Thermodynamics for Tots to Teens

Michele Perrin
University of Missouri

Abstract

This paper describes ten different ways to use a temperature sensor to investigate thermodynamics with younger students. Physical concepts such as temperature scales, heat transfer, phase changes in water, Newton's Law of Cooling, and calorimetry can be explored through typical playtime activities – touching (observation), pouring (manipulation), and sorting (classification). Activities such as mixing cups of hot and cold water allow children to continue experimenting with their first temperature "sensors" (their fingers), while formalizing the process of scientific inquiry with a simple, handheld measurement tool. Exposing students to proper thermodynamics principles and terminology at an early age prevents common misconceptions that surface when students reach college. Through the ten activities described in this paper, teachers can begin to build on a toddler's intuitive thermodynamic notions to help assure success in later academic endeavors.

Introduction

One of the earliest subjects children learn is thermodynamics. Toddlers distinguish hot from cold through food, bath water, snow, sand boxes, and the kitchen stove. Repeatedly, throughout their early years, children experiment with the principles of temperature, heat transfer, phase change, and calorimetry. Yet, thermodynamics continues to be one of the toughest courses in an introductory engineering curriculum. Part of this perception is due to the plethora of technical terms, scientific principles, and mathematical algorithms that are contained in the course. As children play, they are never told that touching a hot stove is called "conduction" or feeling the sun warm your face is called "radiation." In point of fact, they are constantly given negative feedback regarding their explorations into these beginning thermodynamics principles. "Don't touch the stove or don't stay out in the sun too long - you will get burned."

Many freshmen enter college firmly entrenched in "ignorant certainty."[1,2] Their preconceptions about the way the world works are based on information passed on to them by persons in authority. Parents and teachers can unknowingly instill thermodynamic misconceptions in children as they mature. For example, a toddler demanding to know why an ice cube sitting on the table turns into water is often told the ice is "warming up." These misconceptions are doubly hard to overturn, since there is a significant parent-child or teacher-child bond of loyalty involved. Many college professors assume that students are familiar with simple thermodynamic concepts by the time they reach their lecture halls. Unfortunately, this isn't always true. A thermodynamics quiz given by the author to a group of high school students revealed that over half of them were not able to distinguish between heat and temperature by their Junior year. Clearly, if K-12 teachers continued to build on a toddler's basic knowledge of heat and temperature, the success rate in college-level thermodynamics courses would be significantly higher.

Activities

There are a wide variety of activities that can be used to familiarize elementary students with introductory thermodynamics principles and terminology. The goal is to keep the activities simple and fun in order to encourage scientific inquiry and promote a positive attitude. This paper will focus on ten basic topics:

1. Hot versus cold
2. Temperature scales (Celsius versus Fahrenheit)
3. Newton's Law of Cooling
4. Insulators
5. Changing states (ice, water, steam)
6. Calorimetry (thermal equilibrium)
7. Heat exchangers
8. Specific heat
9. Reactions (baking soda and vinegar)
10. Heat engines

These topics form the building blocks for a solid foundation in thermodynamics study through observation, measurement, and exposure to proper scientific terminology. Teachers can build on the intuitive notions of students without requiring them to memorize technical definitions. All activities use a Go!™Temp temperature sensor and LoggerLite software from Vernier Software & Technology for data collection and graphical analysis (see Figure 1). This handheld sensor fits comfortably into small hands and imposes no safety hazard due to glass breakage or mercury leakage from traditional thermometers. It connects directly into the USB port of a computer and uses the colorful software for data collection and display. Using a Go!™Temp is as simple as playing with a stick. Children can hold it, stir with it, cover it, or wave it in the air. However, unlike the stick, this tool allows children to go beyond their basic senses by taking precise thermodynamic measurements.

Figure 1. Go!™Temp sensor.[3]

In the first activity, students explore the concept of hot versus cold by holding onto the end of the Go!™Temp sensor and measuring the temperature of their hands (see Figure 2). Different students will naturally have warmer hands than others. Hand temperature can be varied up or down by vigorously clapping hands or holding a cup of ice. In the figure, Jenny and Jake have significantly lower hand temperatures than Robyn due to holding a cup of ice. This activity introduces the concept of heat transfer through conduction. When holding the cup of ice, the child is transferring heat from a warmer object (hand) to a cooler object (cup). Heat transfer requires a change in temperature. The Go!™Temp sensor provides evidence to support the heat transfer theory.

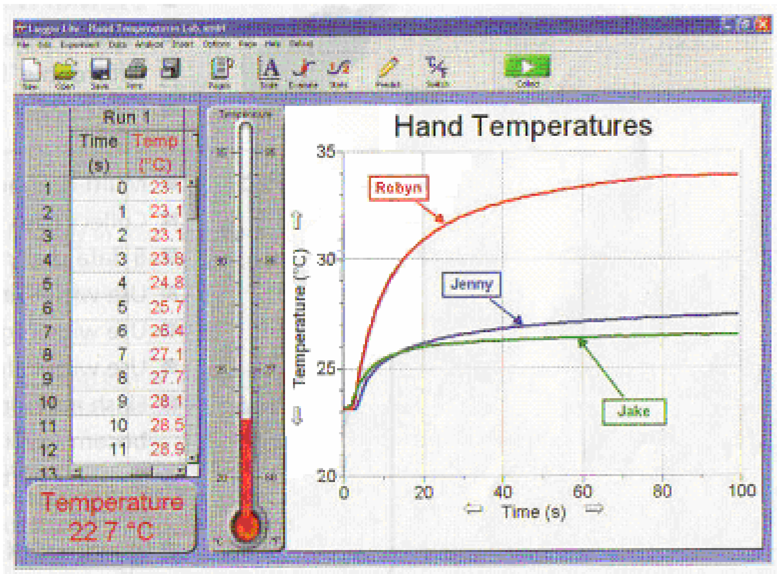

Figure 2. LoggerLite data collection view.[3]

The hot versus cold activity is taken a step further in the second activity by introducing the concept of temperature scales. Scales help to quantify the increase or decrease in hand temperature. Just as some people speak different languages, some people measure with different temperature scales. For example, scientists often measure temperature in Celsius degrees, while meteorologists report temperature in Fahrenheit degrees. Familiarity with vocabulary is much more important with young students than numerical conversions between different scales.

In the third activity, students investigate the cooling rates of different liquids. While the mathematical algorithm developed by Newton to explain this principle would overwhelm most elementary students, a simple observation as to the relative position of various data curves on the graph suffices to reinforce the concept. A strip of filter paper secured to the end of the Go!™Temp sensor provides a simple mechanism for wetting the tip of the sensor with water. Students discover that the wet sensor cools below room temperature through a process called "evaporation." Older students can analyze how other liquids, such as rubbing alcohol or acetone (fingernail polish remover) cool the sensor at different rates. A kitchen provides a wealth of investigative opportunities.

In the fourth activity, students devise ways for keeping hot liquids warm longer through various forms of insulating materials. Simple objects, such as wool or cotton socks can be placed over plastic bottles filled with hot water. As an expansion of the previous activity, students can find that wetting the sock covering will keep a cold liquid cooler longer.

In the fifth activity, students explore the various phases of water. This activity is particularly useful since a common misconception in beginning thermodynamics classes is that a glass of ice water increases in temperature as the ice melts when, in fact, the temperature remains relatively constant at 0°C (32°F) until most of the ice has melted. The same analogy holds true once the water warms up and starts to boil. Many beginning college students believe a vigorously boiling pot of water has a higher temperature than a gently rolling boil. In fact, this is a misconception. The Go!™Temp sensor provides evidence supporting this non-intuitive principle. It contradicts any preconceived notions a child might have.

The previous five activities primarily focused on individual properties of objects; however, the world is much too complex to remain at the property level. The next five activities begin to introduce the concept of a system. A system is an organized group of related components that form a whole. Systems have boundaries, inputs and outputs, and feedback. Once students develop an understanding of the regularities in systems and the interactions within and among systems that result in change, they can begin to develop an understanding of the basic laws that explain the world.[4]

In the sixth activity, students investigate the concept of thermal equilibrium of a system by mixing cups of hot water with cups of cold water. They discover there is a relationship between the mass of the liquid and the final temperature. If two cups of equal volume are mixed, the final temperature will be halfway between the temperature extremes. However, if a larger volume of one cup is mixed with a smaller volume, the temperature of the mixture will lie closer to the temperature of the cup with the larger volume.

Activities seven and eight explore the concepts of heat exchangers and specific heat capacity. Many students confuse the concepts of temperature and heat. Heat, rather than temperature, is a measure of thermal energy; however, the relative change in thermal energy can be approximated through the temperature change of an object. The specific heat capacity of a material is the amount of thermal energy required to raise the temperature of the material by one degree. Common heat exchangers are often metal objects with a low specific heat capacity and rapid temperature increases. When these pre-heated metal objects are placed in contact with materials of higher specific heat capacity, such as water, they quickly transfer their thermal energy to the cooler material. The metal object will decrease in temperature while the water will increase in temperature.

Activity nine introduces the concepts of exothermic and endothermic reactions through the simple chemical interaction of household materials, such as baking soda and vinegar. Exothermic reactions give off heat energy, thus experiencing a decrease in temperature, while endothermic reactions gain heat energy and will experience an increase in temperature. This terminology can seem daunting to an unfamiliar college student, yet when a child is watching the baking soda turn to bubbles and fizz, it seems like play. In addition, it provides a natural incentive for a child to test the interactions of other materials.[4]

The tenth activity explores the concept of heat engines. Many simple steam engines, such as the Otto cycle design,[5] can be made by poking holes into a soda can, filling it with a small amount of boiling water, and letting the steam escape. Students discover that the temperature of the steam inside the can is much hotter than the temperature of the escaping steam outside the can.

Research

The author conducted an informal investigation to help establish the need for this type of exposure to thermodynamic concepts and the importance of providing this exposure through hands-on experience. Specifically, a test on conceptual understanding in thermodynamics was administered to 91 high school juniors. All students had taken a college-prep chemistry course during sophomore year and were scheduled to study a unit on thermal energy in an algebra-based physics course. Most of the students (approximately 80%) answered questions pertaining to temperature with a high degree of accuracy. However, questions involving heat transfer and the specific heat of materials were missed by approximately 50% of the students. For example, one question asked, "When you bite into a slice of pizza fresh from the oven, why do you burn your tongue on the sauce, but not the crust?" It was noteworthy that even after having taken chemistry, 60% of the students responded that the sauce had a higher temperature than the crust, rather than the sauce had a higher specific heat than the crust. Misconceptions in scientific principles at this age can be very hard to overcome in college.

During a two-week unit on thermal energy, topics were either covered in lecture only, or were taught using both lecture and hands-on demonstrations. Principles involving temperature scales and methods of heat transfer, for example, were covered in lecture only; on the other hand, students used temperature sensors to determine the specific heat capacity of several unknown metals to supplement the lecture on this topic. When the test was re-administered, it was found that scores on questions relating to temperature did not change significantly. However, approximately 20% more students answered questions involving heat energy correctly. It is interesting to note that one question on the method of heat transfer used by an air conditioner (a topic only discussed during lecture) was missed by 6% more students the second time. This implies that the lecture alone did little to improve students' knowledge and even created a few additional misconceptions.

Conclusion

The process of intellectual growth is complex. Within the classroom, it is strongly influenced by the types of tasks students are assigned, the clarity with which expectations are communicated, and the support students receive as they attempt to respond to the unfamiliar demands being placed upon them.[1] Students in elementary school have a natural interest in numbers and nature. Yet, many students graduate fearing mathematics and science. Others perceive the topics as too dull or too hard to learn. They see science as a tedious academic activity, not as a way of understanding the world in which they live. The consequences are severe, for it means that the nation's pool of talent from which scientists, mathematicians, and engineers are drawn is smaller than it should be.[6] Using technology to study thermodynamics is actively supported by Content Standard E in the National Science and Education Standards.[4] Even at the K-3 level, students can begin to develop observation and analysis skills. Simple activities, such as those described above can be conducted within the familiar contexts of home and school, require no time-consuming preparation, and provide a well-defined criterion for success. The Go!™Temp sensor is developmentally appropriate for a K-3 child's manipulative skills and has the potential to contribute to a student's later success in college.

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MICHELE PERRIN (MS EE & CE) has fifteen years of experience introducing students to pre-engineering through the use of technology. She has taught classes at the high school and college level in physics, robotics, and computer programming. In 1998, she was named a *Tandy Technology Scholar* and in 2000 she studied in Japan on a teacher exchange. Her current projects include designing electronic sensors and presenting workshops to teachers.