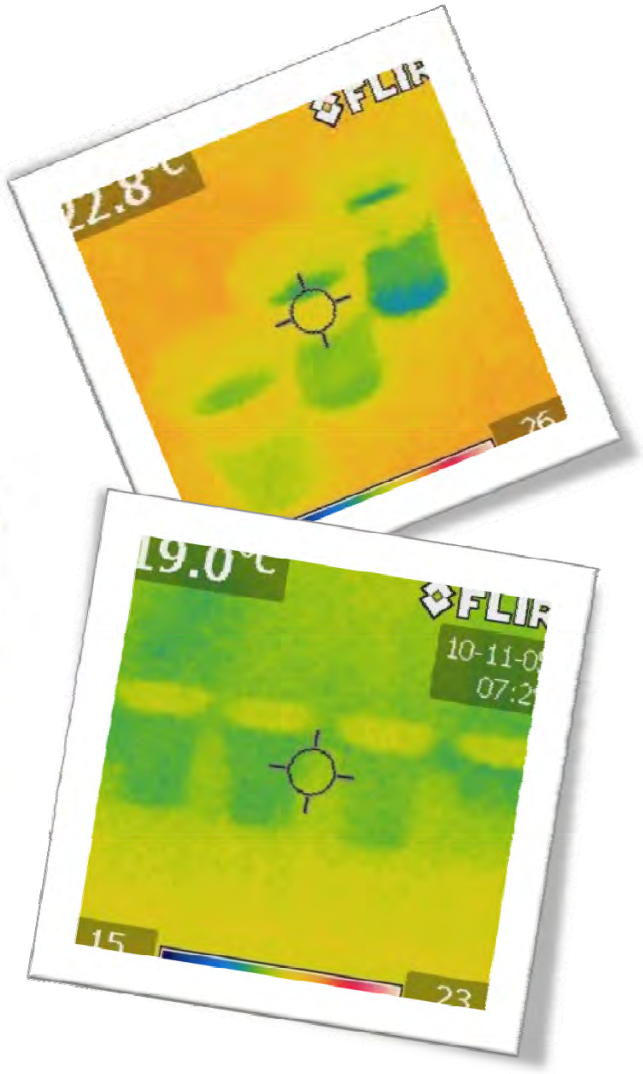



Small cup, big science.

No need to use ink. Thermal energy is the "ink!"

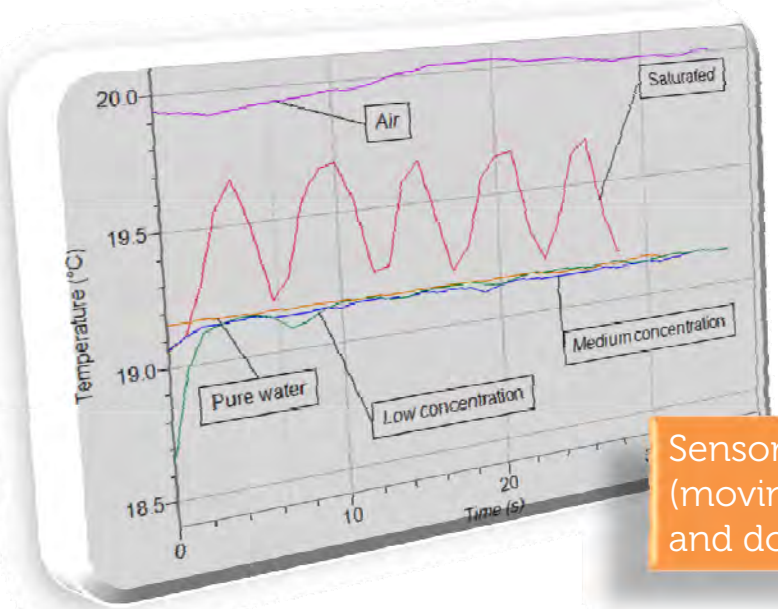

# Finale: A science puzzle for everyone



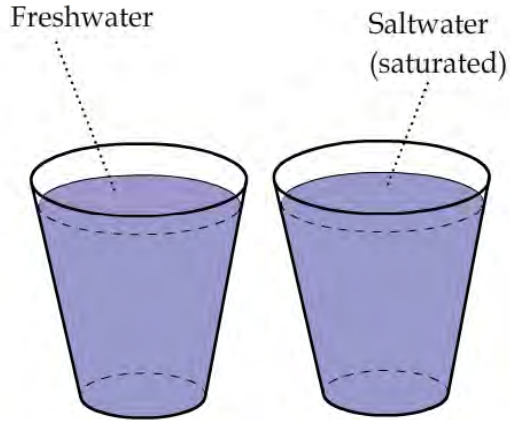



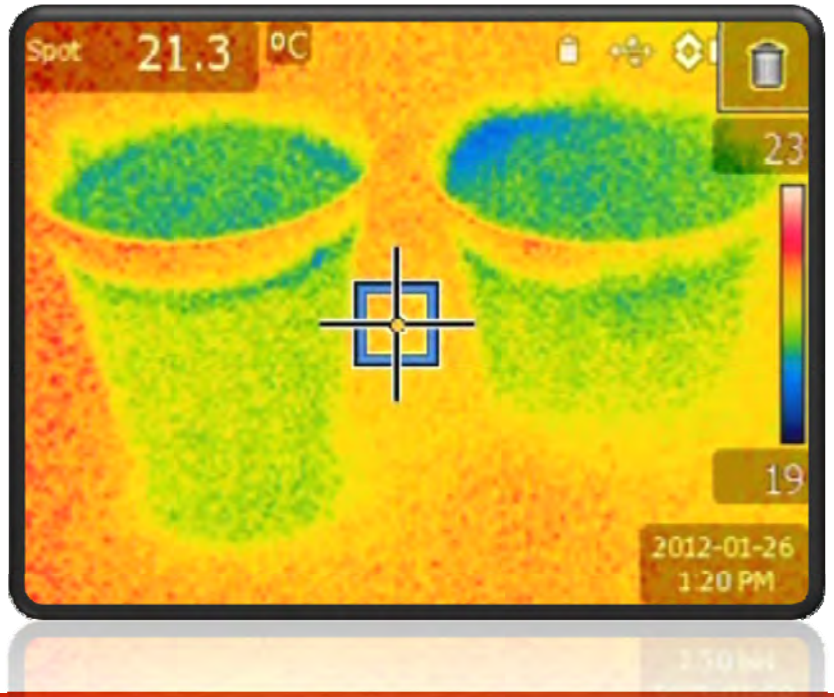
# A mysterious temperature gradient

A temperature gradient up to 0.5 °C / 0.9 °F lasts for weeks!




Sensor data (moving up and down)



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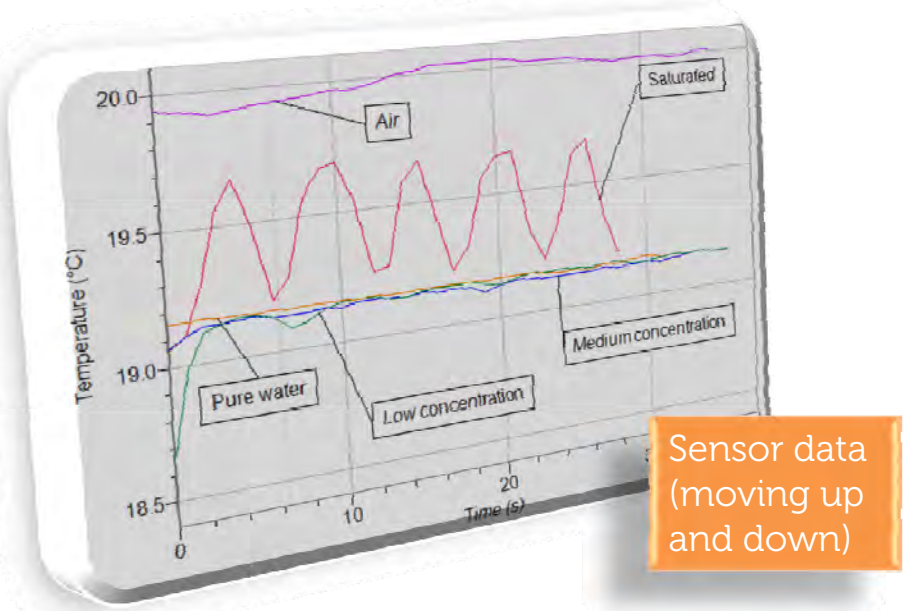
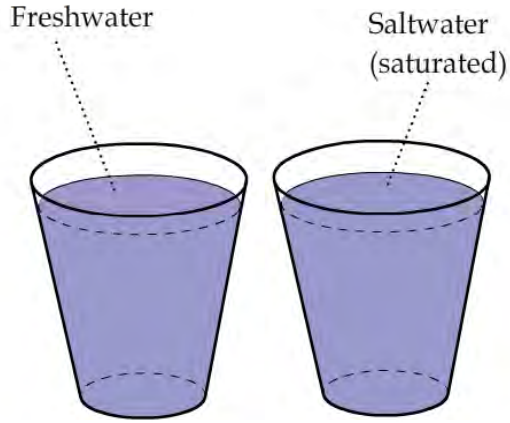
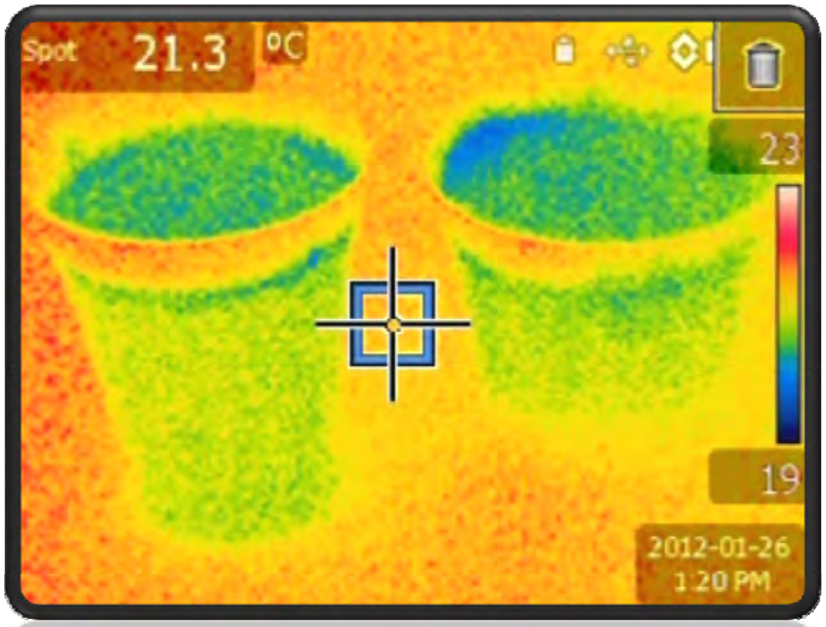



Sensor data (moving up and down)

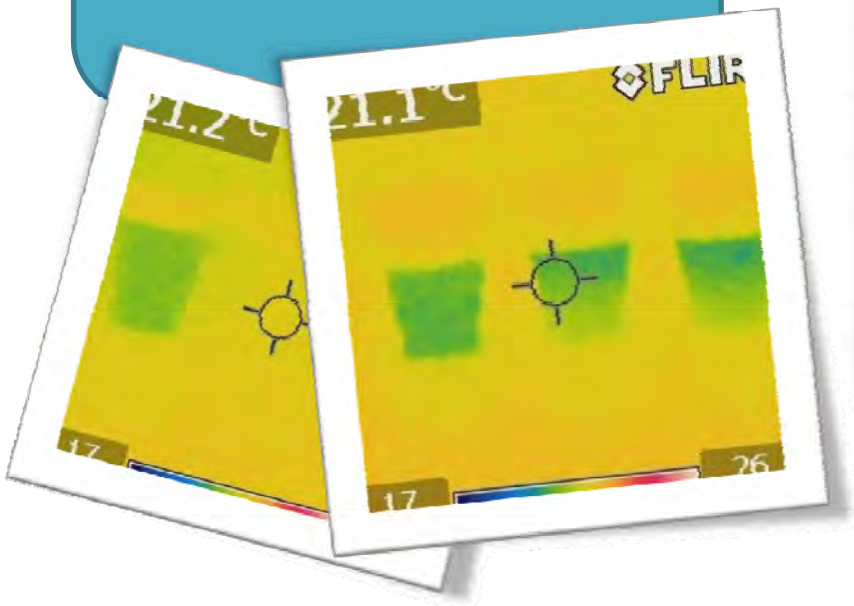


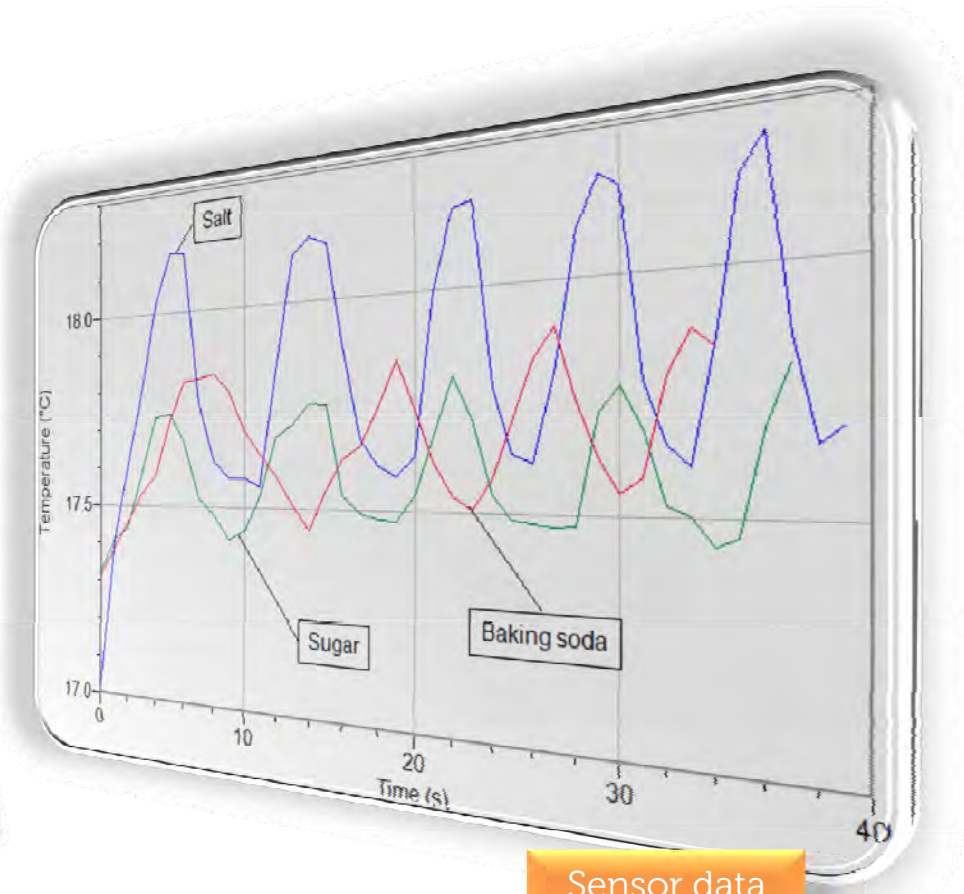




Google has no answer for this mystery...

# A mysterious temperature gradient

This persistent temperature gradient exists in baking soda and sugar solutions as well.




Sensor data (moving up and down)

IR cameras will make it easier for students to make this kind of original scientific discoveries.

# People's reactions


Cover article (2011)

"Captivating, intriguing, and thought-provoking"
-- Journal of Chemical Education

"Thermal cameras can become important in school physics."-- Norrköpings Tidningar


Värmekameran kan
bli viktig i skolfysiken

AAPT PHYSICS EDUCATION
The Physics Teacher

Featured article (2011), YouTube Physics (2012)

Front page Headline (2011)

# Colleges and universities are sold

Professors motivated to buy after knowing our work:

*School of Engineering and Applied Science , Harvard University*
*Department of Chemistry, The King's University College*
*Visual Learning and Communication, Linköpings Universitet*
*Department of Chemistry, Lipscomb University*
*Department of Chemistry, Parkland College*
*Department of Chemistry, Boston College*
*Department of Physics, Sewanee: The University of the South*
*School of Education, University of Georgia*
*Department of Physics, Colgate University*
*Department of Mechanical Engineering, Tufts University*
*Science Department, Tidewater Community College*
*Department of Physics, Tsinghua University*

……

# A sizable education market?

School labs are already using these

Microscopic vision

Astronomic vision

# A sizable education market?

Why not adding some IR cameras?

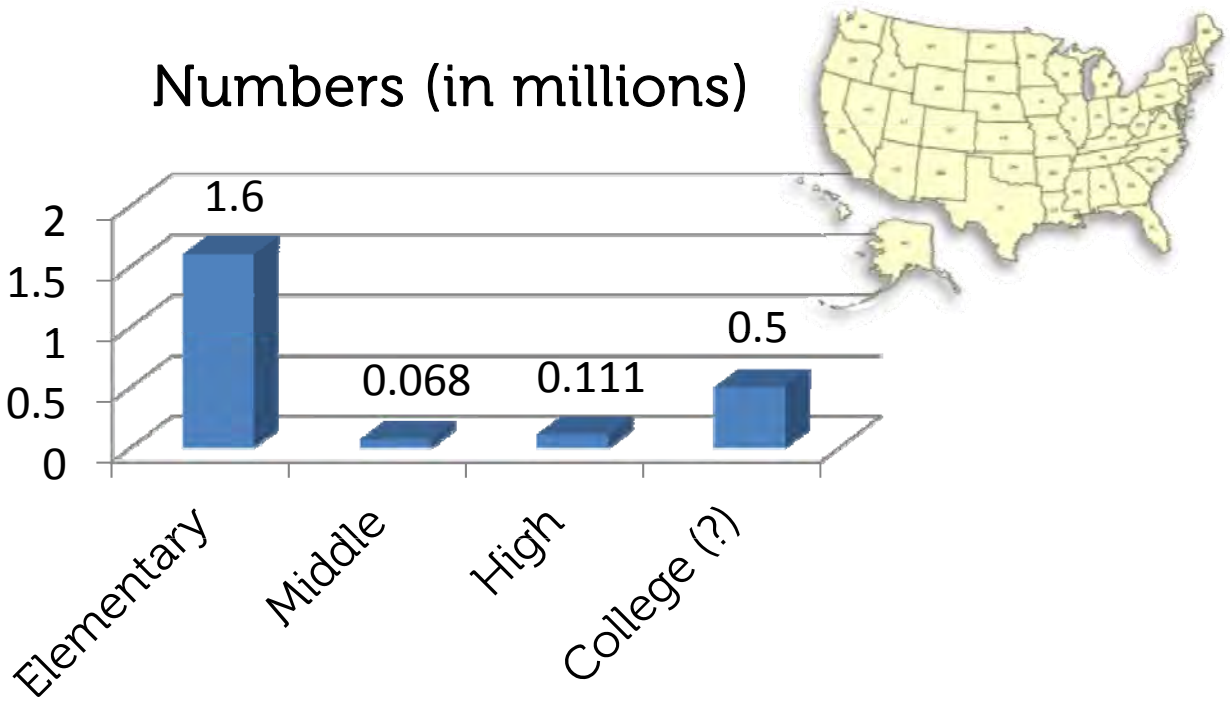
Microscopic vision

Astronomic vision

Thermodynamic vision

# How big is the education market?

*How many science teachers are there in the US?*

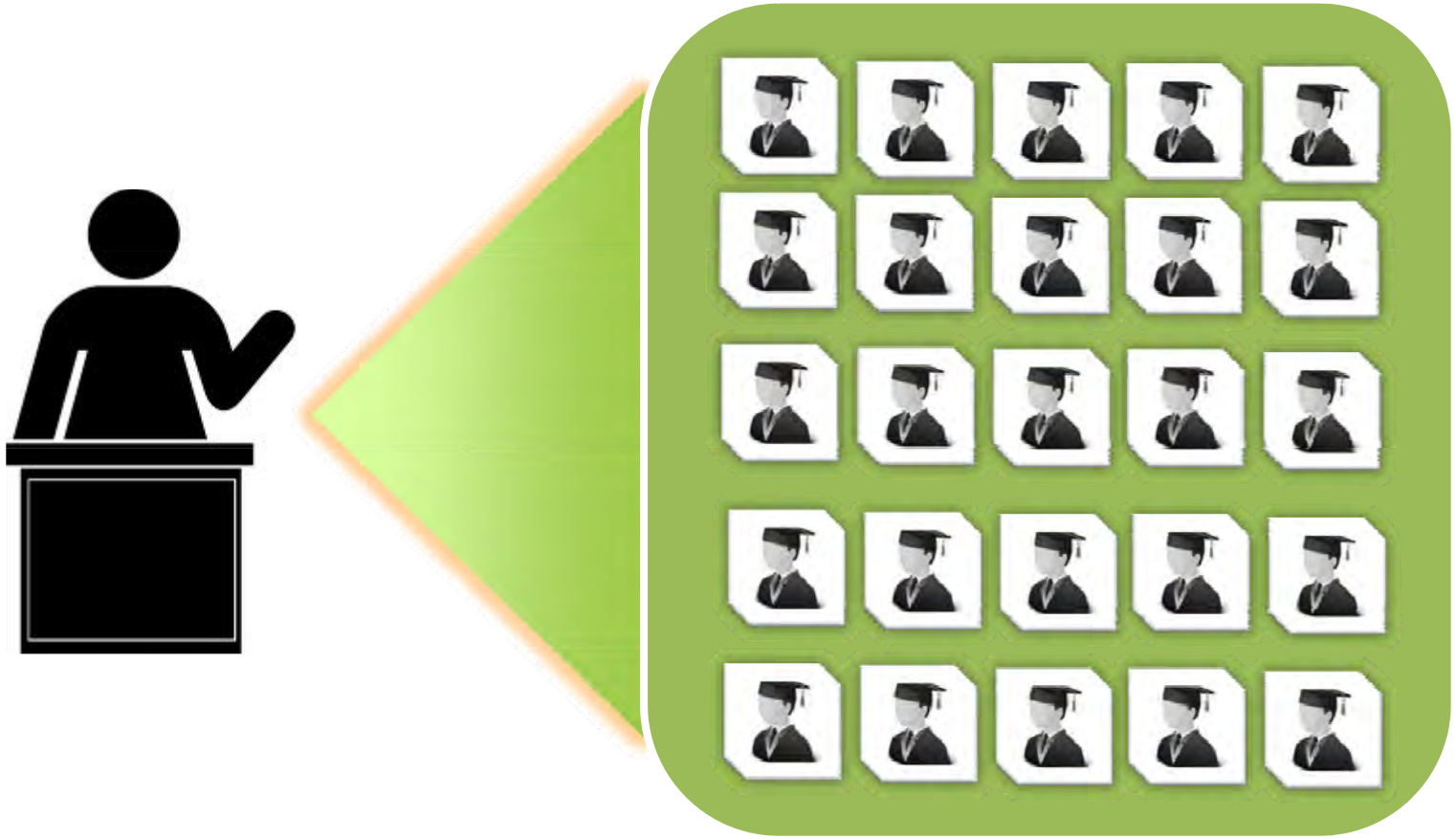




Source: National Science Teachers Association (2008)

If 1% of science teachers buy IR cameras, there will be more than 20,000 new customers — in the US alone.

# How big is the impact?

If one teacher teaches 25 students a year,



# How big is the impact?

In ten years, there would be

5,000,000 more people (>1% of the US population) who have hands-on experience with IR imaging and an eye open to a wide range of applications.

# Opportunities for actions

1. **Work with educators**. We will use IR cameras (10+ per site) in museums and schools: Up to $1,000,000 match fund currently offered by a private funder to support transatlantic collaboration.

2. **Work with scientists**. We will apply for National Science Foundation grants to advance applied IR imaging (e.g., through collaboration with SEAS of Harvard University).

3. **Work with industry**. a) IR manufacturers should present at education conferences and science fairs. b) Consider supporting this educational initiative?

# Acknowledgements





Special thanks to Concord Consortium colleagues Chad Dorsey, Edmund Hazzard, Ethan McElroy, & Robert Tinker and FLIR's Jen Loveland, Robert Madding, & Gary Orlove. And to Prof. Dr. Michael Vollmer for the idea of the Fermi calculation for estimating the thickness of the condensed water layer on paper.

# Thank you
# for your time!

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