Paper 1: Seeing Science beneath the Surface at the Speed of Light

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Abstract (max. 300 words)

Science classes have long used sensors to support scientific inquiry in the material world. In general, students use a sensor to collect a data point at a time, poke around to gather more data, and then input the data into a graphing tool for visualization and analysis. While it is necessary for students to learn this inquiry cycle, it quickly becomes tedious if they must repeat these steps for many times in order to collect sufficient data from which the intended temporal or spatial patterns can be clearly observed. As a consequence of this high workload, only a small percentage of students are persistent enough to reach their full potential in genuine inquiry-based learning. Affordable smartphone-based infrared cameras provide an exemplar of developmentally appropriate technology that promises to change this. By automating the tedious process of data collection, processing, visualization, and contextualization (and thereby eliminating any human error in it), IR cameras instantly reveal unseen scientific phenomena that absorb or release heat and greatly speed up the inquiry cycle. This advantage allows students to focus on the most fun and important part of science while promoting their interest and self-efficacy in practicing science. It also permits instructors to increase the open-endedness and depth of inquiry without worrying that their students may be overwhelmed by unnecessarily complex procedures and large data volume while searching for an answer. In this presentation, I will demonstrate how IR imaging can be used across science disciplines to accelerate inquiry and explore science in unprecedentedly simple, yet deep, ways. None of the experiments that I will show require expensive materials or apparatuses (other than a $150-300 IR camera attached to a smartphone). Yet, some of them have led to true scientific discoveries that have never been reported in literature before.

Extended summary (max. 1250 words)

Opportunities for Actions

Authentic scientific inquiry often involves the use of probeware—a system consisting of sensors, electronic interfaces, and associated software (Tinker, 2000)—to collect, process, and display data from experiments. For simplicity, most probeware in typical educational settings use a single sensor to measure one data point at a time and at a location. In many cases, students are instructed to position the sensor at given locations or in given directions relative to the subjects in order to ensure that they will observe the intended results. This cookbook-like instruction, while necessary to guide students, may reduce the open-endedness of a laboratory activity. In some cases, it may give away the answers and compromise the exploratory nature of science. Furthermore, there are also experiments that require recording data simultaneously at multiple locations over a period of time in order to study the spatial distribution and temporal evolution of certain physical properties. The more sensors an experiment requires, the more complicated the inquiry task becomes, making it less likely for students to succeed and for teachers to adopt.

Infrared imaging is an innovative technology that represents a possible new direction of probeware development to overcome the aforementioned limitations and empower students to accomplish something truly unimaginable before (Xie, 2011, 2012b; Xie

& Hazzard, 2011). An IR camera integrates thousands of microsensors in a chip behind a special lens that lets IR light pass through. It is capable of instantly generating a stream of false-color images of the material world it faces based on dynamically processing the data collected from its microsensor array. Advanced smartphone-based systems can even contextualize a false-color image by overlaying it on top of the edges (where brightness changes sharply) of the true-color image taken at the same time by the conventional camera of the smartphone.

All students need to do with an IR camera in an experiment is to point it towards the subject. From the image stream that shows the dynamic change of a temperature field, subtle, transient phenomena that would otherwise go unnoticed become salient. Figure 1 shows a comparison of doing an experiment using temperature sensors and using an IR camera, respectively. This simple experiment challenges students to explain a paradoxical warming effect on a piece of paper placed on top of a cup of room-temperature water. To construct an explanation, students must propose their own hypotheses and design new experiments to test them (Xie, 2012a). By allowing students to see the effects of their actions instantaneously, an IR camera makes it far easier for students to investigate this strange phenomenon.

(a) (b)

Figure 1. An example of how IR imaging empowers students to explore science more deeply through inquiry with an experiment that involves only a cup of water and a piece of paper. (a) Students use multiple temperature sensors to collect a lot of data for analysis with no guarantee to discover the thermal pattern shown on the screen of the IR camera on the right; (b) Students use an IR camera to instantly discover the thermal pattern, enabling them to conduct more follow-up investigations to dig deeply into the profound science that this seemingly trivial experiment actually reveals (Xie, 2012a).

IR cameras used to be prohibitively expensive to schools. With the releases of two competitively priced IR cameras for smartphones, the year 2014 has become a milestone for IR imaging. Early in 2014, FLIR unveiled the $349 FLIR ONE (now $249), the first IR camera that can be attached to an iPhone. Months later, a startup company Seek Thermal released a $199 IR camera that has an even higher resolution and is attachable to most smartphones. These game changers can take impressive IR images just like taking conventional photos and record IR videos just like recording conventional videos, and then share them online. Both companies provide a software developers kit (SDK) for a third party to create apps linked to their cameras. Excited by these new developments, science educators in Europe and US have started working on a research-based agenda to realize the educational potential of these inexpensive IR cameras (Schönborn, Haglund, & Xie, 2014). This symposium represents an international effort towards the vision that IR cameras will one day become as necessary and pervasive in science labs as microscopes. This presentation will provide some theoretical justifications for this vision.

Not Just Seeing Heat

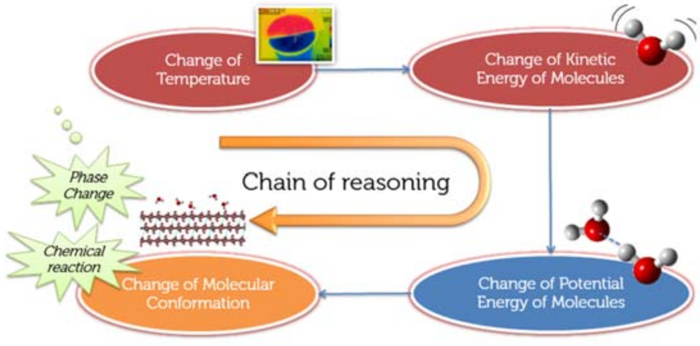

Figure 2. Inferring underlying scientific mechanisms from the dynamic changes of thermograms. In principle, anything that leaves a trace of heat leaves a trace of itself under an IR camera. For instance, microscopic chemical processes that cannot be seen by the naked eye can be deduced and analyzed using IR imaging.

To most people who know what IR imaging is, an IR camera is just a nice instrument for seeing the distribution and change of temperature. This partial truth severely underestimates the power of IR cameras, preventing them from becoming mainstream tools in schools' science labs.

A tool is only as good as the person using it. To do justice to IR imaging, we have to revisit what temperature really is. At the microscopic level, temperature is proportional to the average kinetic energy of molecules. As per the Law of Conservation of Energy, any change of the kinetic energy of molecules must be accompanied by the opposite change of the potential energy of those molecules (Figure 2) or caused by energy inputs/outputs such as light and impact. In the former case, the change of potential energy often results from the change of molecular structures such as chemical reactions or phase transformations. In the latter case, the change of kinetic energy often depends on how the molecular structures respond to external stimuli such as light absorption. This work advocates a *change of mindset* for reading IR images from just thinking in terms of temperature to thinking in terms of its underlying microscopic mechanisms. It is this mindset twist that enables IR imaging to be viewed as a broadly useful technology for supporting scientific inquiry—in theory, any physical, chemical, or biological process that absorbs or releases heat can be visualized and studied by using an IR camera. This molecular perspective of IR imaging is particularly important considering that a large portion of precollege science, at least in the United States, is related to atoms and molecules (NGSS Lead States, 2013) and yet there are very few affordable and applicable experimental technologies that support the hands-on learning of those contents!

Applications of Infrared Imaging across Science

In this presentation, I will back my view with more than a dozen IR imaging experiments, listed as follows: conduction, convection, radiation, heat capacity, evaporative cooling, condensation heating, latent heat, heat of solution, light absorption, vapor pressure depression, freezing point depression, dynamic equilibrium, thermogenesis, capillary action, thermohaline, and greenhouse effect. If time permits, I will also report a few *original* scientific discoveries in physical chemistry. Without any exception, all these experiments do not use expensive materials, are very easy to do, and can be conducted by anyone with an IR camera. The videos of most of these experiments can be viewed at my Infrared Tube website: http://energy.concord.org/ir.

Conclusions

Obviously, IR imaging is a powerful technology for seeing invisible thermal energy. Most applications have focused on that aspect. This presentation promotes a unique view that it can also be widely useful across science disciplines. Through a rich set of demonstrations that show how easy it is to explore deep science with an IR camera, I argue that the technique can and should become an important educational tool for supporting authentic scientific inquiry, accelerating the inquiry cycle, and even empowering students to make their own scientific discoveries.

References

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