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REFRIGERATION CYCLES

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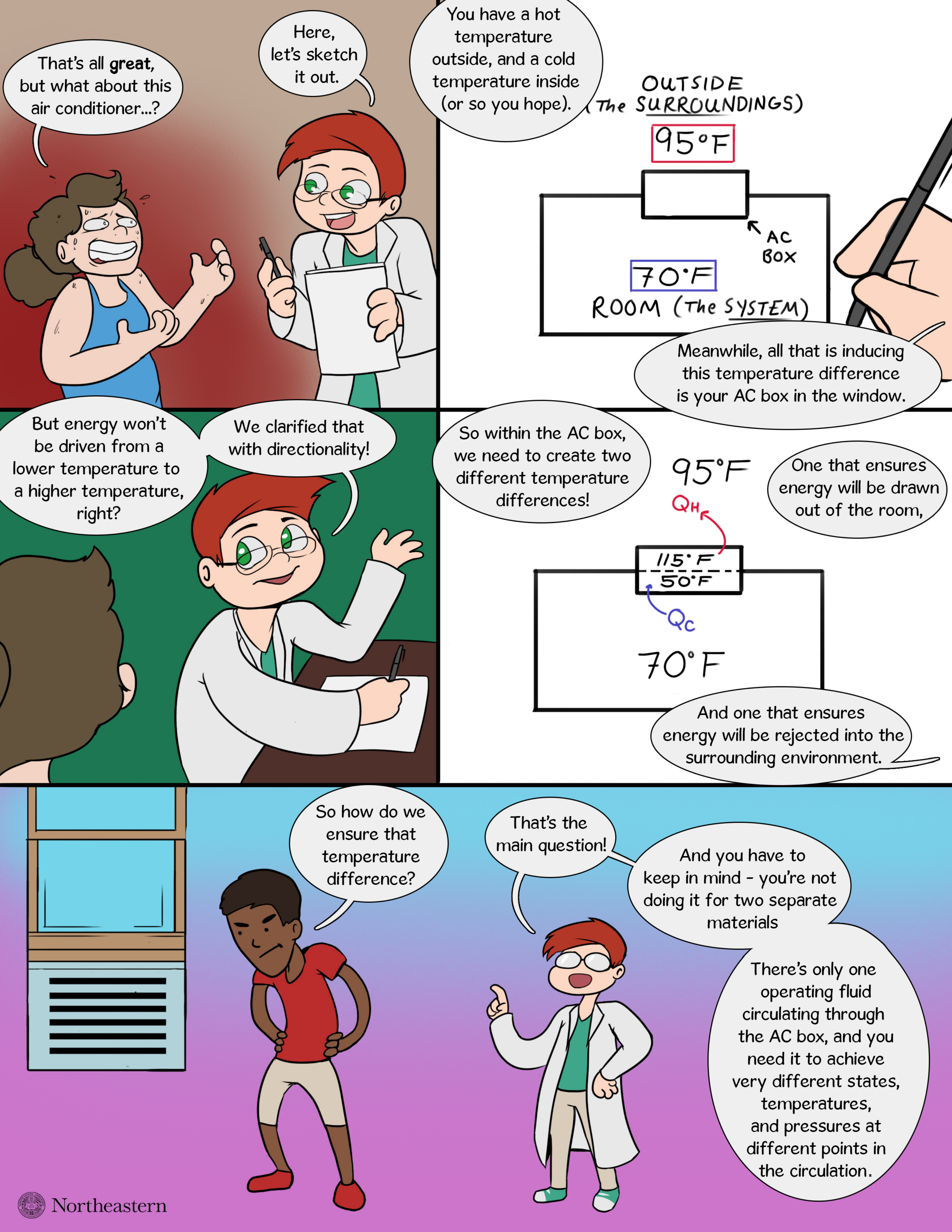
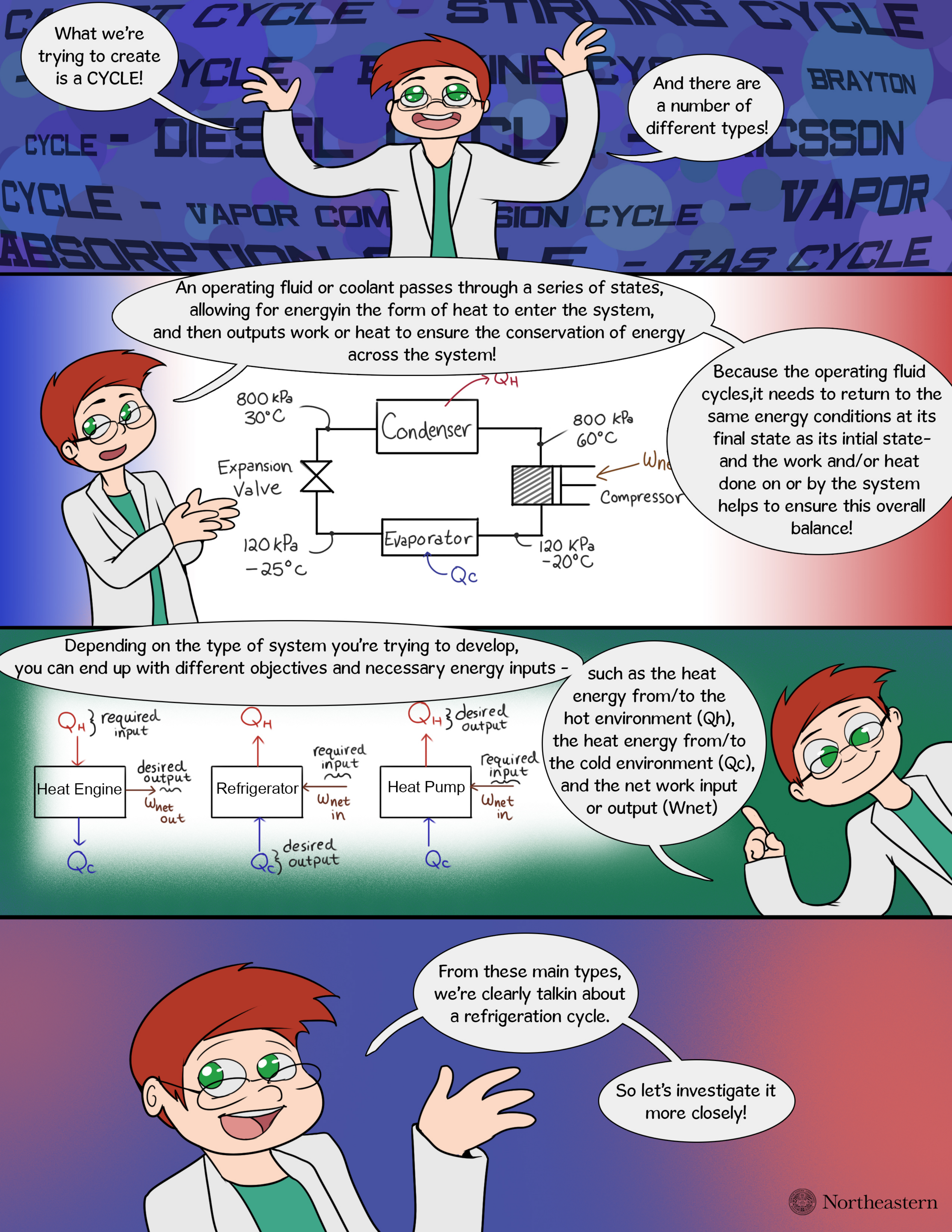
We refer to this as the **First Law of Thermodynamics**-
whatever changes occur in the energy that exists to make a system...
INTERNAL ENERGY
WORK
$\Delta E_K + \Delta E_P + \Delta U = Q + W$
...must be equal to the energy that enters or leaves the system!
$\Delta E_K + \Delta E_P + \Delta H = Q + W_S$
KINETIC ENERGY
POTENTIAL ENERGY
ENTHALPY
HEAT
SHAFT WORK
In the application of thermo-dynamics to a system,
Let's use an example:
there is a limited amount of work that can come from a heat energy input.
I can plug in a hot plate to provide energy to a cup of coffee, right?
Electrical work converted to heat!
HEAT
ELECTRICITY
But I can't draw in heat from a cold room to heat up a warm cup of coffee!
There are limitations on the direction of energy!
This brings us to the **SECOND LAW OF THERMODYNAMICS**- considering the quality of the energy as opposed to the quantity of energy
Entropy has to be greater than or equal to zero...
S
...for a real-world process to be possible!


That's all **great**, but what about this air conditioner...?
Here, let's sketch it out.
You have a hot temperature outside, and a cold temperature inside (or so you hope).
OUTSIDE (The SURROUNDINGS)
95°F
AC BOX
70°F
ROOM (The SYSTEM)
Meanwhile, all that is inducing this temperature difference is your AC box in the window.
But energy won't be driven from a lower temperature to a higher temperature, right?
We clarified that with directionality!
So within the AC box, we need to create two different temperature differences!
95°F
One that ensures energy will be drawn out of the room,
Q_H
115°F
50°F
Q_C
70°F
And one that ensures energy will be rejected into the surrounding environment.
So how do we ensure that temperature difference?
That's the main question!
And you have to keep in mind - you're not doing it for two separate materials
There's only one operating fluid circulating through the AC box, and you need it to achieve very different states, temperatures, and pressures at different points in the circulation.



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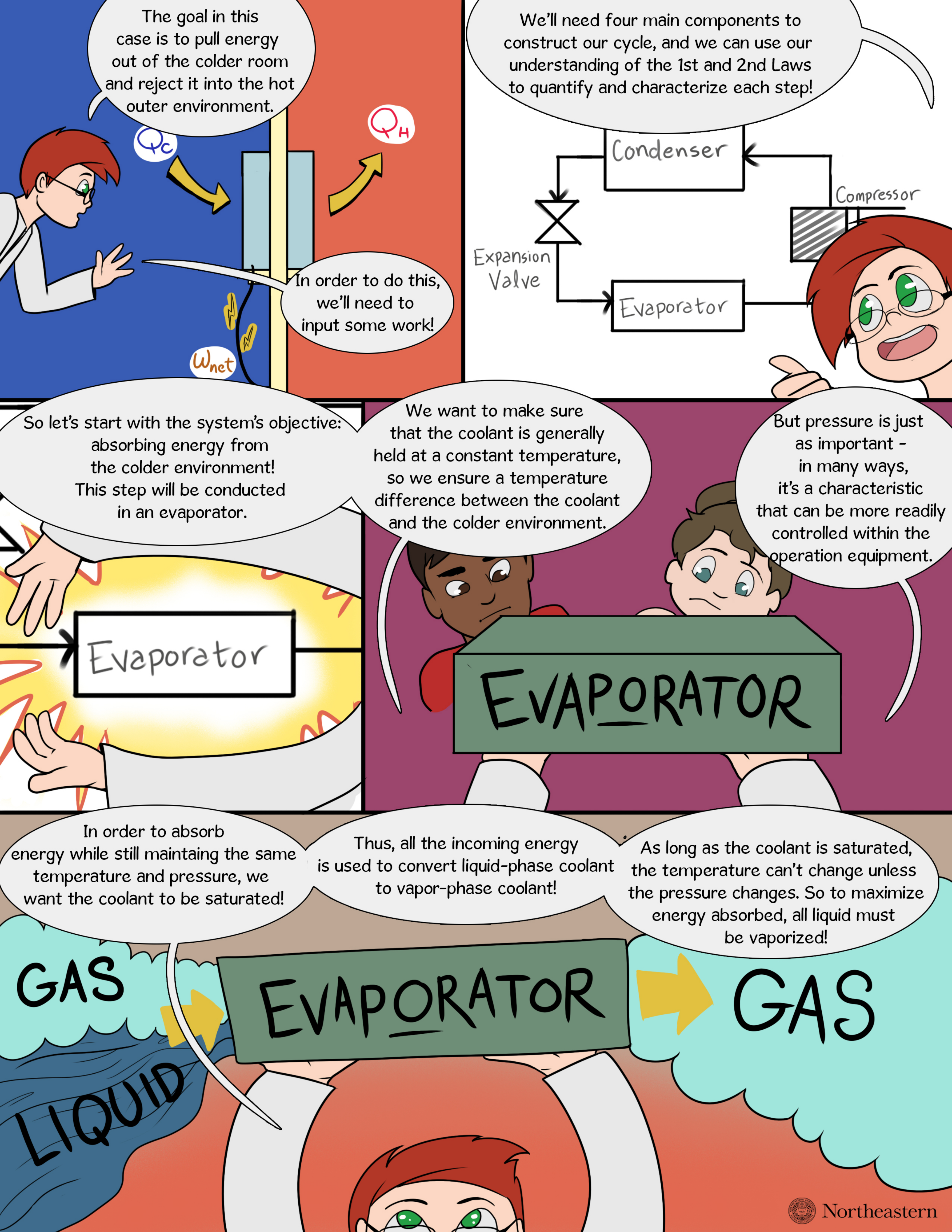
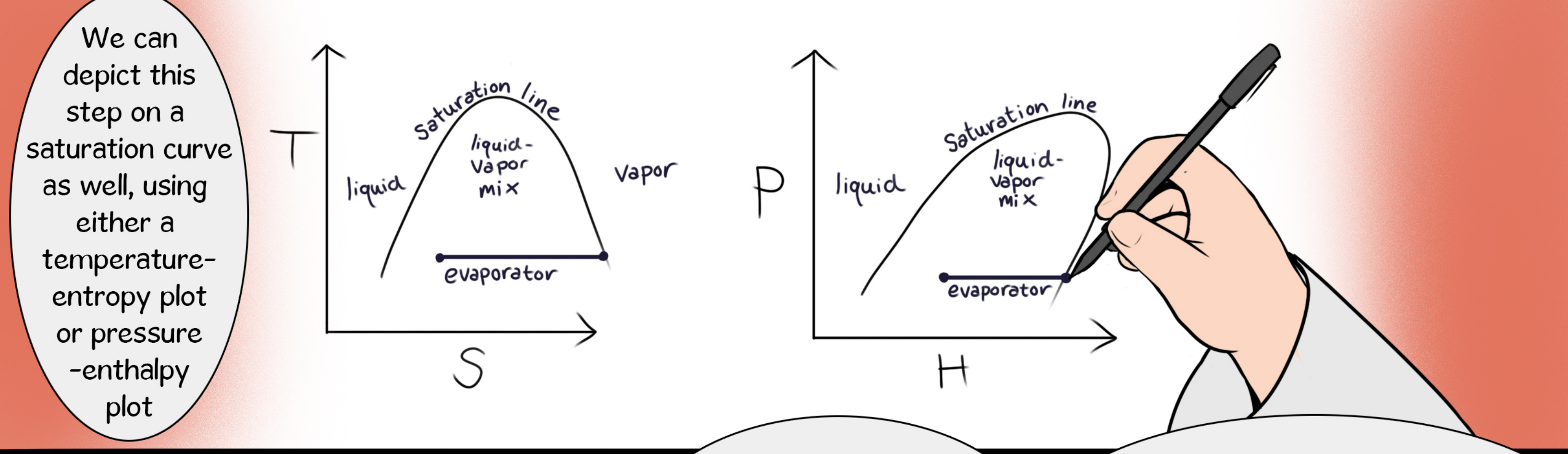

The goal in this case is to pull energy out of the colder room and reject it into the hot outer environment.
Qc
QH
In order to do this, we'll need to input some work!
Wnet
We'll need four main components to construct our cycle, and we can use our understanding of the 1st and 2nd Laws to quantify and characterize each step!
Condenser
Compressor
Expansion Valve
Evaporator
So let's start with the system's objective: absorbing energy from the colder environment! This step will be conducted in an evaporator.
Evaporator
We want to make sure that the coolant is generally held at a constant temperature, so we ensure a temperature difference between the coolant and the colder environment.
But pressure is just as important – in many ways, it's a characteristic that can be more readily controlled within the operation equipment.
EVAPORATOR
In order to absorb energy while still maintaing the same temperature and pressure, we want the coolant to be saturated!
Thus, all the incoming energy is used to convert liquid-phase coolant to vapor-phase coolant!
As long as the coolant is saturated, the temperature can't change unless the pressure changes. So to maximize energy absorbed, all liquid must be vaporized!
GAS
LIQUID
EVAPORATOR
GAS



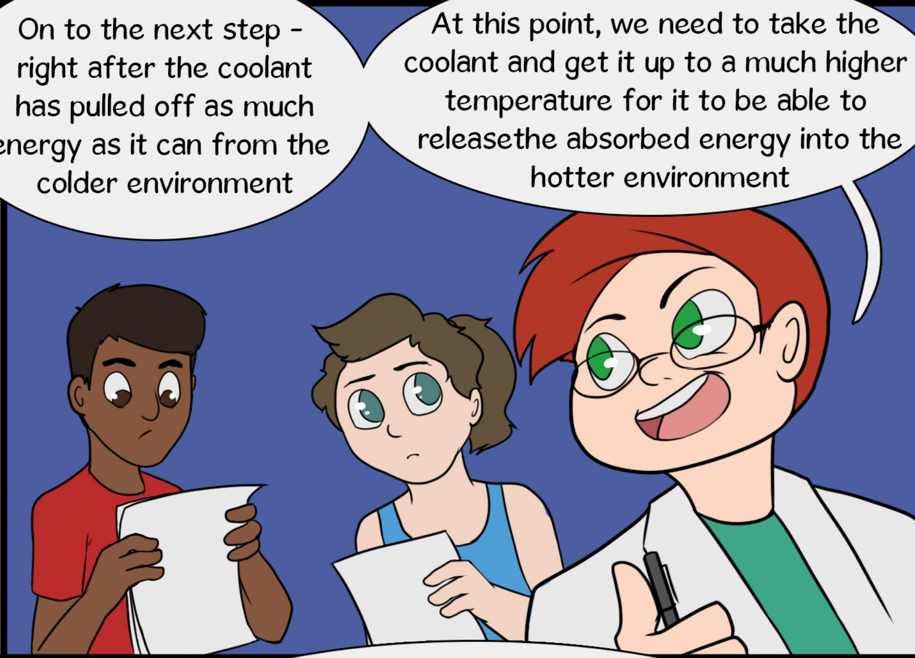
And we can determine how much heat will be absorbed from the simplified 1st law!

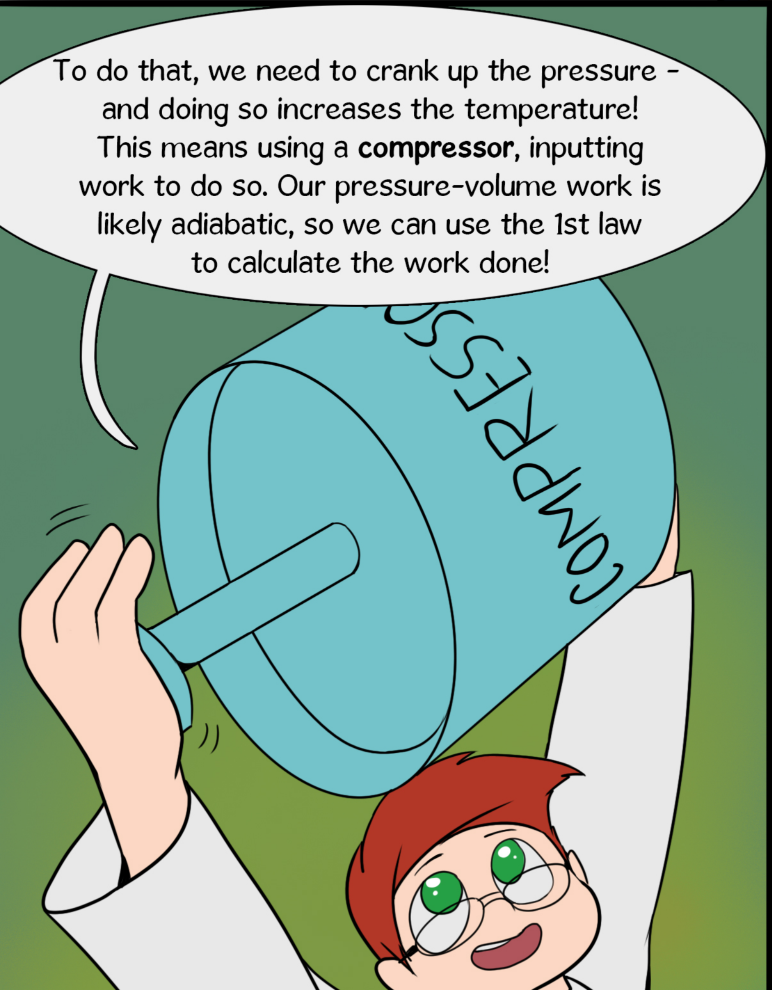
$$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta H = Q_c + \cancel{W_S}$$

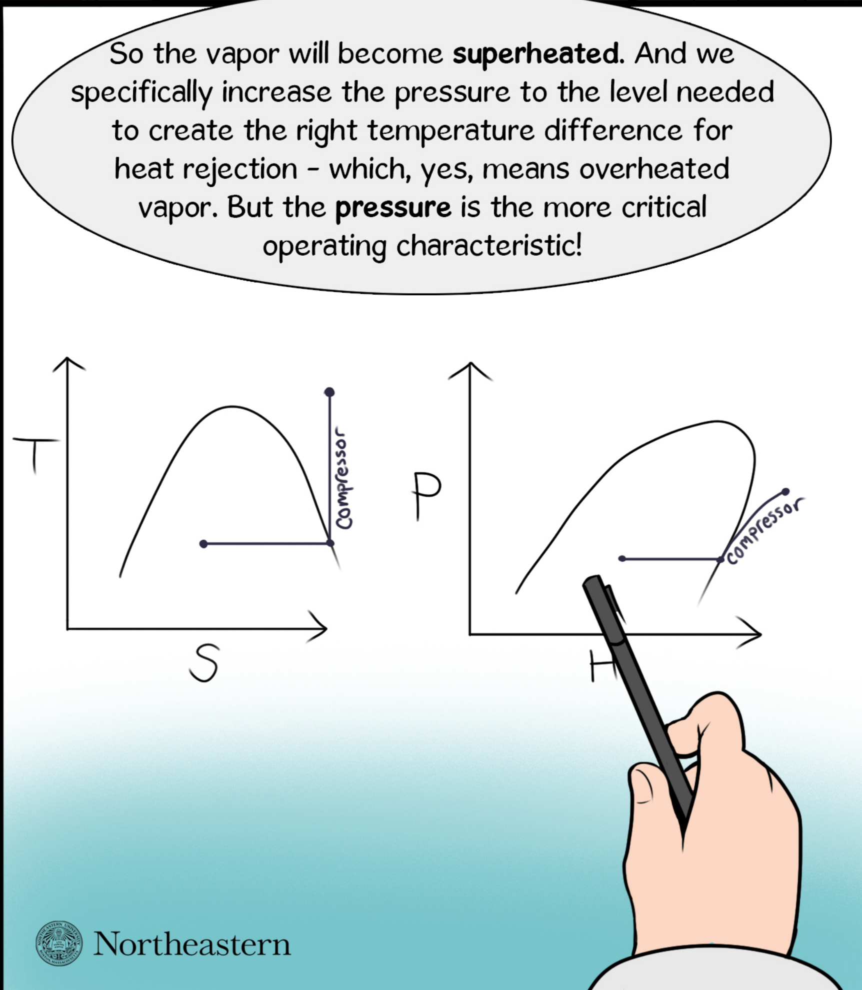
$$\Downarrow$$

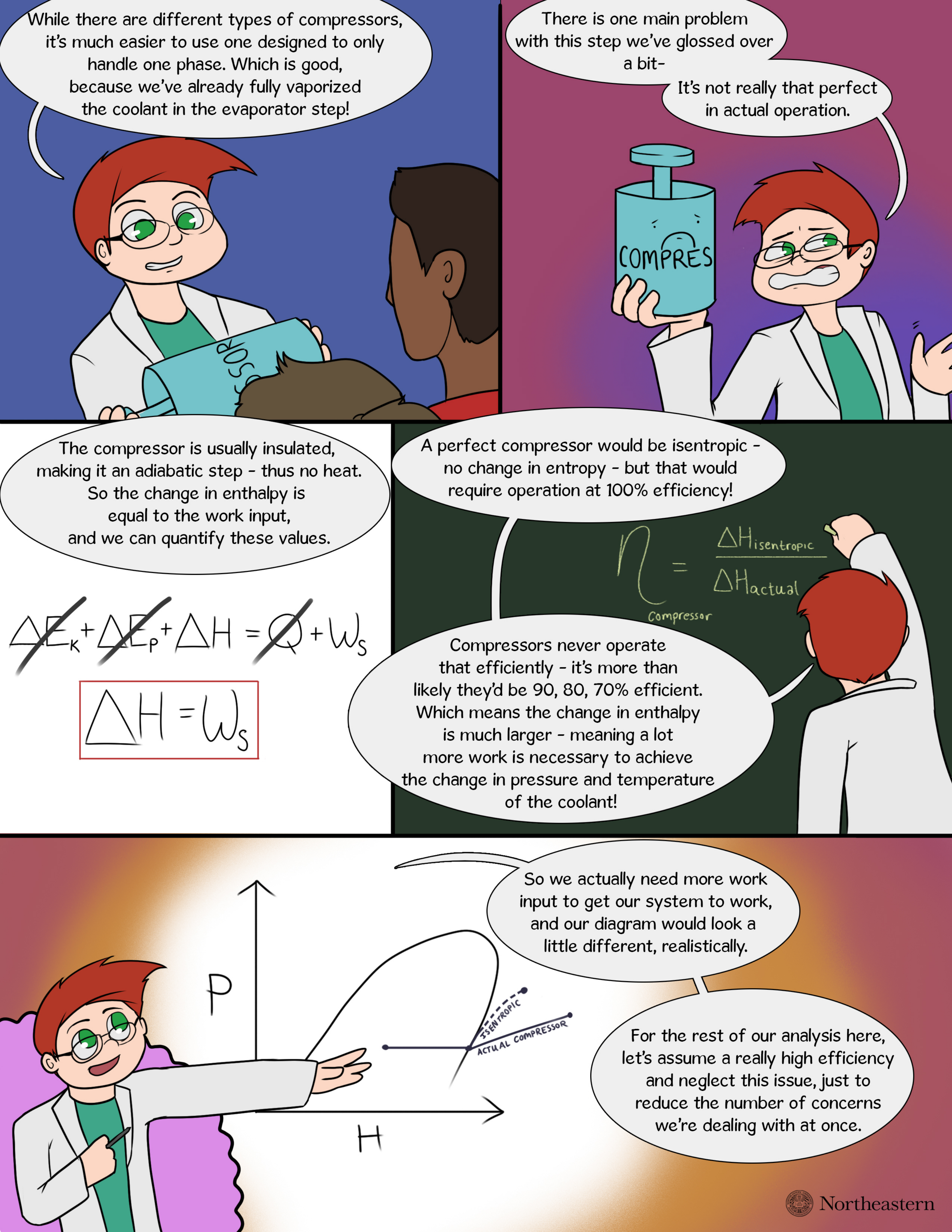
$$\boxed{\Delta H = Q_c}$$

Pressure is constant, so no work is input, so the change in enthalpy is equal to the heat absorbed!








While there are different types of compressors, it's much easier to use one designed to only handle one phase. Which is good, because we've already fully vaporized the coolant in the evaporator step!
SSOR
There is one main problem with this step we've glossed over a bit-
It's not really that perfect in actual operation.
COMPRES
The compressor is usually insulated, making it an adiabatic step - thus no heat. So the change in enthalpy is equal to the work input, and we can quantify these values.
$\cancel{\Delta E_K} + \cancel{\Delta E_P} + \Delta H = \cancel{Q} + W_S$
$\boxed{\Delta H = W_S}$
A perfect compressor would be isentropic - no change in entropy - but that would require operation at 100% efficiency!
$\eta_{\text{Compressor}} = \frac{\Delta H_{\text{isentropic}}}{\Delta H_{\text{actual}}}$
Compressors never operate that efficiently - it's more than likely they'd be 90, 80, 70% efficient. Which means the change in enthalpy is much larger - meaning a lot more work is necessary to achieve the change in pressure and temperature of the coolant!
So we actually need more work input to get our system to work, and our diagram would look a little different, realistically.
P
H
ISENTROPIC
ACTUAL COMPRESSOR
For the rest of our analysis here, let's assume a really high efficiency and neglect this issue, just to reduce the number of concerns we're dealing with at once.
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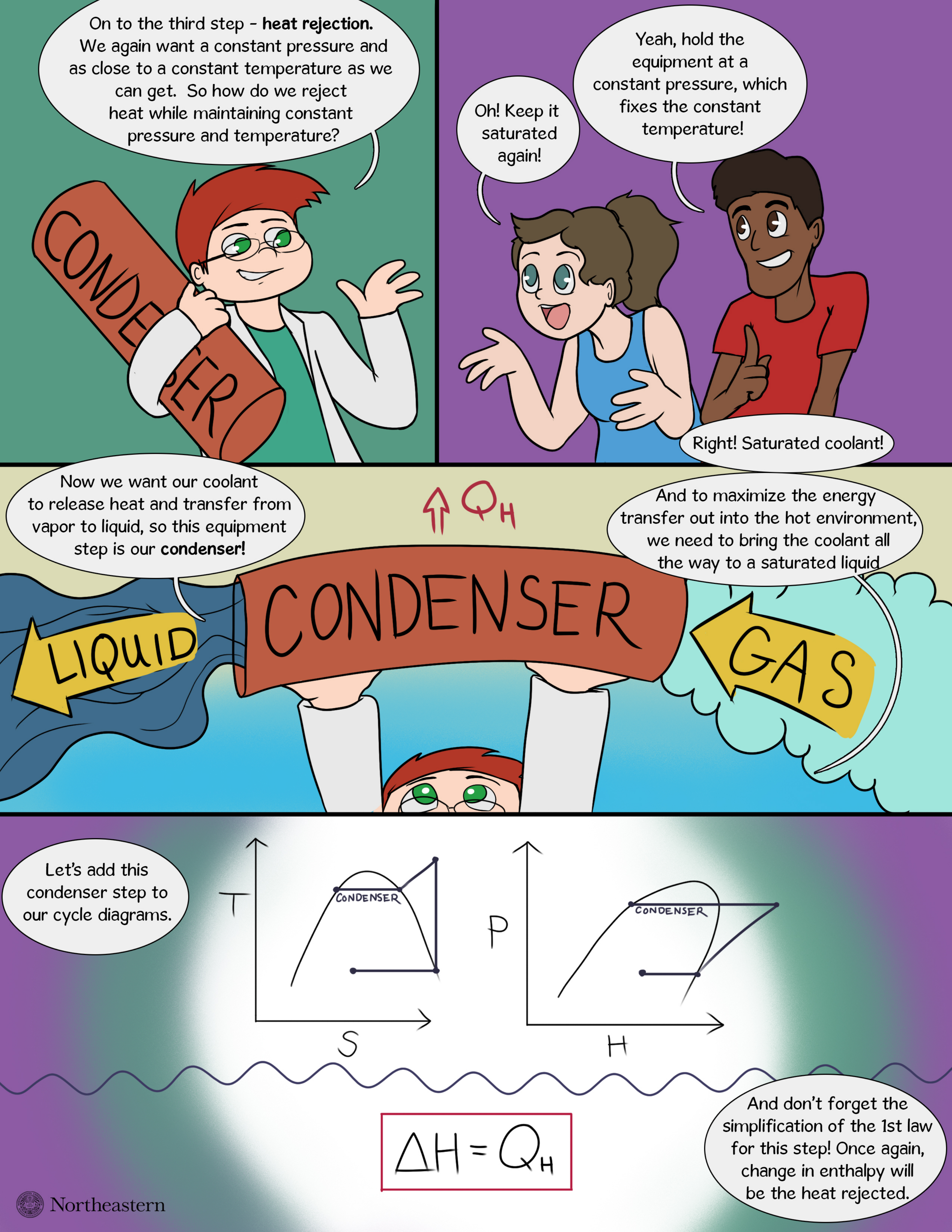
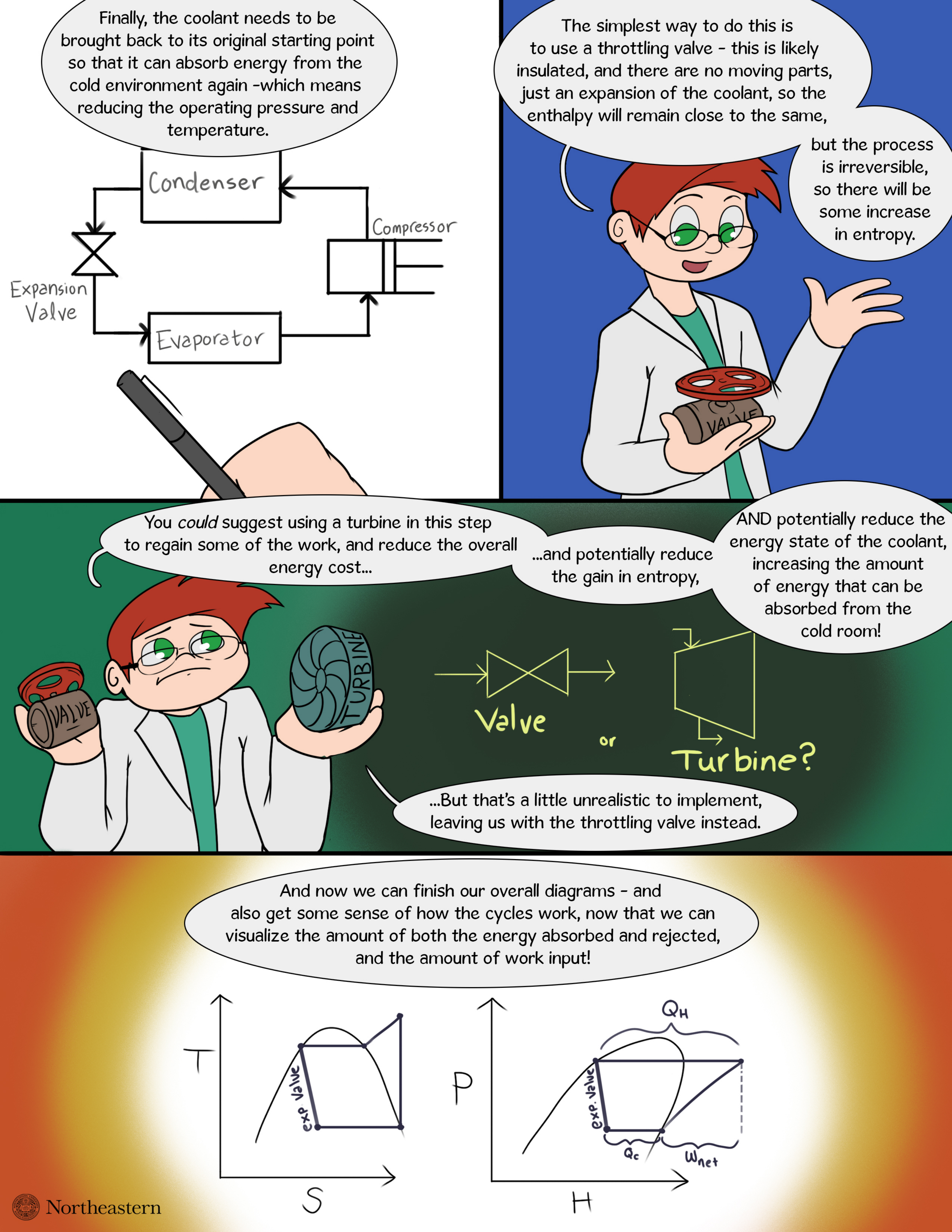

On to the third step - **heat rejection.** We again want a constant pressure and as close to a constant temperature as we can get. So how do we reject heat while maintaining constant pressure and temperature?
CONDENSER
Oh! Keep it saturated again!
Yeah, hold the equipment at a constant pressure, which fixes the constant temperature!
Right! Saturated coolant!
Now we want our coolant to release heat and transfer from vapor to liquid, so this equipment step is our **condenser!**
$\Uparrow Q_H$
And to maximize the energy transfer out into the hot environment, we need to bring the coolant all the way to a saturated liquid
LIQUID
CONDENSER
GAS
Let's add this condenser step to our cycle diagrams.
T
S
CONDENSER
P
H
CONDENSER
$\Delta H = Q_H$
And don't forget the simplification of the 1st law for this step! Once again, change in enthalpy will be the heat rejected.


Finally, the coolant needs to be brought back to its original starting point so that it can absorb energy from the cold environment again -which means reducing the operating pressure and temperature.
Condenser
Compressor
Expansion Valve
Evaporator
The simplest way to do this is to use a throttling valve - this is likely insulated, and there are no moving parts, just an expansion of the coolant, so the enthalpy will remain close to the same,
but the process is irreversible, so there will be some increase in entropy.
VALVE
You *could* suggest using a turbine in this step to regain some of the work, and reduce the overall energy cost...
...and potentially reduce the gain in entropy,
AND potentially reduce the energy state of the coolant, increasing the amount of energy that can be absorbed from the cold room!
VALVE
TURBINE
Valve
or
Turbine?
...But that's a little unrealistic to implement, leaving us with the throttling valve instead.
And now we can finish our overall diagrams - and also get some sense of how the cycles work, now that we can visualize the amount of both the energy absorbed and rejected, and the amount of work input!
T
exp. Valve
S
P
Q_H
exp. Valve
Q_c
W_{net}
H


To quantify how well the refrigeration cycle functions, we rely on the **coefficient of performance**, or COP. The higher COP value, the better!
$CoP_R = \frac{\text{desired output}}{\text{required input}} = \frac{q_c}{w_{net,in}}$
But that still doesn't explain why the AC box isn't working!
Well, assuming that all the components inside are functioning correctly...
Remember the driving force at work?
Temperature difference!
Between the coolant and the surrounding air, on both sides!
Right!
The thing to be careful of is that a **refrigeration cycle** works similarly to a **heat pump** – but the refrigeration cycle is designed to pull heat energy out of a colder environment, and a heat pump is designed to pump heat energy into a warmer environment. A correctly installed AC is essentially a heat pump for the outdoors.
Incorrectly installed, however...
You're telling us we put it in the window as an *indoor heat pump?!*
We put it in **backwards??**
This is what we call a learning experience – in more ways than one! Stay cool!
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