ABSTRACT

Visualizing thermoregulation (endothermy vs. ectothermy) in animals can be challenging for students in undergraduate biology courses. Data-driven, hands-on laboratory activities can enhance student learning while reinforcing application of the scientific method. This article describes a visual-learning, inquiry-based activity that can be applied to introductory high school and college biology laboratories with the use of easily accessible technology (a smartphone and an inexpensive thermal camera attachment). Students generate hypotheses and qualitatively observe real-time thermal images of live endothermic and ectothermic animals. This activity is effective in engaging students by allowing them to visualize thermoregulation and body temperature. We provide suggestions for modifying the activity to further investigate animal behavior related to temperature regulation.

Key Words: thermal ecology; FLIR ONE; smartphone technology; animal physiology; heat exchange; thermoregulation; metabolism.

Introduction

The use of smartphones as an experimental tool has been neglected in the field of education research (Kuhn & Vogt, 2013). Although it can be challenging to integrate smartphones into the classroom while not letting them be a source of distraction (Anshari et al., 2017), they are definitely useful for collecting scientific data for both indoor and outdoor applications, due to their design, ease of use, and ability to enhance student learning (Gutowsky et al., 2013). At the same time, more classroom activities are needed for introductory high school and university biology courses that utilize visual representations of scientific data to increase students’ understanding of typically unobservable scientific phenomena (Arneson & Offerdahl, 2018). One example where smartphone technology can be utilized includes the visualization of thermoregulation, the ability of an organism to maintain its body temperature within certain boundaries. Emerging technologies such as the FLIR ONE thermal camera (https://www.flir.com) and the Seek thermal compact (https://www.thermal.com) allow smartphone users – both students and instructors – to use their phones as thermal cameras.

Thermoregulation in animals falls into two broad categories: endothermic and ectothermic (Vitt & Caldwell, 2013). Endotherms use metabolic activity to maintain a relatively constant body temperature, regardless of ambient temperature, through metabolic activity. Ectotherms, on the other hand, depend primarily (with a few exceptions) on external heat sources and therefore rely on behavioral thermoregulation to increase their body temperature and metabolic rate (Reece et al., 2014). Common organismal examples of endotherms include birds and mammals, while ectotherms include amphibians, fish, many invertebrates, and reptiles.

Recently, lizards (a widespread group of reptiles in the order Squamata) have been identified as an ideal model organism for classroom inquiry, as they are widespread and relatively easy to procure and maintain in a classroom setting (Matthews et al., 2014). Reptiles such as lizards often regulate their body temperature behaviorally by moving between shady and sunny areas (Cowles & Bogert, 1944). Students often have misconceptions about ectothermic animals and about the general biology of reptiles, including lizards, which are often described as “cold-blooded” or “cold to the touch” (Crump, 2015). In addition, students often assume that endothermic animals (i.e., mammals and birds) will always have a higher overall body temperature than reptiles year-round, regardless of behavior. This can discount reptiles such as lizards and turtles, which actively increase their body temperature by basking in warm sunny habitats and,
therefore, can often be found with higher surface temperatures than endotherms. Thermal imaging technology can give students a means to develop their scientific inquiry skills and better understand endotherms and ectotherms by visualizing heat data (i.e., temperature).

Thermal imaging technology has been used extensively in biological research (Tattersall & Cadena, 2010), but while it has been applied in physics classrooms (Haglund et al., 2015), to the best of our knowledge it has not been used in introductory biology classes at the high school or university level, likely due to the expense of traditional thermal imaging cameras, which may cost several thousand dollars each. Yet thermal imaging can enhance the classroom experience by allowing students to interpret body temperature not just as a number, but as a fluid, active landscape of thermal energy represented by color heat signatures or visually appealing digital thermograms (Short, 2012). Recent developments in tablet- and smartphone-enabled devices, such as the FLIR ONE Gen 3 iOS thermal camera (which costs about $200), can open up a world of possibilities and opportunities to engage undergraduate biology majors and high school students in hands-on scientific discovery. Here, we provide a laboratory activity that incorporates smartphone technology and an affordable thermal camera to investigate thermoregulation of lizards and mammals in a high school or university biology classroom.

Objectives
The pedagogical objective of this activity is to utilize accessible technology to teach thermoregulation. Our specific objectives are for students to

1. visualize thermoregulation of an ectothermic vs. endothermic animal, using a FLIR ONE camera to generate digital thermograms (temperature); and
2. generate hypotheses in relation to ectothermic and endothermic animals and relate these findings to animal adaptations and behavior.

This three-hour exercise is appropriate for both high school and university introductory biology laboratories, and it could be modified for upper-level college courses in herpetology, mammalogy, ecology, and physiology or even for courses in nursing or fitness and sports science. It can be adjusted for difficulty level and incorporated into STEM activities based on course objectives and, potentially, outreach science. It could be supplemented with lecture activities and background information on thermal differences between endotherms (mammals and birds) and ectotherms (amphibians, reptiles, and fish) as needed in any relevant biology course.

Materials
The following materials are needed per class of 12–24 students:

- Thermal camera. We used the FLIR ONE Gen 3 iOS camera and FLIR TOOLS application for smartphones (https://www.flir.com). This handheld, smartphone-enabled compact infrared thermal camera plugs directly into smartphones or tablets and is used in conjunction with the application (freely downloadable from iTunes or Google Play). It includes a spot meter option for visualizing temperature and operates between −20°C and 120°C. Other options for a comparable smartphone- or tablet-enabled thermal camera include the Seek thermal compact (https://www.thermal.com). Alternatively, if costs are prohibitive, this activity can be modified to use handheld infrared thermometers, readily available at home improvement stores. However, the latter usually only allow students to record surface temperature and typically do not include thermograms. Instructors with limited funds can purchase one thermal camera per classroom and have students take turns using it.

- Smartphone. An Android or iOS smartphone device can be provided by the instructor or the student. Whichever type of smartphone is used, the instructor must confirm that the thermal camera’s operating system matches the smartphone’s operating system.

- Live animals. Many college biology laboratories or classrooms have “class pets” that fall into either the endothermic or the ectothermic category. We used readily available outreach science animals, including two lizards and a mouse. However, we caution that if live animals are used in the classroom, state and local wildlife laws, animal care and use policies, and permits for keeping animals must be strictly followed. Moreover, many universities have an institutional animal care and use committee, which may require additional approval for work with vertebrates. If live animals are unavailable, this activity can be modified by having students compare body temperatures of classmates while sitting and after having completed a brief exercise.

Activity Procedure

Prelab Preparation
Live animals were housed in appropriate containers following university animal care and use policies. The two anole lizards (Anolis carolinensis) used in the experiment were each placed in a different 10-gallon tank, one outfitted with a standard 75-watt heat lamp while the other was kept at ambient room temperature (~70°F). Both tanks had bark bedding with water bowls and metal screen lids. We housed the mouse (Mus musculus) in a plastic container for this activity, but we recommend that instructors keep the mouse in a similar container as the lizards, only with hardwood bedding, a water bowl, and a hiding shelter at room temperature. All animals were obtained from a local pet store. All electronic devices, including thermal cameras, smartphones, and tablet devices, were charged prior to each laboratory.

Introductory Presentation
A short presentation (~15 minutes) by the instructor at the beginning of the lab period gave the students background information for the activity. This presentation highlighted the differences between endothermic and ectothermic animals and defined the terms thermoregulation, endotherm, and ectotherm (Table 1). Several organismal examples and behavioral adaptations of thermoregulation across organismal groups were presented (Table 2: step 1). Importantly, the instructor also reviewed the steps of the scientific
method prior to the start of this laboratory activity (following Sterner, 1998).

**Laboratory Investigation**

Upon completion of the presentation, the students were given a datasheet that included observational questions for them to answer as part of the activity (Figure 1). Several of the questions on the datasheet were designed to engage students in thinking more broadly about endothermic and ectothermic animals, not only in the laboratory, but also in terms of their behavior and locations in the field (e.g., turtles or lizards basking in summer). The class was then divided into groups of four to six students. Each group was asked to generate at least one specific predictive or generalized hypothesis related to metabolic rates of endothermic and ectothermic animals (Table 2: step 3). Examples of student hypotheses include “It is hypothesized that body temperature of ectotherms (like the lizard) will be closer to ambient room temperature,” “The mouse will show a higher temperature than both lizards,” and “The lizard in the tank with the heat lamp will have a higher temperature than the lizard without a heat lamp.” Next the instructor ensured that the students were generating correct hypotheses before proceeding with the activity.

The student groups then visited three separate stations and used the FLIR ONE infrared thermal imaging camera to photograph animals at each. These stations included (1) a mouse kept at ambient room temperature (~70°C; Figure 2), (2) a lizard kept under a heat lamp, and (3) a lizard kept at ambient room temperature (Figure 3). The spot feature of the FLIR ONE application was

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**Table 1. Definitions of thermoregulation, endotherm, and ectotherm used in this lab activity.**

| Term       | Definition                                                                 | Examples                                                                 |
|------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Thermoregulation | The ability of an organism to maintain its body temperature within certain boundaries | Humans sweat to remain cool Dogs and birds pant to thermoregulate |
| Endotherm  | An animal capable of maintaining a constant body temperature                | Mammals, birds                                                           |
| Ectotherm  | An animal that relies on external sources for heat by altering its behavior | Reptiles, amphibians                                                     |

**Table 2. Laboratory investigation procedure and corresponding steps of the scientific method (modified from Sterner, 1998).**

| Step | Detailed Procedure                                                                 | Steps of the Scientific Method                  |
|------|-----------------------------------------------------------------------------------|--------------------------------------------------|
| 1    | Pre-laboratory presentation: overview on ectothermic and endothermic animals. Outline the laboratory activity. Divide class into groups of four to six students and hand out datasheet. | Observe                                         |
| 2    | Ask groups to work together to answer questions 1 and 2 on datasheet.              | Ask questions                                   |
| 3    | Ask groups to generate hypotheses. Instructor checks that these are valid, properly formatted scientific hypotheses. | Generate hypotheses                             |
| 4    | Groups individually go to one of the three stations (mouse at room temperature, lizard under heat lamp, lizard at room temperature). At each station, groups take a thermal image using the FLIR ONE camera. Upon completion at one station, each group goes to another station until all three stations have been visited by each group. | Test hypotheses, collect data                   |
| 5    | Groups provide their temperature data to the instructor. Class data are pooled and made visible to all students. Results are analyzed by taking averages across groups. | Analyze results                                 |
| 6    | Once students have class data, groups work together to answer question 5 on datasheet. | Draw conclusions, interpret results             |
| 7    | Instructor reviews responses to question 5 on datasheet with whole class to allow for discussion of similarities and discrepancies across groups. | Evaluate the hypotheses, revise unsupported hypotheses as needed |
used to focus on one specific area for collection of temperature in degrees Fahrenheit. The students completed question 4 on the datasheet (Figure 1) by filling out a table for the three experimental animals (mouse, ambient lizard, and heat lamp lizard) with the following cells: “Endotherm or Ectotherm?,” “Air Temp °F,” “Animal Temp °F,” and “Physical/Behavioral Adaptations for Thermoregulation.” Relevant student data were then pooled across groups and provided to the students in laboratory. Next the students completed question 5 on the datasheet (Figure 1), and the instructor reviewed their responses with the whole class. The instructor discussed any similarities or discrepancies the groups may have observed in temperatures or in hypotheses not being supported. A list of steps for this activity, which correspond to specific portions of the scientific method (Sterner, 1998), is presented in Table 2. Potential reflection questions to engage students in discussion of the activity and results include the following:

- Where were the animals located in the tank? (in the case of the lizard, in relation to the heat source)
What is the relationship between ambient temperature and the temperature you recorded for the surface temperature of ectotherms or endotherms?

Were the heat signatures the same across the animals you examined?

How do you account for variation across student groups in terms of temperatures observed?

Additional follow-up questions to generate discussion could be designed to pique student interest and relate thermoregulation to other topics.

○ Results

The students were able to examine and generate thermograms or thermal images with temperature heat signatures represented by varying colors (Figure 3). The average temperatures (pooled across laboratories) that the students recorded with the FLIR ONE for the mouse, ambient lizard, and heat lamp lizard were 85.93 ± 1.39°F, 70.969 ± 0.828°F, and 90.86 ± 2.21°F, respectively (Figure 4).

○ Evaluation of the Activity

Immediately following the activity, a series of follow-up questions were asked to allow the students to reflect on their knowledge (see above). When reviewing these reflection questions with the class, we stressed how temperature and environmental conditions place certain selective pressures on organisms, which lead to various physiological, anatomical, and behavioral adaptations. Finally, the students used a Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Slightly Disagree, 4 = Slightly Agree, 5 = Agree, and 6 = Strongly Agree) to respond to the statement “Using the thermal imaging camera helped me further understand the difference between endothermic and ectothermic animals.” The results for the 98 freshman college students who participated in the activity are as follows: Strongly Disagree, 0%; Disagree, 3%; Slightly Disagree, 1%; Slightly Agree, 10%; Agree, 39%; and Strongly Agree, 47% (Figure 5).

○ Discussion

This activity effectively engages biology students, requires minimal investment, can be modified according to specific needs and availability of materials, and is appropriate at either the high school or the university level. Potential uses of these handheld, smartphone-enabled thermal imaging cameras include a wide variety of laboratory or in-class applications, and this activity leaves room for many modifications and potential improvements based on course and learning objectives.

To assess the thermal habitat selection of ectothermic and endothermic animals outside the classroom at different times of the year, instructors and students could observe birds, common lizards, squirrels, and other animals in and around campus wooded areas or in any urban setting. This could further students’ understanding of thermal ecology and basic temperature data (in shaded vs. unshaded forest canopies) as it relates to thermoregulation. Instructors could also discuss thermoregulation in terms of ecology, adaptation, and even current issues such as climate change’s potential effect on the ability of ectothermic animals to thermoregulate behaviorally (Kearney et al., 2009).

Instructors may choose to modify the FLIR ONE camera settings to record temperature in degrees Celsius. While students may be more familiar with degrees Fahrenheit – for example, in relation to weather, cooking, or human body temperature – scientists typically...
work with Celsius. Instructors could also have students convert between degrees Fahrenheit and Celsius using a standard formula: 
\[ ^\circ C = \frac{(^\circ F - 32) \times 5}{9} \]

There are many other potential modifications. Students could take “thermal selfies” at different levels of physical activity, monitoring a peer’s body temperature while seated compared to immediately following some bout of exercise. This could be useful when teaching physiology; humans are homeothermic endotherms but radiate heat more “explosively” when in the process of evaporative cooling. Another modification could involve recording the temperature of objects (hot vs. cold liquid, etc.), formulating hypotheses, and testing them with the thermal imaging camera. For example, classic studies in reptile thermoregulation have found variations between inanimate objects (like water-filled cans) and reptiles thermoregulating (Heath, 1964). Students could design experiments to study how anole lizards “cool down” through behaviors such as moving away from a perched basking area, whereas inanimate objects are unable to do so. Instructors could also maintain multiple individuals of anoles, mice, snakes, birds, or other organisms (e.g., 5–10 animals) in order to instruct students on variation among individuals and have students perform basic calculations on averages, standard deviation, and statistics. Instructors could have students analyze data pooled across groups or multiple organisms in Microsoft Excel using the “Analysis Toolpack” add-in. Interestingly, many of our students were able to dispel the misconceptions that reptiles are consistently “cold-blooded” or that the mouse will always have a higher heat signature than the basking lizard.

○ Conclusion

This activity allows high school or university students to utilize smartphone technology to learn about thermoregulation using the scientific method. Furthermore, students working together in groups are able to formulate and test their hypothesis, then discuss whether the hypothesis was supported or refuted and why. Overall, we found that this activity piqued student interest while concomitantly reinforcing major concepts of thermoregulation in animals for both the laboratory and lecture in an introductory biology course.

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