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Seeing in the Dark and Through Walls: Using IR Cameras in STEM Outreach

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Seeing in the dark and through walls: using IR cameras in STEM outreach

Abstract

The recent introduction of affordable infrared (IR) cameras and IR imaging attachments for smartphones has provided a unique opportunity to enhance the education of K-12 students. We have acquired a number of different IR cameras and IR camera attachments and discuss the utilization of these devices in both a college course and in our STEM and STEAM outreach efforts. While our outreach efforts have placed us in a classroom for just an hour or two at a time, thanks to local IEEE Chapter support, we have placed IR cameras in these classrooms for several weeks at a time.

This paper discusses the outreach efforts and the utilization of IR cameras by 5th grade elementary school students and their classroom teachers after our departure and the wild enthusiasm that this approach has generated. A comparison of the different IR systems is also made.

1 Introduction

It is well known that student enthusiasm leads to increased interest and learning. The authors have leveraged student enthusiasm to enhance learning in DSP courses for many years.[1–7] Lately, we have been using infrared (IR) cameras in our Energy for Society course at Boise State University, in an attempt to increase student enthusiasm and motivation to learn the course material. The Energy for Society course has been offered for three years now.

What is IR? The infrared (IR) part of the electromagnetic spectrum has longer wavelengths (i.e., lower frequency) than the visible light that we humans take for granted. The *visible spectrum*, which humans can perceive directly with their eyes, spans wavelengths of approximately 400–700 nm, with the extrema depending upon the lighting conditions.[8,9] A broad range of the electromagnetic spectrum is shown in Figure 1, where the IR portion of the spectrum can be seen to the left of the visible spectrum. Our eyes are of no help when it comes to IR; the IR spectrum can only be directly perceived by humans as heat. Thus an IR camera must assign a range of colors that we *can* see to the IR energy we cannot directly see. This technique is often called *pseudocolor* in the literature.[10] Capturing images in IR poses challenges for camera designers. For example, typical optical glass used for visible wavelengths does not pass IR wavelengths well, and normal visible camera sensors have IR-blocking filters to prevent saturation.[11–13] While these and other challenges can be overcome, acceptable quality IR cameras have, until recently, been quite expensive. Today, the availability of IR cameras that combine reasonable price with acceptable image measurement quality provides a new opportunity for STEM outreach.

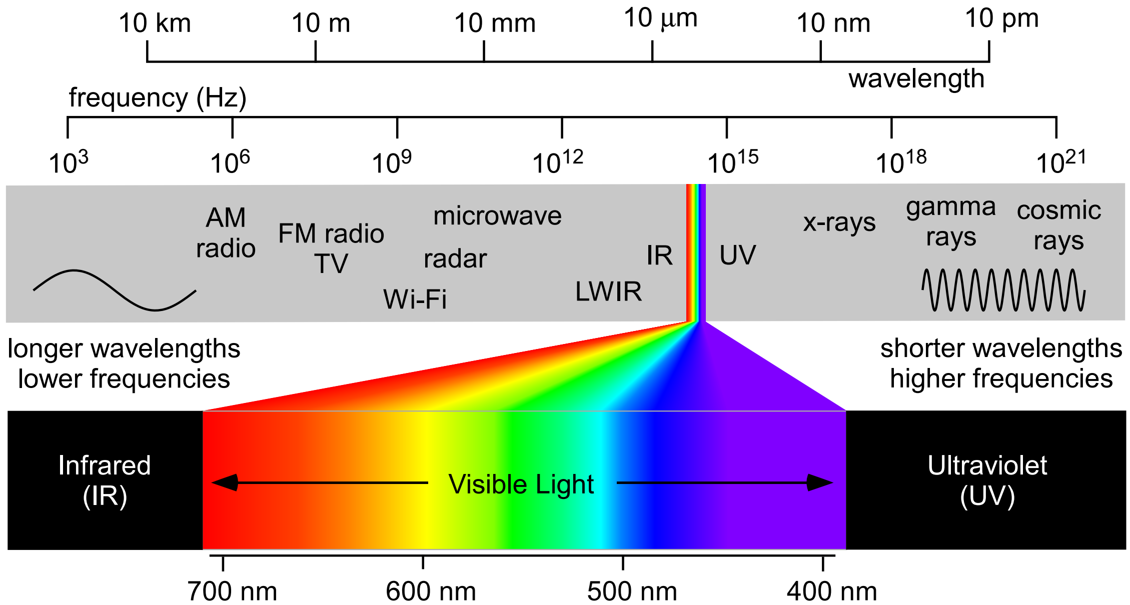

Figure 1: Regions of the electromagnetic spectrum pertinent to this discussion.

2 The Energy for Society Course

The Energy for Society course is a technical literacy course that is provided as an alternative to more traditional course offerings concerning physics, chemistry, or biology. In this course, we use a variety of IR cameras to help our students see heat or its absence. In other words, the IR camera maps temperature to color (i.e., the IR camera provides pseudocolor assignment). For an example of such images, see Figure 2.

These cameras have been very effective at helping students realize issues such as the importance of insulation and weather stripping. This is illustrated, for example, in Figure 3, where inadequate insulation is obvious in IR but otherwise would be difficult to detect. Even apparently “blank” walls yield insights when using IR. In Figure 4 (top), the studs inside the wall can be seen in the IR spectrum, due to a lack of an insulation break. Figure 4 (bottom) shows a standard color image (*not* pseudocolor) of this same wall using visible light wavelengths. These images were both taken at night at approximately the same time and without any artificial lighting.

3 STEM Outreach for Elementary Students

After our successes using IR cameras to help college students understand energy and heat flow, we were invited to discuss energy as it relates to salmon and the damming of rivers with a 5th grade class at Spalding STEM Academy in Boise, Idaho. Dams, and their effect on salmon, is a huge issue in Idaho, since the average fuel mix for Idaho Power states that 49% of the electricity provided must come from hydroelectric power.[14]

In their multi-week module, these students are asked to decide if the dams should be breached to help restore the habitat for the salmon. Regardless of their decision, they must justify the decision’s

Figure 2: Teaching assistants for the Energy for Society course (top), and a teapot filled with hot water (bottom). Both are shown as IR images. Note the key for the pseudocolor assignment of color to temperature (in degrees Celsius) is shown in a vertical bar on the right edge of the images.

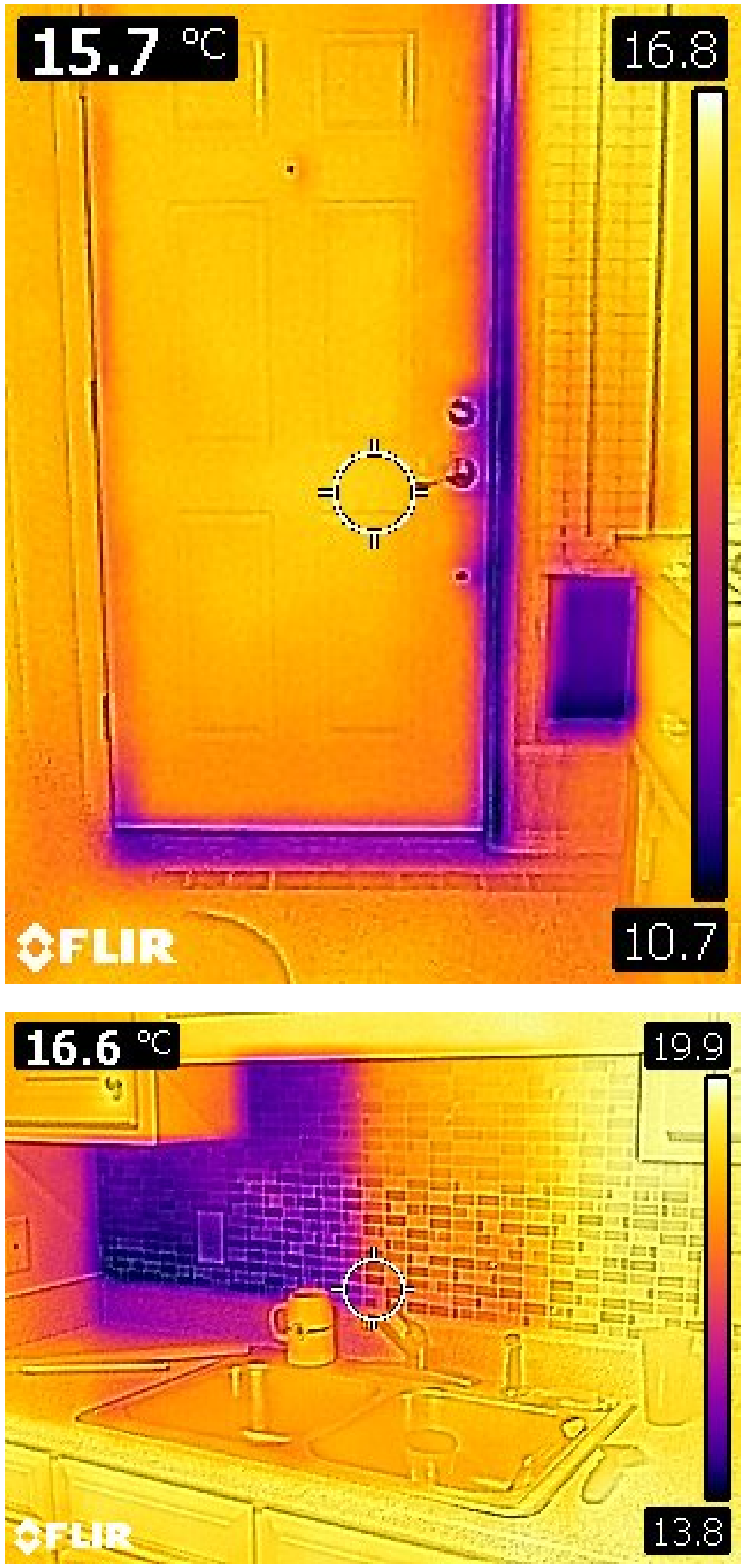

Figure 3: An exterior door with poor weather stripping (top), and an improperly insulated kitchen backsplash (bottom).

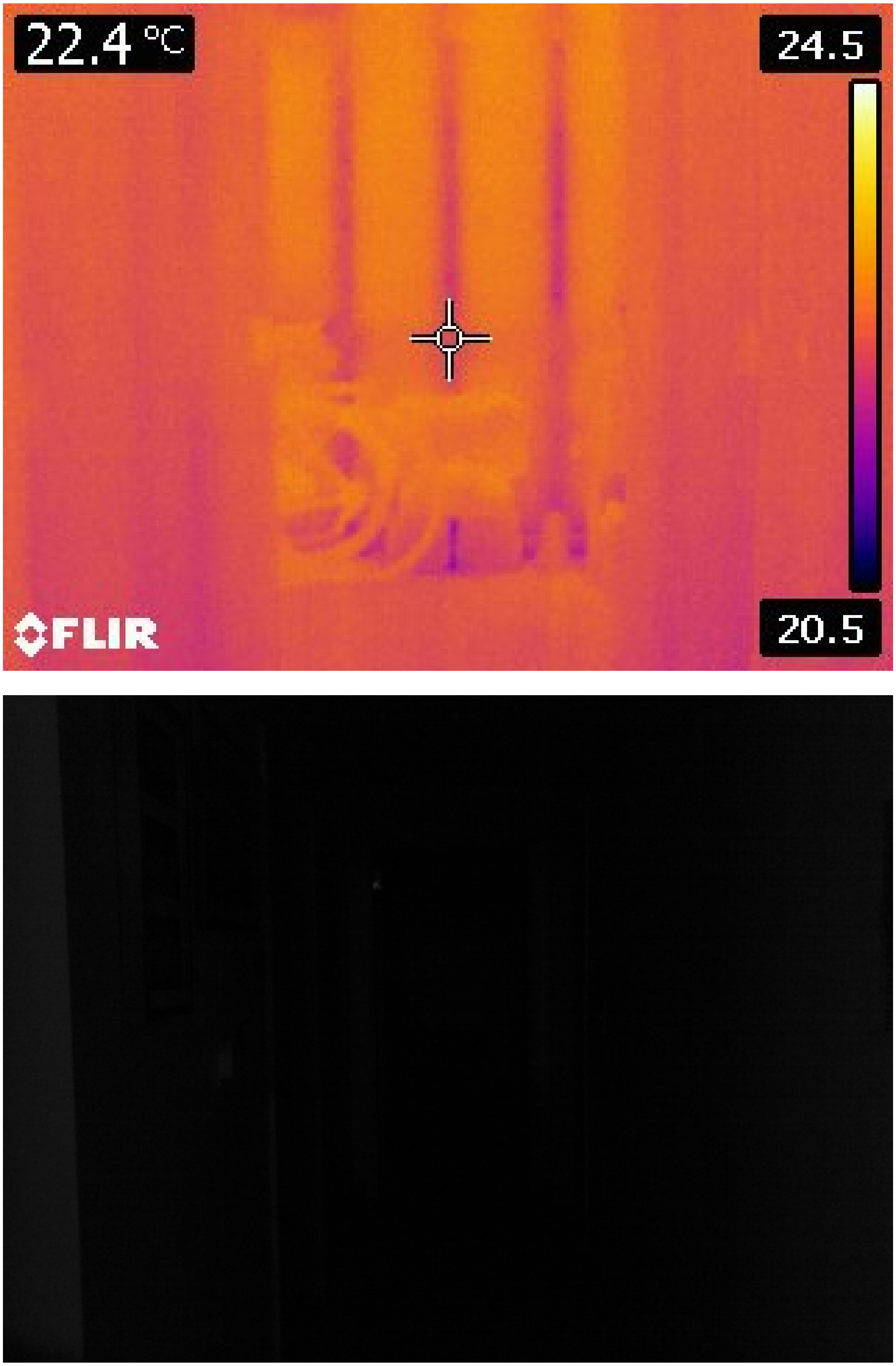

Figure 4: Studs seen through an exterior wall (top), and the same wall imaged using only the visible light spectrum (bottom). Both images were obtained at night without any artificial lighting.

impact on electric power production. Most of these students decided that if we reduced our electric power consumption by at least 49%, then the dams would not be needed for power production. The students were also aware of the fact that a number of these dams provide flood control for a number of towns, cities, and farms.

Given that residential heating/cooling and transportation, taken together, account for a significant portion of electricity usage, these students began using the FLIR C2 IR camera that we left with their teacher to find wasted energy, by identifying various heat signatures. The local IEEE Chapter made leaving an IR camera with the class possible.

In addition to the FLIR C2 IR camera, we also left a copy of an IR camera introduction document that we created. This document is appended to this paper as Appendix A.

The success of motivating 5th graders in Boise led us to expand the outreach to 5th graders at Coles Elementary School in Manassas, Virginia. These students used inquiry-based practice with a Seek-Thermal Camera attachment for a smartphone. The learning goal was, "The student will investigate and understand that matter is anything that has mass and takes up space; and occurs as a solid, liquid, or gas; and the effect of temperature on the phases of matter." Students were tasked with exploring and creating the most light- and sound-efficient classroom. To do this, students were placed in groups to solve the stated problem. Throughout the lessons, they gained more knowledge and understanding of the problem at hand. To create their "perfect" classroom, students brainstormed ideas of what they thought would be the best insulator of heat after learning about each state of matter. Each group selected materials with which to perform their experiment. Once hypotheses were created and constants were set, each group selected different materials to be placed on the classroom windowsill. Each item was placed on the windowsill for one hour, while being tested to see how effective the material was at insulating heat. The test was conducted with the same material over three different days. During this time, students recorded their findings and created an answer to their over arching question, "Which material would be the best insulation for our classroom?" During their experiment, students took one IR picture every fifteen minutes, for the entire hour. This gave each group enough data to make the best decision regarding the most effective, insulating material to use.

A 5-point Likert-scale psychometric survey was given to the 88 participants in the 5th grade at Coles Elementary School. The survey question was, "The infrared camera helped me better understand energy and heat." The results are given in Table 1.

Additional comments were optional. Some of the comments provided by the 5th grade students are given below.

- "Yes! The camera helped me see what material to use in my classroom!"
- "The experiment was able to show me what materials would be best to conserve heat"
- "I liked being able to choose my own materials and test the heat energy!"

As a whole, the 5th graders decided that using the infrared camera was extremely beneficial to their

Table 1: Results from 5th graders at Coles Elementary School in Manassas, Virginia. The survey question was, “The infrared camera helped me better understand energy and heat.”

Response Category	**Response Rate** ($N = 88$)
Strongly disagree	0%
Disagree	0%
Undecided	4%
Agree	25%
Strongly agree	71%

learning. They were able to identify which materials were the best for conserving heat energy. In addition, once they started the experiment and finished their first trial, they were able to predict how everyone else’s experiments would conclude. Using the IR camera led to extended discussions in the classroom, and the students were able to see and understand the relationships of heat and energy.

4 Something for everyone: an IR camera comparison

As mentioned earlier, IR cameras are now becoming available that combine both reasonable performance and affordable price, which means their use for STEM outreach is more realistic. After a brief period of familiarization, the cameras were relatively easy to use, which is an important factor if STEM outreach is the goal. The IR cameras that we used for the work described in this paper come in a wide variety of both capabilities and prices. A brief comparison of some of the key specifications of these IR cameras is provided in Table 2.

5 Engineering student perspectives

College engineering students participated in our STEM classroom visits and provided very positive feedback about the experience. A couple of their observations are quoted below.

- “Demonstrating the functionality and usage of the IR Camera in K-12 classrooms was extremely rewarding. The passion for learning that students have at that age was exhibited when describing the IR camera and allowing the students to use it.”
- “I think that by bringing the IR camera into classrooms and allowing students to experiment with it we are instilling an early passion for sustainability. By allowing students to become more aware of energy usage at an early age, they may be more likely to develop more energy conscientious habits.”

Table 2: A comparison of some of the key specifications of our IR cameras.

	FLIR E60	FLIR C2	Seek Thermal Compact (2)	Seek Thermal XR (2)
Cost	$$$	$$	$	$
IR resolution	320 x 240	80 x 60	206 x 156	206 x 156
IR FOV	25^o	41^o	36^o	20^o
Spectral range	7.5 – 13 um	7.5 – 14 um	7.2 – 13 um	7.2 – 13 um
Temperature range	-20^o to 650^o C	-10^o to 150^o C	-40^o to 330^o C	-40^o to 330^o C
Color camera	3.1 MP	640 x 480	N/A (3)	N/A (3)
Focus	Manual	Auto (4)	Manual	Manual
Image Fusion	Yes, MSX (1)	Yes, MSX (1)	Yes	Yes
Physical size	Large	Small	Very small	Very small

Table 2 notes:
(1) MSX - FLIRs patented multi spectral dynamic imaging (IR image enhancement using visual image).
(2) An iPhone and an Android version are available. The Seek Thermal app is required.
(3) The color camera is built into the smartphone.
(4) The autofocus feature is based on the color camera's image.

6 A 5th grade teacher's perspective

Quoted feedback from a 5th grade teacher who participated follows.

- "The kids are in love with the infrared camera. So was my son-in-law when I brought it home. He was just like the kids, saying, 'Do this! Do this!' After you left, the students brainstormed ideas on how to use the camera. We ran around frantically checking out things. The poor bus driver was surprised when we descended on him and the kids were yelling, 'Get the exhaust pipe!' It was very fun! I found an article about Net Zero building for homes and gave it to the kids this week to read. Might as well get them young!"

Figure 5 shows one of the 5th grader's IR images of a school bus tire and its friction brake.

7 Other outreach efforts

Boise State University sponsors a number of both on- and off-campus outreach events. The largest of these events is held each year, is attended by thousands of participants of all ages, and is now called the "Engineering and Science Festival." Each February, during the Festival, we have offered an IR camera event, emphasizing the FLIR E60. See Figure 6. This camera has a Wi-Fi link that allows one person to utilize the camera, while a number of others view the camera's images on an iPad. This technique allows for several others to learn about the IR camera's capabilities and features while they were waiting their turn to operate the camera. Additionally, an opportunity also exists to email the IR image to interested participants.

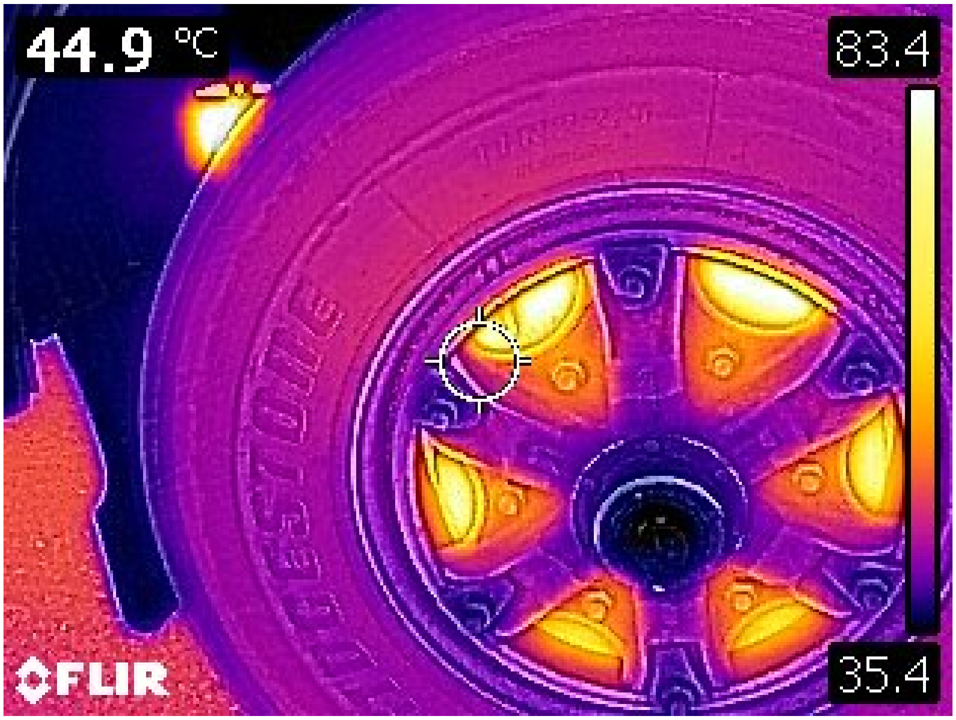

Figure 5: Infrared image of a school bus tire/friction brake system taken by a student in a 5th grade class using a FLIR C2 IR camera.

Figure 6: IR camera event, part of the "Engineering and Science Festival" at Boise State University.

8 Conclusions

IR cameras have long been an invaluable tool to help students see heat, heat flow, and inefficiencies associated with a number of in-building/home appliances. However, in the past, the price of such cameras was a significant obstacle to their use at many institutions. The relatively recent introduction of affordable stand-alone IR cameras, along with relatively inexpensive IR imaging attachments for smartphones, has greatly reduced the financial obstacle. As a result, we have acquired a number of different IR cameras and IR camera attachments and investigated the use of such tools to enhance the education of students.

We have found IR cameras to be highly motivating for both college students who participated in the Energy for Society course and for elementary school students who participated in our STEM outreach efforts. We highly recommend that educators incorporate IR cameras into their courses and outreach efforts wherever concepts such as heat, energy, insulation, and so forth will be covered.

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Appendix A
Infrared (IR) Camera Introduction

Figure 1. An image of our infrared camera made by FLIR.

What is it?

- Uses infrared light spectrum
- Colors based on relative temperature

Uses

- Find inadequate insulation
- Identify vampire devices
- Detect failing appliances
- Structure hotspots
- Spot heat from lighting
- See through smoke
- Thermal night vision

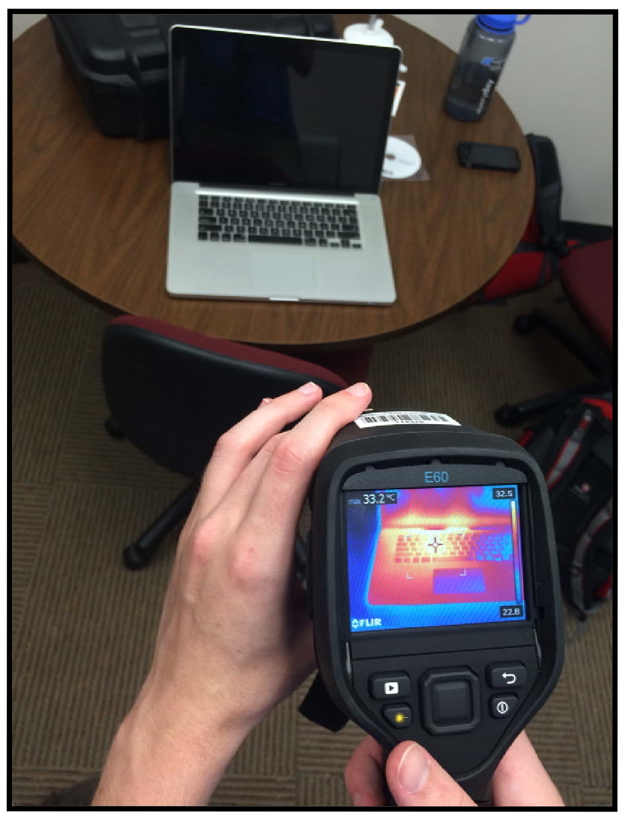

Figure 2. The view of what is seen by the camera operator.

IR cameras work like regular cameras, except they detect infrared wavelengths in the electromagnetic spectrum instead of visible wavelengths, as do regular cameras. One notable difference between regular cameras and IR cameras is that IR cameras use Germanium lenses instead of glass lenses because infrared radiation doesn't pass through glass very well. The camera we have shown here automatically adjusts the color scale. The camera scans to find the highest and lowest temperature and then assigns the "hot" color to the highest found temperature and the "cold" color to the lowest found temperature. This means that yellow represents the hot spot on the laptop, as show in Figure 2 above. The color assigned to a temperature depends on the range of temperatures that surround it.

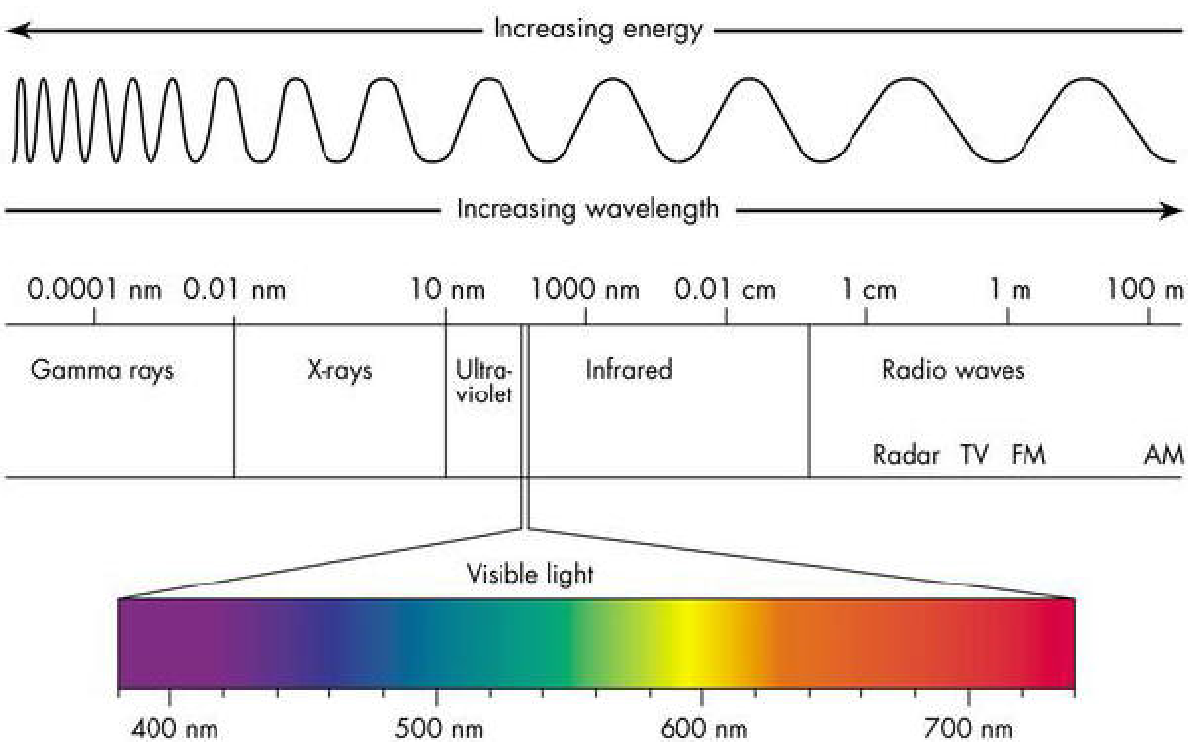

Figure 3. The infrared spectrum is shown. What we are interested in, the infrared wavelengths, are just to the right of the visible spectrum. This means that the wavelengths are longer than those of visible light.

Source: http://9-4fordham.wikispaces.com/file/view/em_spectrum.jpg/244287321/em_spectrum.jpg

Reveals Differences

Figure 4. Two identical mugs in the visible spectrum.

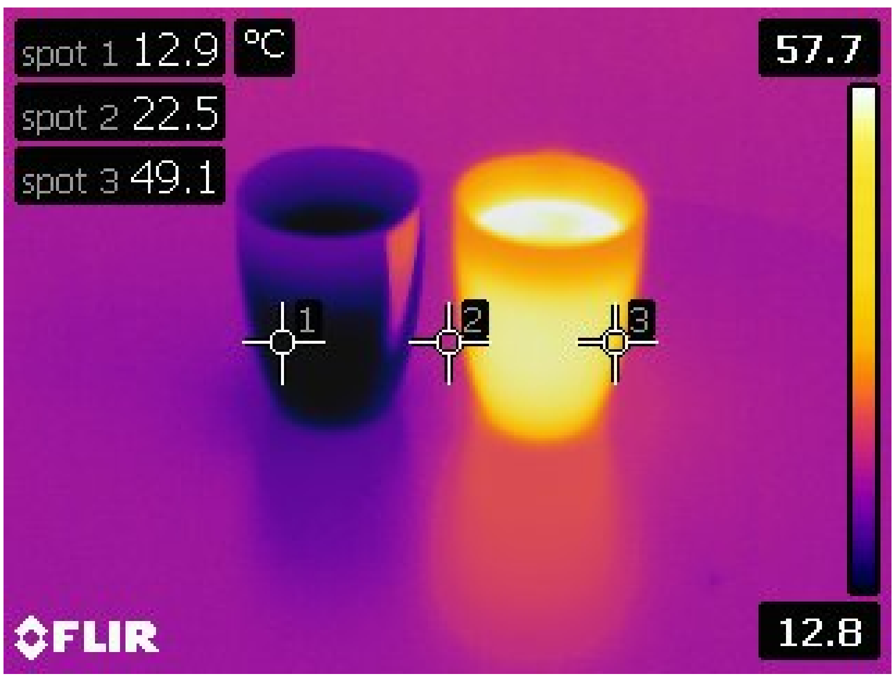

Figure 5. The two mugs viewed in the infrared spectrum.

Figures 4 and 5 illustrate how infrared imaging can be used to see things that are otherwise impossible to see. Figure 4 shows two seemingly identical mugs. However, as shown in Figure 5, the mug on the left has been filled with cold water, and the mug on the right has been filled with hot water. One really interesting aspect of this image is that we can see the reflection of the heat, the infrared radiation, from the hot mug on the cold mug and on the table.

Shows Hot Spots

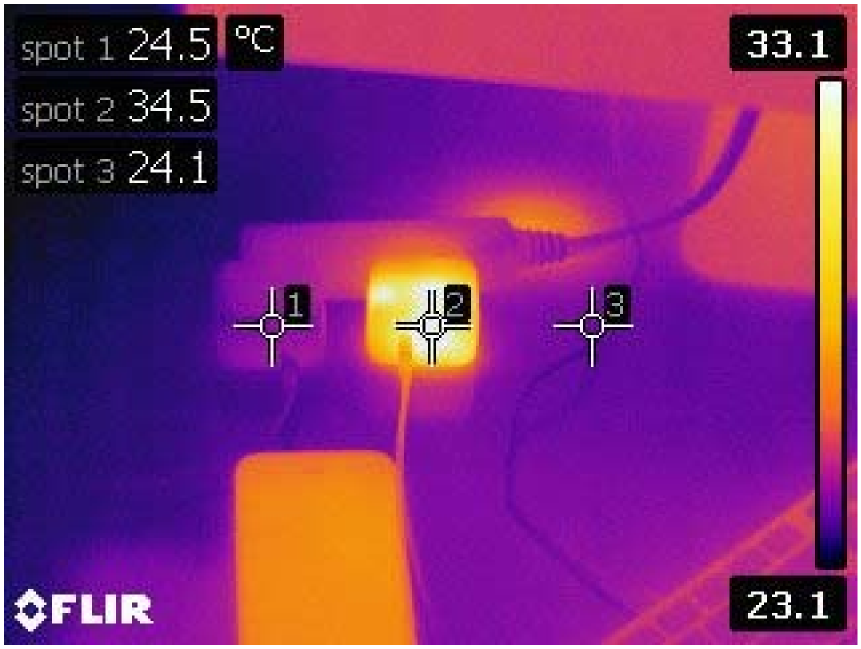

Figure 6: Phone chargers

The picture in Figure 6 is of a couple of phone chargers. The charger at spot 1 is not charging and therefore its temperature is similar to the room temperature at spot 3. The charger at spot 2 is charging a phone and is much warmer than its surroundings.

Shows cold spots

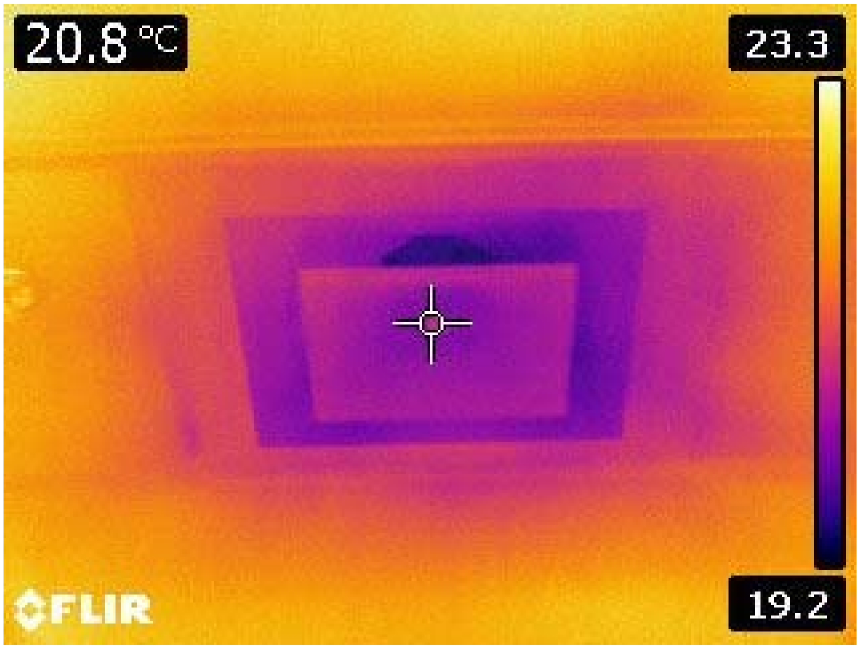

Figure 7

Figure 8

The same air vent is shown in Figures 7 and 8. As shown by the temperature scale, the air vent is colder than the surrounding ceiling.

Germanium lenses

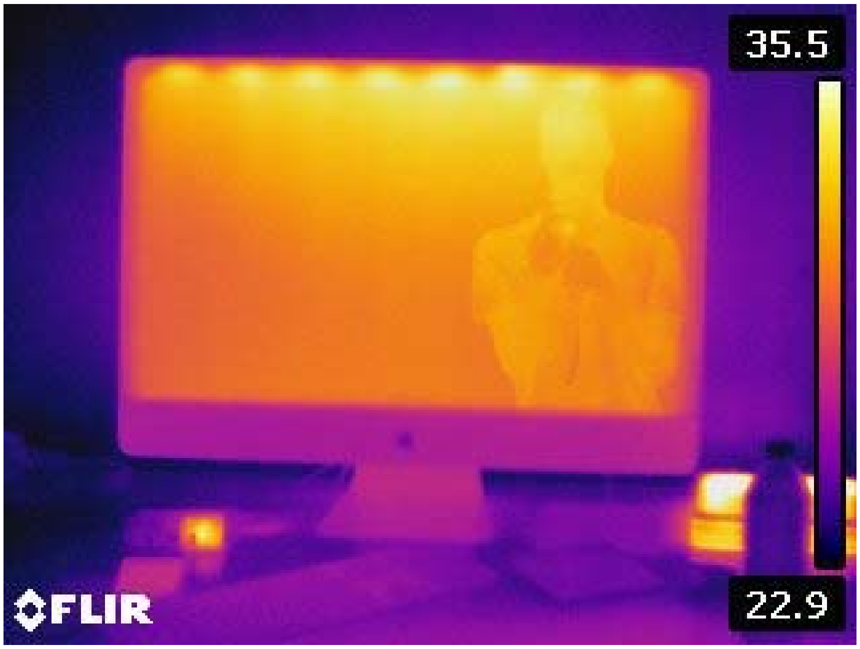

Figure 9

Glass is an excellent reflector of infrared radiation. Shown in Figure 9 is a reflection in the screen of an iMac of the person taking the picture with the infrared camera. This demonstrates why germanium lenses are used instead of glass lenses

Residual Heat

Figure 10

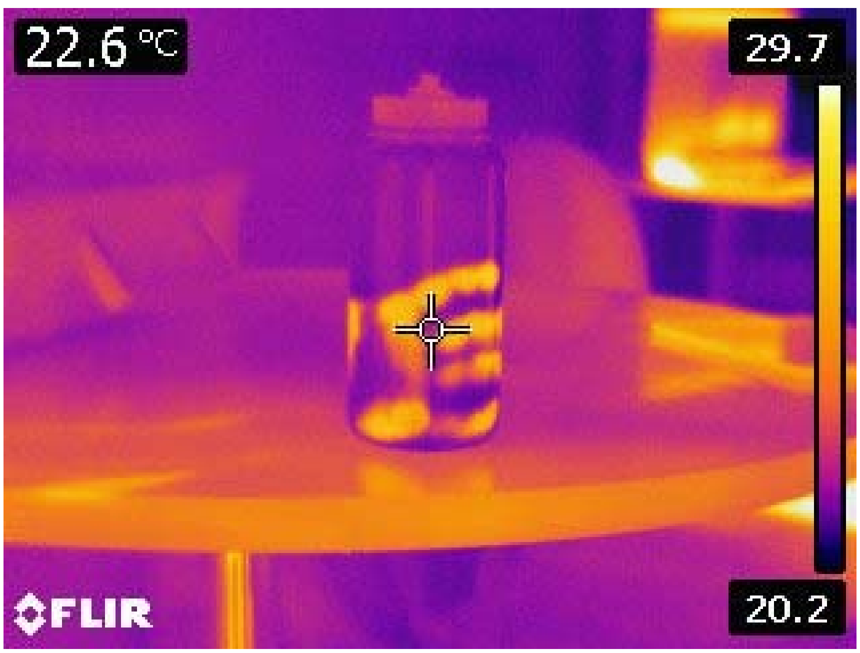

Figure 11

Figure 10 shows a water bottle being held by a hand. Previously, the water bottle was all the same temperature as the upper, untouched portion is in Figures 10 and 11. Figure 11 shows the residual heat remaining on the water bottle a couple of seconds after the hand was removed.

Heat signature through solid objects

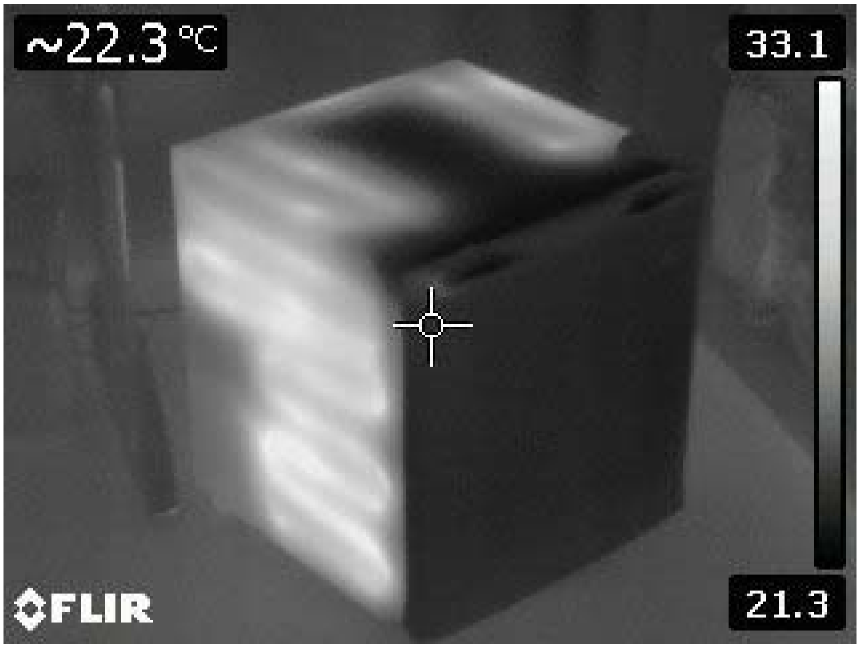

Figure 12

Figure 13

Figures 12 and 13 show images of a mini-fridge in infrared and visual wavelengths, respectively. As the fridge cycles on to remove heat from the interior, the heat is dumped into the environment through the coils that wind around the body of the fridge. With visible wavelengths, these coils are completely invisible through the sheet metal. However, because of the heat they are dumping, they are easily seen when viewed through infrared radiation.

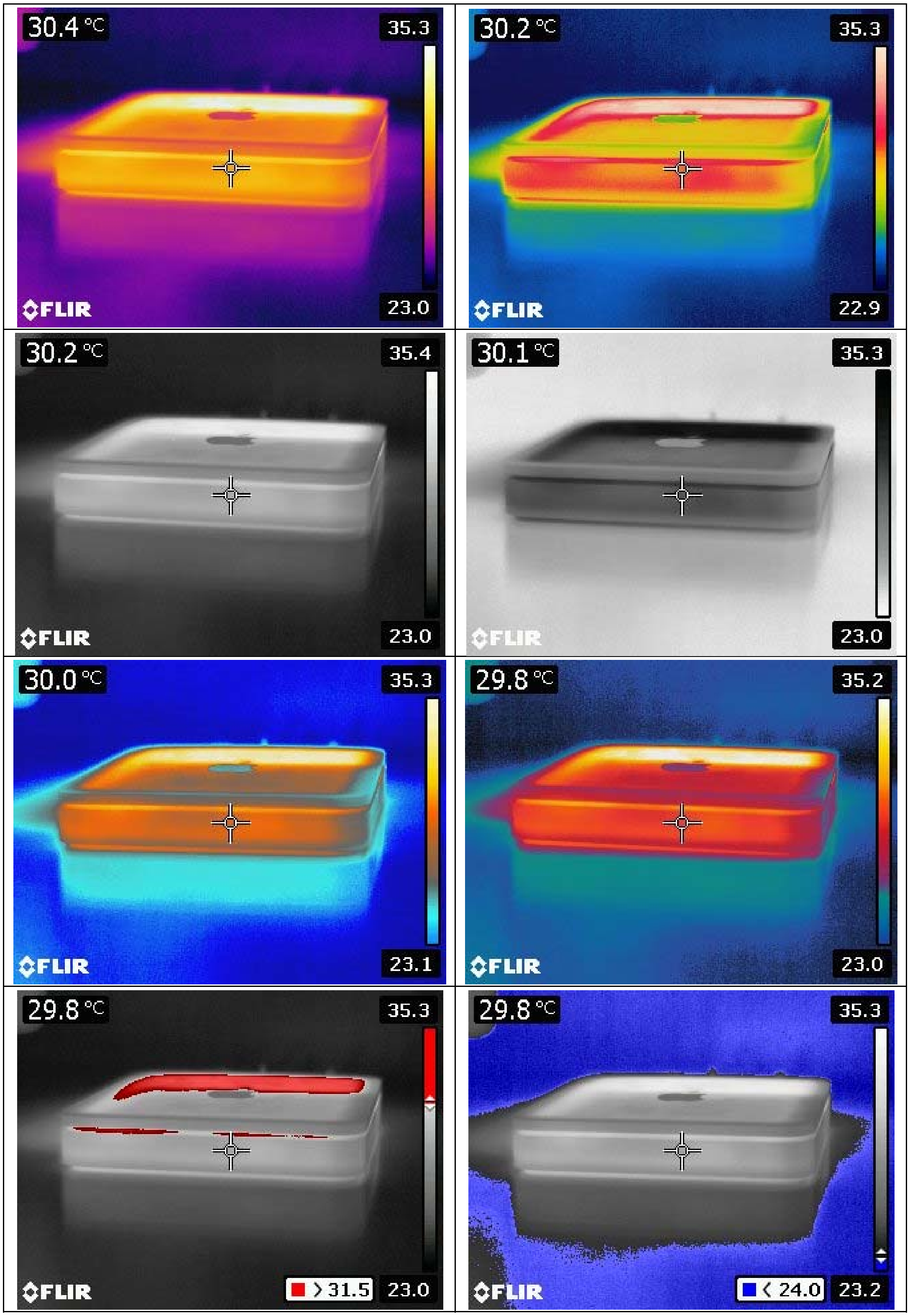

Figure 14. Pictured above are the different color schemes that can be used by the infrared camera according to your preference or application.