Overview
You know that putting on another layer of clothing helps keep you warm on a chilly day. The same is true for the Earth — the layers of the atmosphere keep Earth’s surface warm.

Theory
If the Earth was bare rock with no atmosphere, like the Moon, the average surface temperature would be approximately -18°C (about 0°F). Earth is, of course, warmer than this — quite a bit warmer, as it turns out. The average surface temperature on the earth is approximately 15°C (about 60°F). Earth is kept warmer by its atmosphere; the mechanism by which this occurs is known as the greenhouse effect. It’s easy to do a simple experiment that gives clues as to how the atmosphere works this magic. The key, just like the key to keeping warm in the winter, is layers.

If you place your hand in a cup of cold water, heat will flow from your hand to the water. If you then put your hand in a cup of hot water, heat will flow from the water to your hand. That’s thermodynamics — specifically, the second law of thermodynamics: Heat flows from hot to cold. The rate at which heat flows depends on the temperature difference; heat flows more quickly if the temperature difference is large, more slowly if it is small. If you swim in a cool river, you’ll get chilly after a while; if you swim in the Arctic Ocean, you will rapidly develop hypothermia.

This dependence on temperature difference is true for all mechanisms of heat exchange, including conduction (direct transfer by two objects in physical contact), convection (transport of fluids, like water or air), or radiation (transfer of energy by emission of electromagnetic waves.) Earth sits in the vacuum of space, so the only way it can gain or lose energy is by radiation. Understanding energy gain and loss by radiation helps us explain why the Earth is warmer than it “should” be.

Layers keep you warm by gradually “stepping down” the temperature between your body and the outside world. Adding more layers will decrease the temperature difference across each layer — each “step” will be smaller. The atmosphere above us has many layers, and their temperatures vary. Earth gets energy in the form of electromagnetic radiation from the sun, and it gives off energy, again as electromagnetic radiation, to space. But there’s a difference in these two types of radiation.

The wavelength of the electromagnetic waves that an object emits depends on the object’s temperature. Higher temperature means shorter wavelength. The incoming radiation from the Sun, a star with an average surface temperature around 6000°C, is mostly visible light. The visible light passes right through the atmosphere. The outgoing radiation from the surface of Earth, a planet with an average temperature around 15°C, is mostly longer-wavelength thermal radiation. Thermal radiation doesn’t pass through the atmosphere so easily; much of it is absorbed by greenhouse gases (especially water vapor and carbon dioxide) in the atmosphere and then re-emitted. The direction in which the radiation is re-emitted is random; some travels toward space, but some travels back toward Earth’s surface. These gases in the layers of our atmosphere thus keep us warmer.

Doing the activity
This lesson gives you a good excuse to teach outside — in the winter! You want your (warmly attired) students to be outside long enough that the temperatures of the layers of their clothes have equilibrated. This will take some time, at least 10-15 minutes. After this time, their garments will be warm on the inside, cool on the outside. You’ll get the most interesting results from students wearing layers — a shirt, an insulating inner jacket, and a thin outer “shell” jacket would be ideal.
We'll assume this set of layers for the following description.

- Have one student with a good set of layered clothing serve as the test subject. Pick a spot on their arm and use the thermal radiation sensor to measure the surface temperature of their jacket.
- Now, have them quickly remove his outer jacket, and measure the surface temperature of their sweater at the same spot.
- Next, have them quickly remove his inner jacket, and measure the surface temperature of their shirt.
- Finally, use the thermal radiation sensor to measure their skin temperature (the inside of the forearm works well here).
- Look at the range of temperatures, from the skin to the outside of the jacket. There's a big temperature difference between the inside and the outside, but each layer sits next to another layer which is only slightly different in temperature. Ask your students to explain how this layering, this “stepped” temperature profile, helps them stay warm.

Now, do this:

- Aim the thermal radiation sensor at the sky. Space is quite cold — deep space is about -270°C, or -455°F. But the sensor measures a temperature that is much less frosty; it will probably read about 0°C, or perhaps as cool as -10°C or even -30°C. Cold, yes, but not -270°C! (It’s important to note that what you measure isn’t actually the temperature of the sky, for reasons explained below.)

The sensor is measuring thermal radiation emitted by a layer of the atmosphere that absorbs the earth’s emitted thermal radiation. This is, in general, how thermal radiation sensors work: They measure thermal radiation, and make some assumptions to calculate a temperature based on this measurement. This is why we prefer not to call them “infrared thermometers” — they’re not really measuring temperature! The assumptions the device makes aren’t accurate for the earth’s atmosphere, so if you measure a sky temperature of -12°C, this just means that you’re getting very little thermal radiation from the sky (but still more than you’d get from space). Because the Earth is covered by a layer of atmosphere that is cooler than the earth but warmer than space, it keeps the earth warmer. After making both measurements, you can help your students make this connection.

**Summing up**

Now, for the obvious question: If Earth is kept warm by the atmosphere, and if carbon dioxide in the atmosphere is in no small part responsible for this warming, and if we as a species are increasing the level of carbon dioxide in the atmosphere, won’t that cause the earth to warm up? The answer is: Almost certainly. It’s like putting on another layer of clothing on a cold winter day, a simple matter of thermodynamics. Of course, the atmosphere is more complicated than this; there might be other effects. But it is a fact that we are adding carbon dioxide to the air, and that the climate is changing.

**For more information**

Little Shop of Physics: [https://www.lsop.colostate.edu](https://www.lsop.colostate.edu)

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