How Things Work: A Physical Science Workshop for K-8th Grade Teachers.

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Abstract
This paper describes a physical science workshop for K-8th grade teachers that has been offered the past 3 years as part of the Redwood Science Project at Humboldt State University. The Redwood Science Project is one of 18 sites of the California Science Project. The goals of the How Things Work workshop are: 1) to increase the level of physical science content knowledge of K-8th grade teachers, 2) to increase the level of confidence of K-8th grade teachers have when working with physical science concepts and 3) to increase K-8th grade teachers' understanding of the California State Science Standards. The pedagogical approach used in the workshop is a discovery/constructivist approach. The paper specifically describes in detail the electricity and magnetism module and the reverse engineering/mechanical dissection module, the use of minute papers to assess participant learning, observations from the course instructors and participants and references to the course website. The electricity and magnetism module includes building simple examples of a compass, an electromagnet, a motor and a speaker. This activity complements the mechanical dissection activity as many of the objects dissected by the teachers are electrical and contain motors, electromagnets and speakers. Teachers express an increase in confidence and an increase in their willingness to experiment with science teaching. The workshop is very popular amongst teachers who state initially they are unconfident with their physical science knowledge. Teacher feedback attributes the popularity of the course to 1) hands on activities 2) instructors' approachableness, and 3) use of minute papers.

How Things Work Workshop

The purpose of the California Science Project[1] (CSP) is to serve as a provider of services to strengthen the science programs and science instruction of California Schools in a manner consistent with the California Science Framework and California Science Content Standards.[2] The CSP funded the Redwood Science Project[3], which sponsors the Redwood Science Summer Institute for K-8th grade teachers. The institute offers 4 courses, one of which is our How Things Work course. During the summer participants attend our class four hours per day for five days with a 10-hour weekend follow up during the school year for a total of 30 in-class hours. The topics covered in the 2003-2004 course were Energy, Electricity and Magnetism, Mechanical Dissection, Light and Lens, Sound and Waves, and Forces and Motion. This paper describes two of the modules covered: Electricity and Magnetism, and Mechanical Dissection. These two units were covered in approximately 8 class hours spanning three instructional days.

Our main course goal is to aid teachers in becoming comfortable with some of the physical science concepts that are applicable to a wide variety of common machines. By increasing teachers' confidence in their understanding of physical science and by providing resources (both material and information) we encourage teachers to do more hands on physical science activities in their classrooms. Two important resources for the course are the How Things Work course website[4] and the book The New Way Things Work by David Macaulay[5]. The course website provides links to addition resources including the animation that were viewed during class. In addition to increasing teacher content knowledge and confidence with physical science, participants become more familiar with the California Science Standards.

The course is designed to engage the teachers to be active learners to develop their understanding, confidence and enthusiasm for science. The course approach is to avoid lecturing and focus on hands-on activities and investigations of fundamental physical principles.

Electricity and Magnetism Module[6]

This portion of the How Things Work class concentrates on developing teachers' understanding of electricity and magnetism and how basic principles can be used to understand the operation of many common devices that have motors or speakers. Electricity and Magnetism is primarily covered in the fourth grade California Science Standards[2]. The Electricity and Magnetism course website[6] outlines relevant state science standards as well as related text readings and websites.

The order of presentation, which is typical for modules in the class, is an assigned reading from the text, a series of introductory demonstrations, a brief lecture as a primer to a discussion of the station activities, a review discussion driven by the teachers' questions in their minute papers and finally a reflection in small groups on how teachers can use this material in their own classrooms. Also, the teachers take home a package of material that is sufficient to build an electromagnet, a motor and a speaker. These materials will be presented at the ASEE 2004 conference.

Demonstrations

The purpose of the demonstrations is to start the teachers thinking about the abstract concepts that are part of this lesson. For example, a magnetic field cannot be <u>directly</u> seen, touched, heard, tasted or smelled. Yet, the effects of the magnetic fields are observable, predictable and of tremendous practical use.

3-D Magnetic Field Demonstration

A commercially available[7] container of iron filings is used to make the magnetic field lines visible. A sealed clear Plexiglas container that has a slender cavity down the middle contains a suspension of iron filings in glycerin. The container is shaken to evenly distribute the fillings. A magnet is inserted into the slender cavity and secured with a cork. The container is immediately placed on a overhead projector. The filings align along the magnetic field lines.

Coil and Magnet - produces electric current

Approximately 50 turns of wire are connected to a galvanometer with a very large display. The galvanometer is used to measure the amount of charge passing through the wire. A magnet is moved in and out of the coil demonstrating that passing a magnetic field through a coil of wire moves electric charges or in other words produces an electric current. Participants are prompted to note that if the magnet is stationary with respect to the coil no current is produced. Participants also observe that the flow of charge (current) reverse when the magnetic field passing through the coil changes from increasing to decreasing. Also, size of current depends on the speed with which the magnet moves.

Electromagnetic generator with LEDs - generation of electric current

A homemade coil with a large number of turns is spun by hand in the magnetic field of a large horseshoe magnet. The ends of the coil are attached across a red light emitting diode (LED) and a green LED. Physically, both LEDs point along the axis of the coil so as to shine light in the same direction. Electrically, the diodes are connected to conduct current in opposite directions. Spinning the coil in a fixed magnet field produces current that alternates in direction and lights up both LEDs.

Hand generator activities

Participants are given instruction on how to use the commercial available[8] hand generators and shown how to prevent damage to the included capacitor.

Electricity, Magnetism and Motor Stations

The following seven activity stations are setup before the participants arrive:

1. Series and Parallel Circuits
2. Mystery Box
3. Floating Compass
4. Paper Cup Speaker
5. Nail Electromagnet
6. Electric Motor
7. Hand Generator Station

Duplicate stations are setup to keep the number of people at each station small. In our experience extra setups are required for the Series and Parallel circuit stations, the Mystery Box stations and the Electric Motor stations as these stations take the most time and generate the most interest.

Series and Parallel Circuit Station

The equipment for this station is a 12-volt dc ("wall wart") power supply, cables with banana plug ends and 12-volt lamps with banana plug jacks. The participants are asked to make the following three circuits and record their observations:

1. One circuit with one light and the power supply.
2. One circuit with two lights in series and the power supply.
3. One circuit with two lights in parallel and the power supply.

The lamps are noticeably dimmer in series than they are in parallel. The participants who are comfortable with simple series and parallel circuits create more complicated circuits to test their understanding at a deeper level.

Mystery Box Station

This station requires a deeper understanding of series and parallel circuits. Participants who were unfamiliar with series and parallel circuits were encouraged to bypass this station. The station consisted of several (actual) black boxes with an on switch and 5 l2-volts lamp sockets with lamps. The lamps are connected in some combination of parallel and series circuits that cannot be directly observed. The challenge is to deduce how the lights are connected by observing the effects of unscrewing the light bulbs. For some of the teachers this challenge became an obsession. One teacher took a number of the boxes home overnight. For most of the participants this station was too difficult; however the station is very good at testing the more advanced teachers. Several teachers who thought they fully understood series and parallel went back to the series and parallel station for a review after trying the black boxes.

Compass Station

A strong magnet is used to magnetize a needle (we clipped the end off a safety pin). The pin is pushed through a small piece of Styrofoam or cork and floated near the center of a large container of water. The direction that the needle points is compared to a standard compass. The effect of bringing a magnet close to the needle is investigated. Web resources for this station include[9] and [10].

Speaker Station[11]

The participants make a speaker by scotch taping approximately 10 turns of wire to the back of a paper cup. The ends of the wire are connected to clips that lead to the speaker outputs of a radio. The cup is held over a magnet and the participant listens to his or her speaker play music. This project is easy to build and understand and often generates a lot of discussion of how a radio works including radio waves, electronics, electromagnets, vibrations, sound waves and how we hear. The concept of using an electromagnet in a speaker to turn electrical pulses into motion of the speaker cone to produce sound is common enough to be interesting, magic enough to be mysterious and yet simple enough to be clearly understood. Hearing music coming from a paper cup never fails to impress the participants.

Electromagnet

To create an electromagnet an insulated wire is wrapped around a nail, the ends are stripped and connected to a D-cell battery. The electromagnet is used to pick up paper clips. The batteries go dead fairly quickly but many of the participants are familiar with this activity. Mainly this station is used to reinforce the concept that an electrical current can be used to create a force.

Electric Motor

A very simple dc electric motor is made from a coil of wire suspended by the ends of the coil wire that pass through the hole in two safety pins based on the Exploratorium Motor[12]. One end of the coil is completely stripped and the other end has the insulation carefully removed from one side of the wire. A magnet is placed under the coil. The paper clips are connected to the battery with wire. If the coil is oriented so that the half stripped end is in contact with the safety pin, current flows through the coil producing a magnetic field that rotates the coil. When the coil rotates far enough to place the insulated potion of the wire in contact with the safety pin and current path is interrupted and no magnet underneath the coil no longer acts to turn the coil. When the coil is properly balanced the coil will have sufficient inertia to complete the half turn necessary to reestablish the electrical connection that produces the torque that drives the motor. A small kick is often necessary to start the coil turning. The construction of the motor requires patience and some practice. In our class we provide a dc power supply so that the participants can test their motors without draining a large number of batteries. Once the motor is working it can be powered from a battery.

This motor is simple enough conceptually for the teachers to understand. The electric motor is similar enough to the one that is described in the text to reinforce what the teachers have learned.

Further, this conceptually simple motor can be used as model to understand the motors many participants will find in their mechanical dissection projects. Several teachers report that the difficulty in getting the motor to run was seen as a worthwhile challenge by a subset of their students who do not respond to more traditional academic challenges.

Hand Generator Station

These commercially available small hand cranked generators[8] are used to light up a lamp directly, to charge a capacitor, and to turn the handle to the other generator (the second generator is acting as a motor). Once charged, the capacitor can be discharged to turn the crank one of the generators or to light a lamp.

Mechanical Dissection

Mechanical Dissection (or Reverse Engineering) is used in How It Works workshop to provide teachers a hands-on opportunity to learn more about how common every day devices work. Most of these teachers expressed that they do not often use hand tools, so this time provides them an opportunity to become more confident. Mechanical Dissection has been used in engineering education[13],[14], as well as in K-12 education. The assignment is detailed here[15] and objectives of the activity are:

- Participants experience mechanical dissection and the reverse engineering process.
- Participants are invited to "think like engineers".
- Participants become more familiar with the use of tools.
- Participants use diagrams, photos and written descriptions to describe and analyze an object.
- Participants present their dissected object and explain how they think the object was produced to their classmates.
- Participants consider the use of mechanical dissection in their own classrooms.

Each teacher is invited to bring in a device that he or she would like to learn more about how it works. The teachers are encouraged to select a device that is not entirely electronic, as these devices are more difficult to determine how they work. Over the course of the 5 day summer session, the teachers are provided approximately 4 hours to work on their mechanical dissection projects. Everyone acknowledges that 4 hours is not enough time to complete a thorough dissection project. Often, teachers work on the projects during their free time. Some choose to work more on the documentation of the project, while others choose to work solely on the actual dismantling of their device.

The first hour of the assignment the teachers are provided an introduction on how Mechanical Dissection is used in engineering education as well as an introduction to terms such as life cycle analysis and subsystem. The teachers invited to keep a lab notebook with a page for each of the following questions.

- What is the purpose of this object?
- How do you think this object is made?
- What subsystems do you think exist as part of this object?
- What part(s) of this object might be recyclable?
- What do you think is the life cycle of this object?
- What other questions do you have that are related to your object?
- What ideas do you have about using mechanical dissection (reverse engineering) in your class?

Teachers are also invited to make a sketch of their object, prior to dissection, labeling different parts of their object and to continue making sketches as they dismantle their device. A digital image is made of each object, prior to dissection that is included in the lab notebook.

The teachers are provided 2.5 hours during the institute for unstructured dissection time. They refer to their texts, their neighbors and the instructors while discovering how their device works. Teachers have dissected clocks, printers, toasters, blenders, reciprocating saws and McDonalds windup toys.

The last hour of the assignment occurs on the last day of the institute. Teachers that teach similar grade levels meet in groups of 3, spending approximately 20 minutes presenting their devices and discussing what they have learned. They discuss how they might use this type of assignment in their classrooms identifying any difficulties they anticipate. The groups report out the most important issues, which becomes a lively discussion. Teachers agree this type of activity can be integrated with many different types of learning units, including those with themes of sustainability and environmental responsibility. The difficulties teachers anticipate with this activity include storage, as teachers generally have little extra space in their classrooms. They also recognize a waste management issue with the destroyed devices and they express concern for hazardous waste and safety issues, especially with electronic devices.

Minute Paper

A key component of our workshop has been the use of minute papers[16]. As K-8th grade teachers have different issues and learning styles than our typical physics and engineering students, the feedback the teachers provided via the minute papers was invaluable in guiding our lessons for the next day. We attribute our success with the teachers to our use of minute papers. Our implementation of the minute paper asks the following.

1. What is the most important thing you learned today?
2. What 1 or 2 questions do you have?
3. Please give us feedback to help us improve the class?

The purpose of each question is address in the following subsections. Example of teacher quotes can be found in the observations section of this paper.

Most important lesson of the day

The first question has been a tremendous help in helping the instructors accessing the class's grasp of the material. We usually start the next class by discussing what the teachers thought was the most important part of the previous lesson. Typically, the discussion is useful because some of the responses contain misconceptions that need to be addressed and others serve as an excellent review of the most important material from the previous day.

Questions to address the next day

Answering the responses generated by the second question in the minute paper has produced some of the best moments and the some of the most trying moments in our class. Many of the teachers have had questions and/or misconceptions that have bothered them on some topic peripherally related to the class for many years. Being able to help them construct the knowledge that they really want to know can be a great confidence booster for them. The instructors also explicitly model the idea that an instructor does not needed to know the answer to every question. Many times the resource used to answer the question is presented before the answer is discussed.

The questions in the minute papers are often not directly related to the current lesson. The questions might be a question the participant had had for a long time, a question that a student had asked him or her, an uncertainty in the meaning of their textbook or some concept that they had read or heard about in the popular press. We tried to answer all these questions as well as time allowed, although we tried to steer the discussion toward the principles that we were addressing in a given lesson. Staying on topic and on schedule in a wide-ranging discussion can be very difficult. However, we felt the effort was worthwhile due to the enthusiastic feedback we received from the teachers. One of our goals is to increase the enthusiasm of the teacher for science because the teachers will communicate their attitudes toward physical science to their students. Most of the teachers began to look forward to the time we would use to address their questions from the minute papers.

Feedback to improve class

The teachers have had insightful suggestions on how to present topics to teachers as well as to K-8^{th} grade students. Acting on feedback from the teachers is an excellent way of implicitly communicating that we are all professional educators and are all still learning. This communication creates a classroom environment that makes teachers more willing to ask questions without regard for whether they should know the answer.

Observations

This section will first present the feedback we have received from the participants on their experience in our class. The lessons we have learned in teaching will be explained.

Teacher/participants Attitudes and Feedback

Feedback from teachers rate the Mechanical Dissection as one their favorite aspects of the Redwood Science Institute. Many teachers gain confidence in their ability to use tools and their diagnostic abilities. We have received testimonials from teachers that use mechanical dissection in their classes ranging from 2nd grade to 8th grade. Teachers say the activity provides another approach for students to learn, as some students are not able to focus on reading and writing, but become extremely focused when dissecting their device. Teachers use Mechanical Dissection as a way to reward students; they can work on their mechanical dissection projects after they have completed their other work. Below are some quotes from teachers' minute papers.

The Mechanical Dissection was great. It was exciting to take apart something and actually be able to identify how it works! I will definitely use it with my kids.

I learned more stuff about capacitors and I'm excited about finding why I have so many capacitors in my machine!

Through my mechanical dissection, I learned how a transformer works. Also, yesterday's talk about magnetic fields help it all come together, along with the book's explanation.

Most motors work off of electromagnets – discovered that in looking at people's dissected appliances – Cool.

The most important thing I learned today was building machines, while intimidating, can still be done.

I had such an exciting time discovering how my mechanical dissection object worked. I can't wait to do similar activities with class. This class has really allowed me to "play" with concepts I've always steered away from because I didn't know enough – felt I couldn't do.

Many teachers were extremely positive about the course website[4]. Each module has a webpage outlining the activities and often has related animations. We show several animations for each unit both for the educational content and to demonstrate the type of web-based resources that are available. Although the course website is fairly simple, the teachers were very enthusiastic. They appreciated someone else organizing the material on their behalf.

Instructor Observations

Most of the teachers are not confident in their ability to understand and teach physical science concepts. We feel it is very important to create a classroom climate where the participants are willing to expose what they do not know to each other and to the instructors.

Classroom Climate

To set a classroom climate where active learning can occur we have found the following techniques to be helpful. We explicitly recognize that the participants are professional educators with valuable expertise. We encourage participants to work in small groups. By discussing the material with a peer, the participants become aware that others lack confidence as well. The participants appreciate that we do not force them to work through all activity stations; we describe the stations and the available time and let the participants choose how to use their time.

Grade level Appropriate Curriculum Development

We start by immediately telling the teachers that they are the experts in designing curriculum for their grade level. We do not have their expertise and experience. We provide them with in class time to work in small groups transforming the material they are learning into appropriate lessons for their classes. Having a more definite plan for implementing a physical science topic should increase the chance that the teacher will make use of the material they learn in this class.

E & M & Dissection Connection

The electricity and magnetism unit and the mechanical dissection activity seem to complement each other because so many of the objects the teachers choose to dissect contain electrical subsystems. Electric motors are found in mixers, toys, VCRs and saws. Electromagnets are in pumps and toys. Radios and toys that play sounds have speakers. The participants who have just finished assembling a speaker know to look for a coil, a flexible membrane and a magnet in their dissection item. Even when the details are not exactly the same, the participants have a general understanding of what to look for.

Summary and Conclusions

Our goal is to improve the physical science that is taught in elementary education classrooms. We hope to achieve that goal by helping the teachers who attend our class to increase their knowledge of physical science concepts, to be more confident in their ability to learn and teach physical science and to be more enthusiastic in their presentation of science in the classroom. We found that the use of minute papers allowed us to gauge the proper level and pacing for the class by getting a snapshot of the participants understanding each day.

The electricity and magnetism unit and the mechanical dissection project complement each other well. Learning about electric motors gives the participants a sense of what to look for in the devices they dissect. Also, taking apart a device with a motor inside provides a strong incentive to learn how a motor works. Many participants report the experience as being very empowering. They could understand the operation of a device that had always seemed like magic to them.

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