
CONVECTION
Welcome back to heat transfer!
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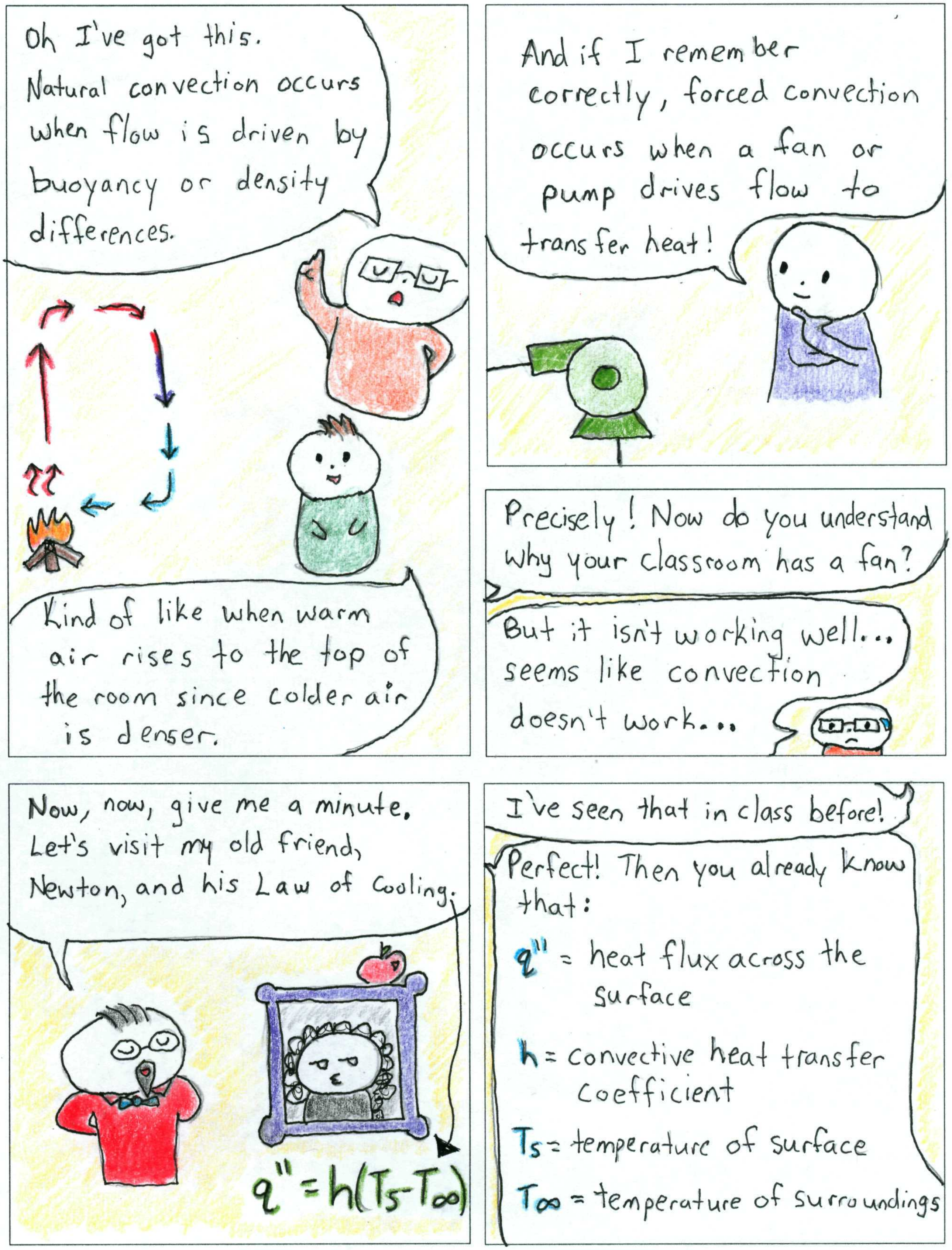
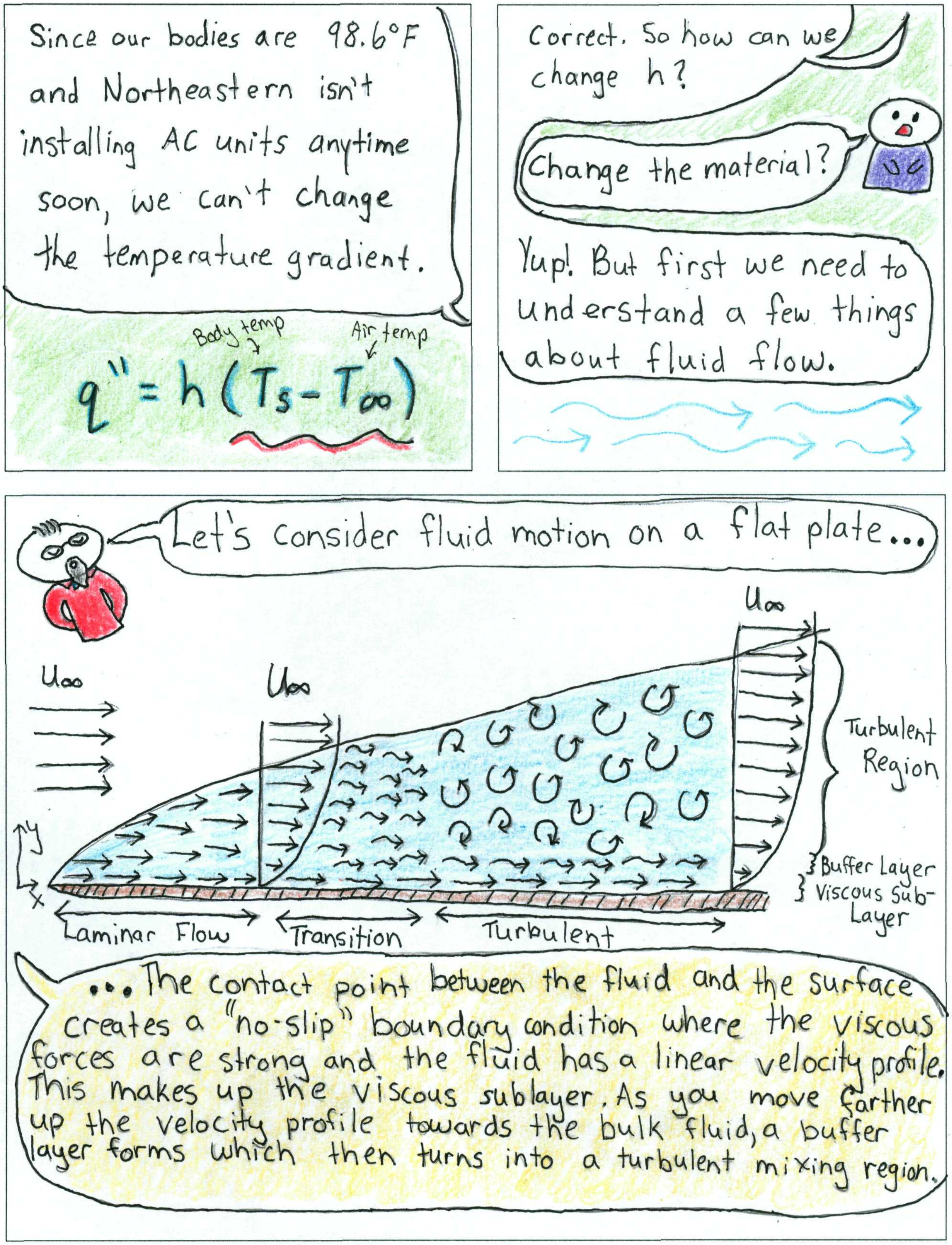
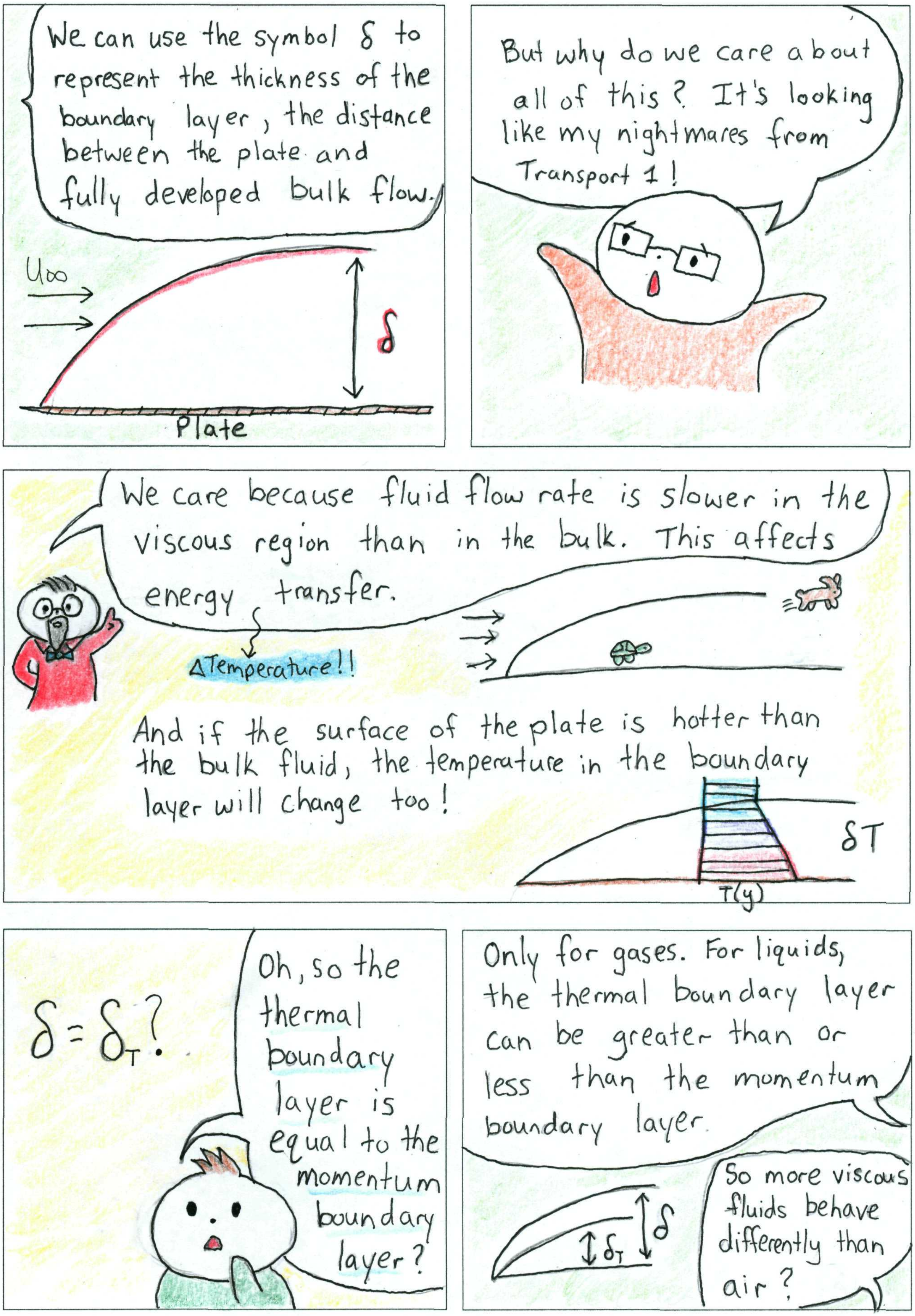
ZZZ...
Why is it so hot in here?
I wish we had A/C...
Too bad the school doesn't have the infrastructure.
What else can we use to cool off? We are in heat transfer class...
Z Z Z
!
Now that I have your attention, here are all the things you need to know but will surely forget...

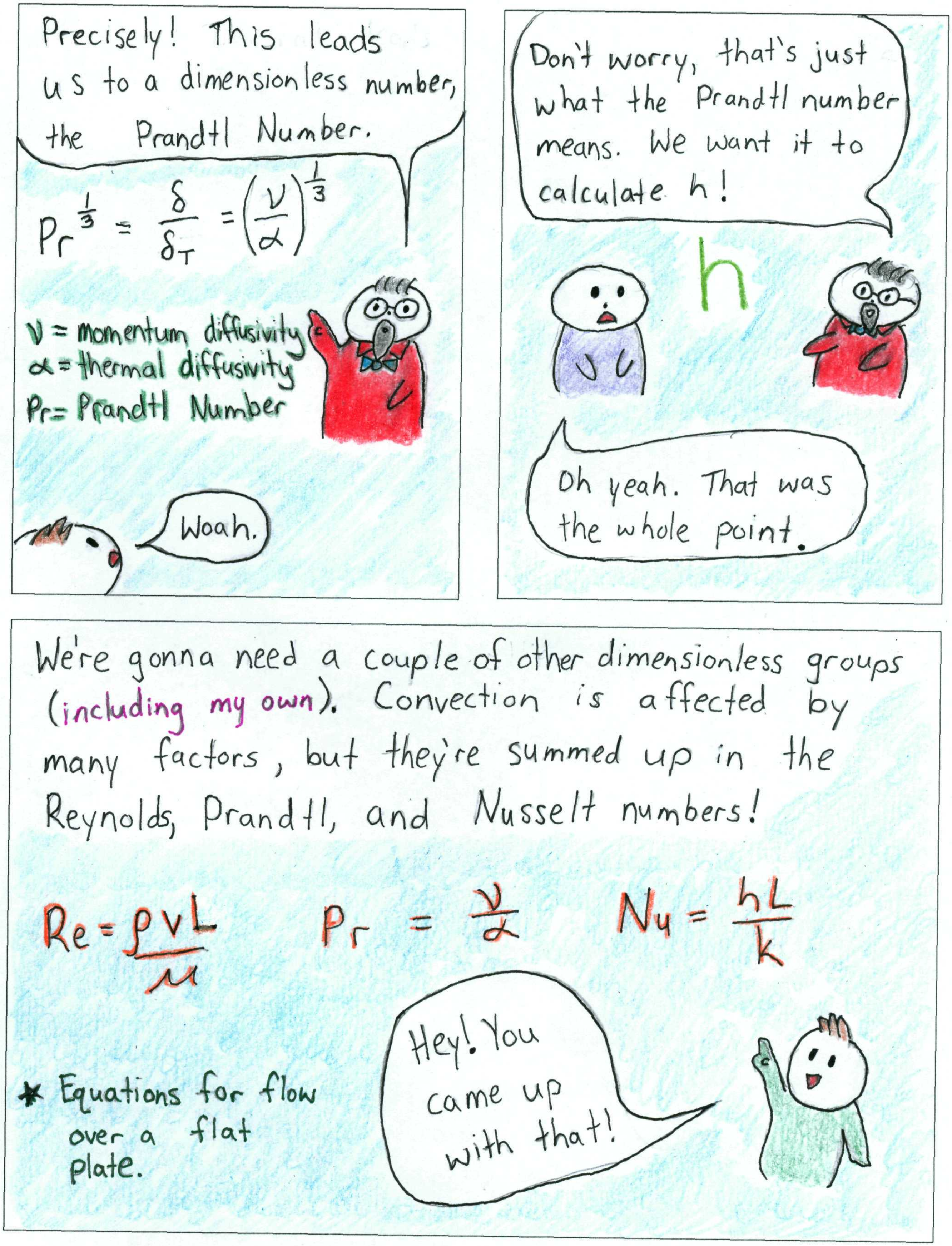
Poof!
Hiya kids! Welcome to the world of heat transfer. I'm Wilhelm Nusselt, here to be your guide! I couldn't help but overhear your dilemma. Ever heard of convection?
We're supposed to learn about it today.
Well then it's a shame you're sleeping through it. Convection is one of the three main modes of heat transfer. Can you name the others?
Well there's 1. Conduction and 2. Radiation.
Great! So how can you use conduction to cool off?
Ice cubes!
But those would melt in this heat...
Wet!
What about radiation?
No... radiation is related to the temperature of the surroundings like the walls. Those are too hot to cool us off.
So that leaves us with convection! Heat transfer via bulk fluid motion. There are 2 types:
Free (natural)
Forced

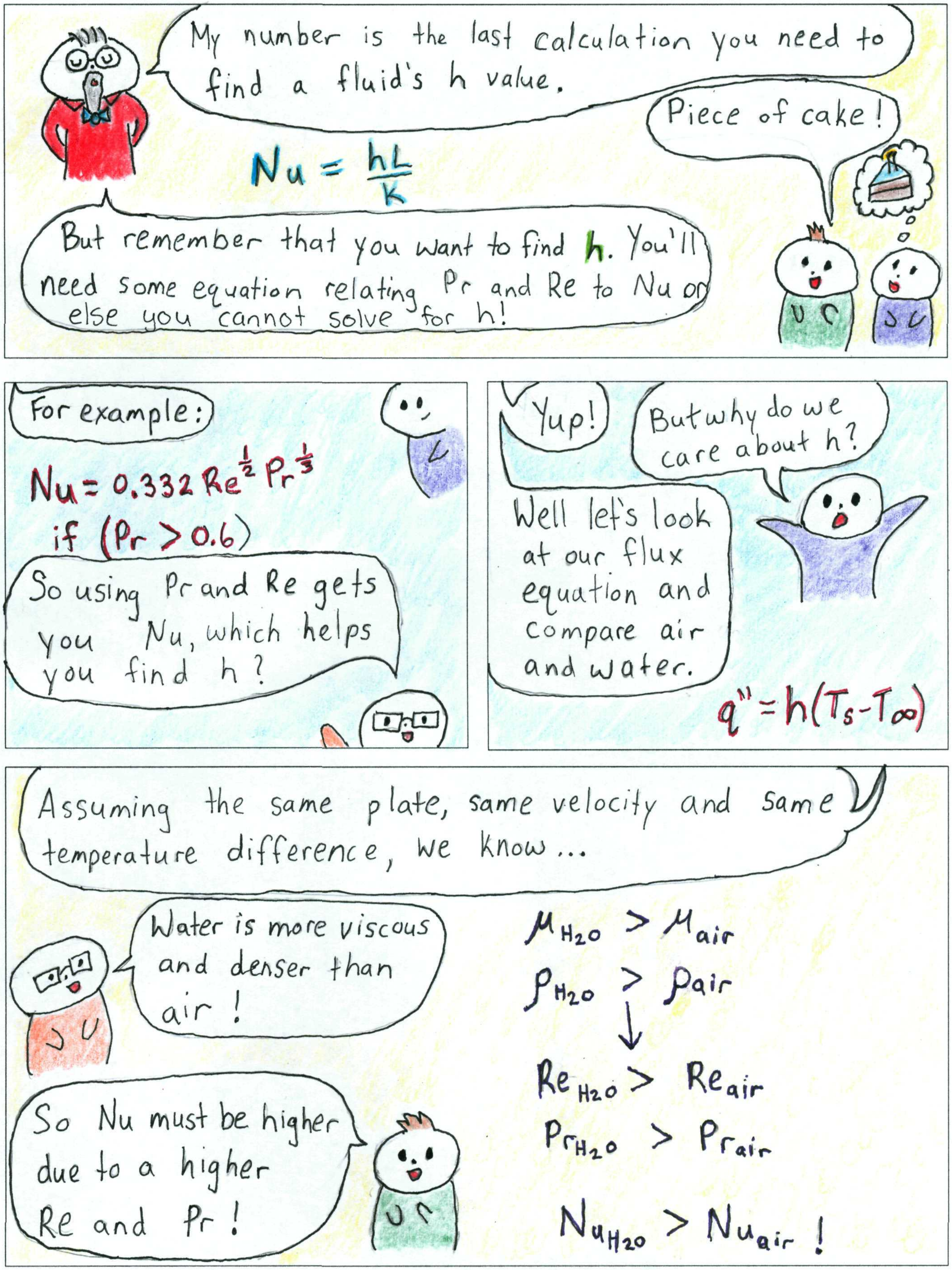


Oh I've got this. Natural convection occurs when flow is driven by buoyancy or density differences.
Kind of like when warm air rises to the top of the room since colder air is denser.
And if I remember correctly, forced convection occurs when a fan or pump drives flow to transfer heat!
Precisely! Now do you understand why your classroom has a fan?
But it isn't working well... seems like convection doesn't work...
Now, now, give me a minute. Let's visit my old friend, Newton, and his Law of Cooling.
q'' = h(Ts-T∞)
I've seen that in class before!
Perfect! Then you already know that:
q'' = heat flux across the surface
h = convective heat transfer coefficient
Ts = temperature of surface
T∞ = temperature of surroundings


Since our bodies are 98.6°F and Northeastern isn't installing AC units anytime soon, we can't change the temperature gradient.
Body temp
Air temp
$q'' = h(T_s - T_\infty)$
Correct. So how can we change h?
Change the material?
Yup! But first we need to understand a few things about fluid flow.
Let's consider fluid motion on a flat plate...
u_∞
u_∞
u_∞
y
x
Turbulent Region
Buffer Layer
Viscous Sub-Layer
Laminar Flow
Transition
Turbulent
...The contact point between the fluid and the surface creates a "no-slip" boundary condition where the viscous forces are strong and the fluid has a linear velocity profile. This makes up the viscous sublayer. As you move farther up the velocity profile towards the bulk fluid, a buffer layer forms which then turns into a turbulent mixing region.

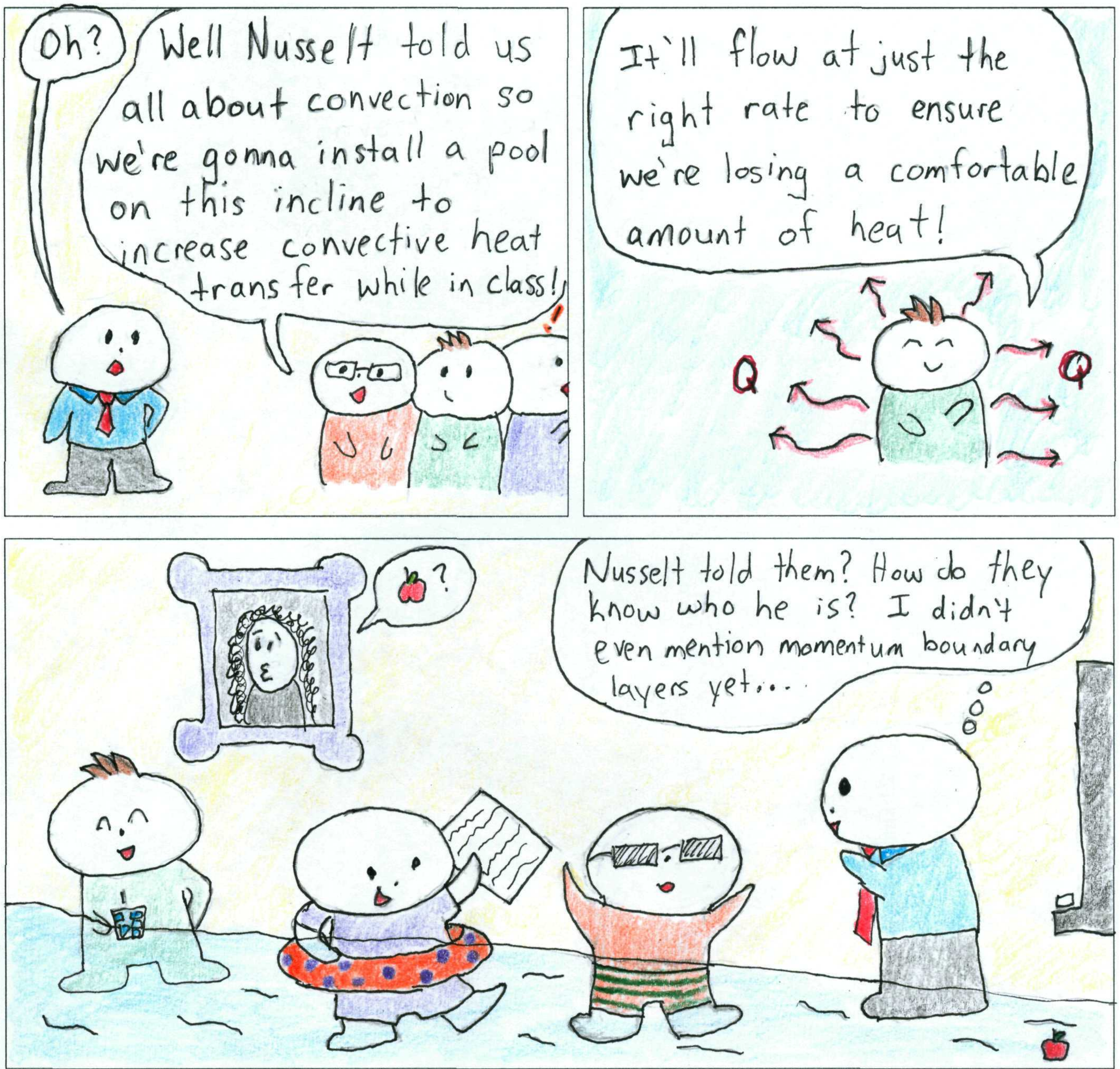

We can use the symbol δ to represent the thickness of the boundary layer, the distance between the plate and fully developed bulk flow.
u∞
δ
Plate
But why do we care about all of this? It's looking like my nightmares from Transport 1!
We care because fluid flow rate is slower in the viscous region than in the bulk. This affects energy transfer.
ΔTemperature!!
And if the surface of the plate is hotter than the bulk fluid, the temperature in the boundary layer will change too!
δT
T(y)
δ = δT?
Oh, so the thermal boundary layer is equal to the momentum boundary layer?
Only for gases. For liquids, the thermal boundary layer can be greater than or less than the momentum boundary layer.
δ
δT
So more viscous fluids behave differently than air?


Precisely! This leads us to a dimensionless number, the Prandtl Number.
$Pr^{\frac{1}{3}} = \frac{\delta}{\delta_T} = \left(\frac{\nu}{\alpha}\right)^{\frac{1}{3}}$
ν = momentum diffusivity
α = thermal diffusivity
Pr = Prandtl Number
Woah.
Don't worry, that's just what the Prandtl number means. We want it to calculate h!
h
Oh yeah. That was the whole point.
We're gonna need a couple of other dimensionless groups (including my own). Convection is affected by many factors, but they're summed up in the Reynolds, Prandtl, and Nusselt numbers!
$Re = \frac{\rho v L}{\mu}$
$Pr = \frac{\nu}{\alpha}$
$Nu = \frac{hL}{k}$
* Equations for flow over a flat plate.
Hey! You came up with that!



My number is the last calculation you need to find a fluid's h value.
Piece of cake!
$Nu = \frac{hL}{k}$
But remember that you want to find h. You'll need some equation relating Pr and Re to Nu or else you cannot solve for h!
For example:
$Nu = 0.332\, Re^{\frac{1}{2}} Pr^{\frac{1}{3}}$ if $(Pr > 0.6)$
So using Pr and Re gets you Nu, which helps you find h?
Yup!
But why do we care about h?
Well let's look at our flux equation and compare air and water.
$q'' = h(T_s - T_\infty)$
Assuming the same plate, same velocity and same temperature difference, we know...
Water is more viscous and denser than air!
$\mu_{H_2O} > \mu_{air}$
$\rho_{H_2O} > \rho_{air}$
$Re_{H_2O} > Re_{air}$
$Pr_{H_2O} > Pr_{air}$
So Nu must be higher due to a higher Re and Pr!
$Nu_{H_2O} > Nu_{air}$!

Nu = hL/k
so...
Nu↑ , h↑
Wait, so that means water has a higher h value than air!
Which causes heat to leave our bodies faster when in room temperature water!
q" = h(Ts-T∞)
h↑, q"↑
Looks like you have a solution to your problem! Bye-bye now!
zzZ
Bye-bye ghost of Nusselt!
...
... and that's why we need to consider the type of fluid...
Professor! We have a solution to this heat!
It's really quite easy...
It may require a little redecorating...
!
How Newton truly discovered gravity



Oh?
Well Nusselt told us all about convection so we're gonna install a pool on this incline to increase convective heat transfer while in class!
!
It'll flow at just the right rate to ensure we're losing a comfortable amount of heat!
Q
Q
?
Nusselt told them? How do they know who he is? I didn't even mention momentum boundary layers yet...

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