Barcode of the Cosmos: Exploring the Electromagnetic Spectrum

(Describing the spectrum as a barcode is owed to Richard Dawkins' excellent book "Unweaving the Rainbow", see "Resources".)

Teacher Background

Every object in the universe--stars and human beings--emits, reflects, and absorbs electromagnetic radiation. The characteristic way an object does this can be used to explore its chemical and physical composition and state. Infrared radiation, radio waves, ultraviolet light, x-rays, and gamma rays are all different forms of electromagnetic radiation. They are alike in that all are waves, but the length of the wave (i.e. the wavelength) varies with the different kinds of radiation. Unaided human eyes can only see visible wavelengths. We've evolved to use that portion of the Sun's output which most readily reaches the surface of the Earth. Unprotected human skin (especially fair skin) is also, unfortunately, an ultraviolet "radiation detector" and turns red after exposure.

Technically speaking, electromagnetic radiation is a transverse energy wave with two components--an electric field and a magnetic field. A wave can be characterized by wavelength and frequency. But unlike other types of waves, such as sound waves or waves in water, electromagnetic radiation does not require the involvement of matter to transfer energy. It passes through a vacuum at the constant speed of 300,000 km per second (the speed of light). The basis for this behavior is the photon, a small bundle of mass-less electromagnetic radiation. So we need to think of electromagnetic radiation (in one of the mind-blowing findings of 20th Century physics) as being at various times both a wave and a particle.

These different wavelengths and frequencies are organized into what we call the "electromagnetic spectrum", or EMS. In the EMS, as wavelength decreases, frequency and energy levels increase. Humans can see only a portion of the EMS, called the "spectrum of visible light." But these visible wavelengths make up only a small section of the total EMS. Longer wavelengths outside the visible range in one direction can be felt as infrared radiation or heat. Humans radiate infrared radiation since they are warm-blooded organisms and body heat is released into the environment. Shorter wavelengths, just outside the visible range in the other direction, are called ultraviolet radiation. Sunburn is evidence of this radiation.

This Activity provides a way to make the key concepts of wavelength and frequency meaningful. It then offers students the opportunity to explore portions of the EMS reprising some of the classic experiments first undertaken by Newton, Herschel and Ritter, through which we humans discovered key characteristics of the EMS existing beyond visible light. You may find that by breaking down your class into "Spectrum Teams" and having them undertake the various activities, writing up their own particular labs as a poster or other form of presentation , and then reporting back to the whole class, you can make the entire spectrum meaningful. Sorry, but even we could not come up with a hands-on gamma ray Activity!

Objective
Students will be able to identify key components of the EMS in terms of wavelength and relationship to visible light.
Students will be able to identify many ways in which parts of the electromagnetic spectrum other than visible light are encountered in daily life.

Vocabulary
amplitude, crest, frequency, gamma ray, infrared, interference, prism, radio, trough, ultraviolet, wavelength

Engage
Ask students to extend a bare arm into bright sunlight. Have them report what they feel. Do they see any radiation on their arms? How do they explain the warmth they are feeling? Ask if they can think of other situations where energy is present and some type of change occurs. Make a list, guiding discussion to include microwave ovens used for cooking, communication satellites, x-rays for medicine, radio and TV waves for communication, etc.

Ask students if sunlight, radio waves, microwave ovens in kitchens and medical X-rays are somehow related, or are all different. Ask students if all living creatures on Earth see the same world around them. (Bees see "bee-purple" and many insects see patterns of ultraviolet light on flowers which we do not perceive.) List all answers. Guide discussion to include the full spectrum of radiation, such as medical X-rays, infrared devices such as remote controllers, ultraviolet, etc: you may be surprised by how well science fiction on TV [e.g. Star Trek, The X-Files, etc.] and in film has exposed them to the names of (if not actual understanding of) more exotic forms of radiation.) Ask how they know that these forms of radiation exist, and how they impact their lives. Accept all ideas.

Now they’re ready to hop onto the "Shoulders of Giants" (as Newton expressed a scientist’s debt to those who came before), and explore the electromagnetic spectrum for themselves. We suggest starting with Newton and prisms, then moving on to wavelength, and then exploring as many other regions of the EMS as you can--perhaps by using "Spectrum Teams" as "Co-Investigators" as suggested above.