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The Pedagogical Potential of Infrared Cameras in Biology Education

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Abstract

Thermal imagery provides new opportunities to study concepts and processes in biology. Examples include using infrared (IR) cameras in educational activities to explore energy transfer and transformation in human physiology, animal thermoregulation, and plant metabolism. The user-friendly and visually intuitive nature of IR technology is well suited to the study of rapidly changing temperatures on biological surfaces, due to such energy transfers. IR cameras are therefore potentially helpful pedagogical tools for approaching the Energy and Matter crosscutting concept in the Life Sciences discipline of the Next Generation Science Standards.

Key Words: *Infrared cameras; biology education; NGSS.*

○ Introduction

Thermal imaging technology is based on the fact that all objects emit thermal radiation. The wavelength of the radiation depends on the temperature of the object – for typical temperatures on Earth, predominantly in the infrared (IR) range. An IR camera detects the radiation emitted from an object's surface. Together with assumptions of surface emissivity, the object's temperature can be calculated and displayed on a screen numerically and along a selected color scale – for example, where warmer surfaces are rendered red and colder surfaces blue (Vollmer & Möllmann, 2017). Thermal imaging is used for a multitude of applications, including detecting heat leakages in buildings, avoiding overheating of electronic components, surveillance, and aerial observation of any remaining hot spots after forest fires. In medical science, applications include detection of increased body temperature due to infection or poor blood circulation due to diabetes (Lahiri et al., 2012). Apart from industrial and medical use, thermal imaging has also become increasingly popular in displaying nocturnal animal behavior in wildlife films, such as the National Geographic production *Night of the Lion*.

Entry-level handheld IR cameras are durable, intuitive to use, and becoming increasingly more affordable. The FLIR C3 model that we used in our experiments costs ~$700. Less expensive IR camera versions such as FLIR ONE and Seek Thermal can be directly connected to a smartphone or tablet computer. Due to the versatility of thermal imaging, IR cameras are gaining momentum as pedagogical tools across all levels of science education. To date, the technology has been adopted mostly in physics and chemistry educational practice (e.g., Vollmer et al., 2001; Xie, 2011; Haglund et al., 2015), but there are also compelling opportunities for the learning of various concepts and principles in biology. In the sections below, we describe a range of life science content areas where the use of IR cameras can enhance students' biology learning. We also suggest how the activities can be mapped onto specific learning objectives at different grade levels in the *Next Generation Science Standards* (NGSS).

○ IR Applications in Human Physiology

Kubsch et al. (2017) describe an experiment in teaching human physiology in which students use an IR camera to observe local temperature increases of muscle tissue during exercise. While sitting in the "wall seat" position with thighs perpendicular to the wall, increases in temperature on the surface of students' legs are visible after 40–50 seconds. In other experiments concerning the human somatosensory system, an IR camera can help students explore how the sense of touch relates to temperature measurements. For instance, at room temperature, metal feels colder than wood or plastic, due to differences in the thermal conductivity of different materials (Haglund et al., 2015). Similarly, a hand that is moved from cold water to tepid water feels warm, but a hand that is moved from hot water to the same tepid water feels cold (see Figure 1); hence, the exercise demonstrates that the sense of touch is not a reliable thermometer (Jeppsson et al., 2017). In addition, one's skin feels cool when stepping out of a shower. Using an IR camera, one can observe

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that the cool sensation is caused by a temperature decrease due to evaporation of water from the skin (Vollmer & Möllmann, 2017), which also serves as the main mechanism of thermoregulation through sweating.

By combining IR imaging with students' physical experiences of thermal phenomena, such activities are useful in targeting the NGSS disciplinary core idea Organization for Matter and Energy Flow in Organisms. In particular, apart from enhancing middle (or even late elementary) school students' understanding of concepts such as heat and temperature in the physical sciences, IR cameras may help students gain insight into different ways in which energy is transferred from their bodies to the surroundings.

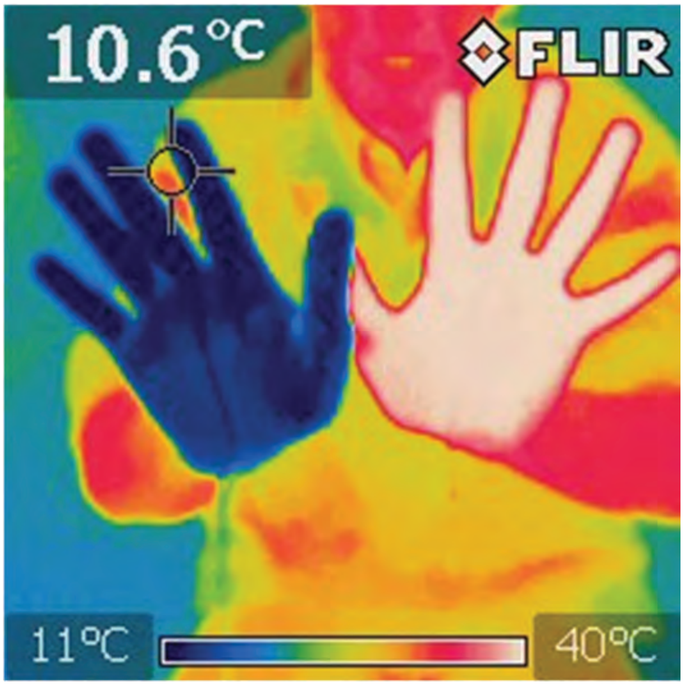

Figure 1. IR image captured with a FLIR i3 camera following submerging one's hands in cold (left) and warm (right) water.

○ Studying Animals' Thermal Regulation with IR Cameras

Thermal imaging also contributes to research in animal physiology and veterinary medicine (McCafferty, 2007), which opens up for various potential educational interventions. For instance, with a handheld IR camera, students can compare respective temperatures and thermal profiles of a horse's inflamed leg with an otherwise healthy leg (see Figure 2, left). In addition, in adapting to cold climates, different horse breeds develop a thick coat during winter, which also leads to increased sweating during exercise. Some horse owners trim their horses' coats in order to avoid this (and a buildup of dirt), but then they have to cover the horses when they are at rest to avoid cooling. In this regard, an IR camera allows students to study various aspects of equine thermoregulation during different temperature conditions and states of physical activity (see Figure 2).

In a similar fashion to investigating human physiology, when applied to animal thermoregulation at the middle and high school levels, IR cameras are useful in targeting the NGSS disciplinary core idea Organization for Matter and Energy Flows in Organisms. Here, the recognition of the insulating function of fur becomes particularly salient, which helps emphasize energy as a crosscutting concept in physics and biology.

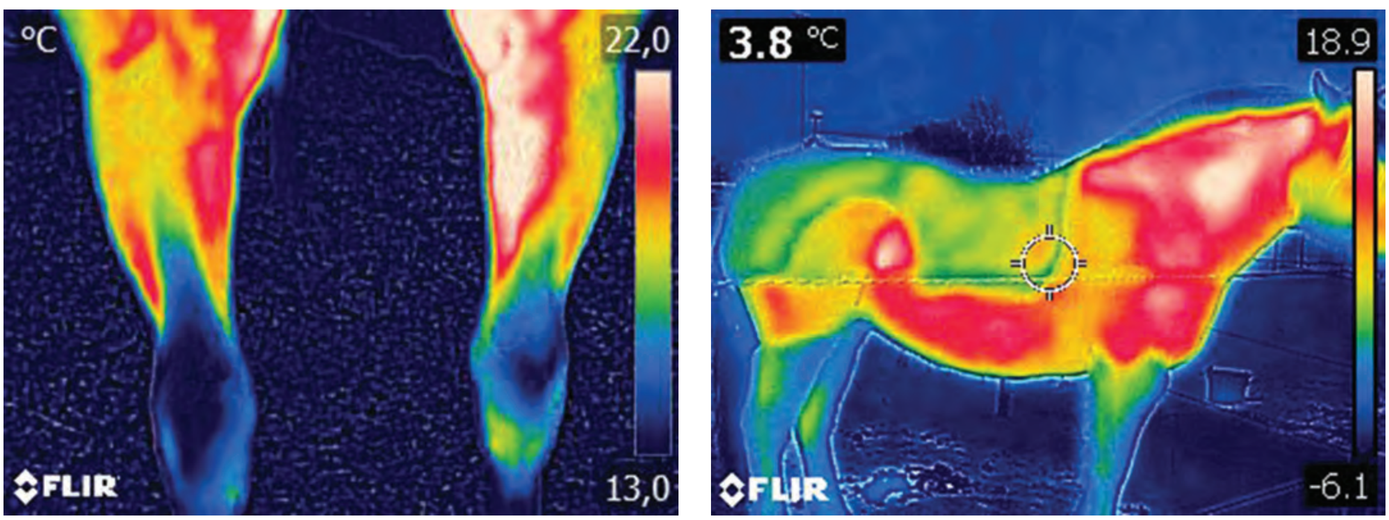

Figure 2. (Left) The temperature of the right hind leg of a horse is shown to be higher (see the lighter-colored accompanying thermal profile) than the temperature of the left hind leg due to an inflammation, which can inform the decision to cease training. (Right) A thermal image of a horse while outdoors during a winter temperature of –6°C. The horse's coat has been shortened on the barrel and shoulders, which have a higher temperature than on the back and croup, where the increased coat growth insulates against the cold. Note the low temperature of the legs, even though the leg hair has not been trimmed. (Both IR images were taken by students at the Lillerudsgymnasiet high school in Sweden with a FLIR C3 camera.)

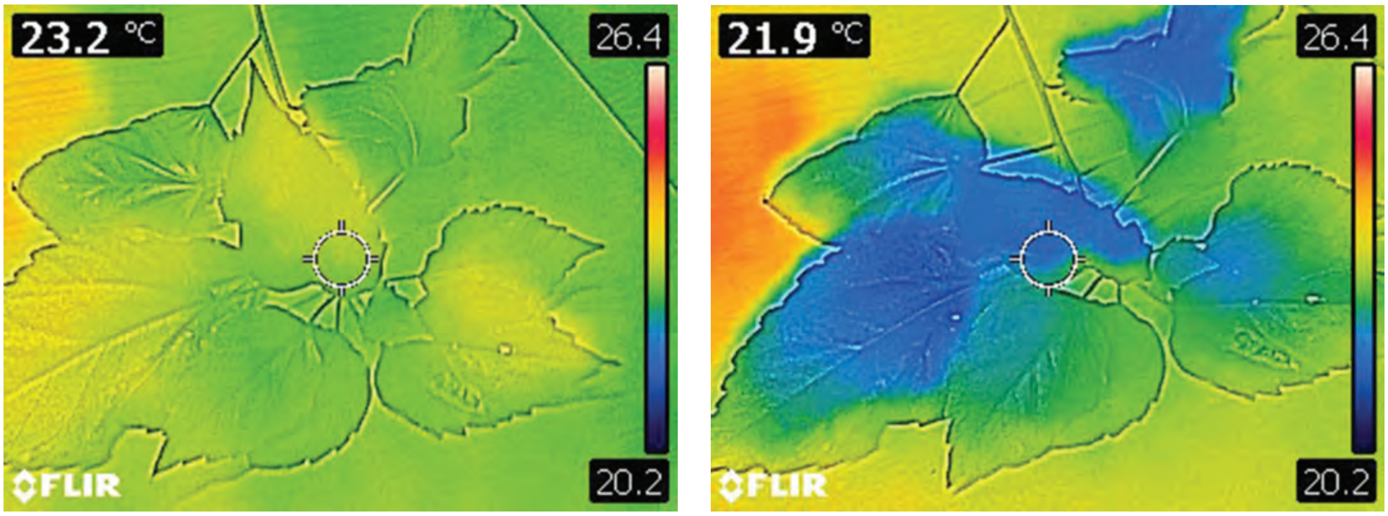

Figure 3. Thermal images taken with a FLIR C3 camera of a leaf surface one minute (left) and 25 minutes (right) after the leaf was severed from a plant. The image on the right displays the temperature decrease due to rapid initial stomatal opening (and consequent increased transpiration) as a physiological stress response to water deficit.

○ Visualizing Plant Metabolism in IR

Plant physiology is a further topic of instruction that can be supported with the use of an IR camera. One clear example is investigating temperature variation of plant leaves due to stomatal regulation. In agriculture, studying the response of crops to drought, fertilizers, or genetic manipulation is an important application of thermal imaging, either in laboratory conditions or through remote sensing in aerial observations with drones and helicopters (Jones, 2004; Costa et al., 2013). As part of undergraduate teaching of energy-related aspects of photosynthesis and cellular respiration, Donovan et al. (2013) have introduced students to IR images of titan arum (corpse flowers) that exhibit higher temperatures than their surroundings. An increase in plant metabolism produces foul odors to attract pollinators to a mimicked rotten-meat smell that is associated with a significant temperature increase while the spathe opens. In applying handheld IR cameras to biology education contexts, Xie (2012) has demonstrated that fresh leaves and dry leaves have the same temperature in conditions where they have reached thermal equilibrium with the surrounding air. However, the leaves of well-watered plants can exhibit temperatures considerably lower than the surroundings. In addition, in a process known as the Iwanov effect (Jones, 2004), severing the leaves from a plant induces cooling of the leaf surface as stomata initially open rapidly due to a water deficit (see Figure 3).

As part of the NGSS disciplinary core idea From Molecules to Organisms: Structures and Processes, high school students are expected to develop an understanding of energy transfer and transformation involved in cellular respiration and how organisms maintain their temperature. Visualizing such processes with thermal cameras provides interesting learning opportunities for practical inquiry-based approaches to the content area.

○ Conclusions

Handheld IR cameras offer new pedagogical opportunities to study thermal phenomena in biology education. The technology is well suited to identifying and visualizing differences and changes in surface temperatures, which is difficult to accomplish with conventional classroom and laboratory thermometers. The described IR camera activities emphasize the cross-disciplinary nature of the NGSS, particularly in relation to the crosscutting concept Energy and Matter.

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