Summer Workshop Experiences for Middle School Teachers and Students

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Abstract

For the past three summers we have presented two one-week workshops. One entitled *Introduction to Fabrication* has been offered to middle and high school students, while the other entitled *Introduction to Energy Conversion and Distribution* has been offered to middle school science teachers. This paper presents a summary of the experience and lessons learned.

The goal of the fabrication workshop is for the students to develop an awareness of the processes involved with the creation of objects they encounter daily. There are mechanical and electrical segments of the workshop. During the mechanical segment the students are introduced to a small milling machine and lathe that are capable of machining a variety of materials ranging from plastics to mild steels. Emphasis is placed on safety and proper machining techniques. Through a variety of machining projects, the students also learn how to drill and tap a hole, how to make accurate measurements using calipers and a micrometer, and gain an appreciation for the costs associated with maintaining high tolerances on machined parts. Students also have the opportunity to spend time in a professional machine shop and observe numerically controlled machines in operation. During the electrical segment the students use a breadboard to build a small electronic circuit, and then transfer it to a printed circuit board of their own design. In the process the students learn about simple electronic circuits, proper soldering techniques, pc board layout and fabrication. On the last day of the workshop we take the group on a field trip to a local industry site at which a variety of fabrication and productions methods are observed.

The goal of the energy conversions workshop is to provide science teachers an opportunity to develop an understanding of energy conversion and power distribution systems. During morning sessions, materials covering thermodynamics, fluid mechanics, and electro-mechanical machines are presented and discussed. Afternoon sessions in the laboratory are used to reinforce the morning topics and typically generate new questions for explorations. During the past two summers, a complete energy conversion system consisting of a water wheel and a small generator has been built and the performance characterized. A special emphasis is made on characterizing system losses.

The Sid W. Richardson Foundation sponsored both workshops the first two summers and the student workshop the third summer. TXU sponsored the teachers' workshop last summer. Both projects are part of an informal outreach program within the Department of Engineering, and are administered through the TCU Institute of Mathematics, Science and Technology Education.

Introduction

For the past three summers we have presented two one-week workshops: one entitled *Introduction to Fabrication* has been offered to middle and high school students, and the other entitled *Introduction to Energy Conversion and Distribution* has been offered to middle school science teachers. Both of these workshops have been part of an informal outreach program within the Department of Engineering at Texas Christian University. They are administered through the TCU Institute of Mathematics, Science and Technology Education.

The audiences for the two workshops are entirely different, as are the workshop objectives. In the *Fabrications* workshop, our global objective is for the students to learn through doing. This is accomplished by allowing them to get their hands dirty while creating something they can take home and show to their friends and family. It is *not* a point-and-click virtual experience. In the *Energy Conversions* workshop, our objective is for the teachers to develop an understanding of energy conversion and power distribution systems from a scientific point of view by building and characterizing a complete energy conversion system that begins with a hydrostatic pressure source and ends with a generator supplying power to an electrical load. We found that many concepts were brought into focus during afternoon laboratory sessions and provided an informal and free-flowing atmosphere in which many questions were asked and answered.

This paper presents a summary of our experiences and lessons we have learned.

Energy Conversions Workshop

The participants in the teacher workshops have come from private and public schools from surrounding independent school districts. We have had a good male/female balance. We offer a small stipend (about $250). The teachers become aware of the workshop through a newsletter the TCU Institute of Mathematics, Science and Technology Education sends out periodically during the spring semester, which lists a series of offerings coordinated though the Institutes office each year. The past three workshops have had 8, 6, and 8 participants, respectively.

The workshop meets Monday through Friday, from 9:00AM through 4:00 PM, with a break for lunch. Two mornings are devoted to basic thermodynamics and water wheel mechanics, two mornings are devoted to electrical power generation and distribution, while the final morning is spent as a wrap-up period in the lab. During the morning sessions we utilize typical classroom tools such as the white board and overhead transparencies, but small segments of formal presentation material is intermingled with numerous demonstrations and show-and-tell items of common use such as:

- Steam power generation demonstrated by directing steam from boiling water into the airfoils of a simple pinwheel.
- First law concepts of work and internal energy are demonstrated by doing “work” on a hand-size chunk of lead using a hammer and measuring the increase in temperature.
- An example of a good heat transfer design concept is demonstrated using a longneck bottle.
- A Stirling engine is used to demonstrate conversion of heat energy (either an open flame or the sun) to mechanical shaft work.
- A linear motor used as an electromagnetic rail launcher.
- An open-frame permanent magnet electrical machine.
- A very simple single-coil electric motor demonstrator[1]

The two morning sessions covering thermal science basics begin with a discussion of forms of energy and the energy transfer processes of work and heat transfer. Once the teachers are comfortable with these fundamental ideas, we introduce the first law of thermodynamics and spend time discussing familiar applications to household appliances, automobiles, power plants, and home heating and cooling. Second law concepts are discussed next, beginning with the idea of an irrecoverable loss in conversion between energy forms. This then leads into the concept of energy conversion efficiency, which is a primary theme throughout the week. Power cycles are presented during the second morning, which leads into a discussion of hydrodynamics power systems and water wheel mechanics.

The morning sessions on electrical power generation and distribution begin by reviewing the different types of electricity and highlighting applications for each. Electrical properties of materials are then reviewed with some insight given into the physical causes of resistance. The classes of conductors, insulators, and semiconductors are also revisited. The basic ideas of voltage, current, resistance, power, and energy are then reviewed. The analogy of water systems seems to be the most effective way of teaching these ideas.

Our discussion of the generation and distribution of electrical energy begins with a discussion of the alternative choices. A diagram depicting the system including generators, transformers, and transmission lines is then presented and each components function in the system is discussed. Having examined the overall system, the discussion then centers on electromagnetic induction. Faraday’s law is presented and discussed in the context of a linear machine. A small linear machine is then analyzed and demonstrated.

The second morning of the electrical discussion begins with a review of the previous material. Then the generation of an electrical voltage in a loop in a magnetic field is discussed using Lorentz’s Law. The teachers are then asked if this electrical voltage generation process violates the conservation of energy. An electrical load is then added to the loop and the question is repeated. This emphasizes the ideas of the conservation of energy and electrical power generation. Having determined that once current flows there must be a counter torque, it is explained using two bar magnets. The causes of the generator's iron, copper and rotational power losses are then explained.

Because of the enthusiasm for learning that the individuals attending our summer course have, the classroom sessions are always interactive and filled with lively discussions. The time goes by very quickly.

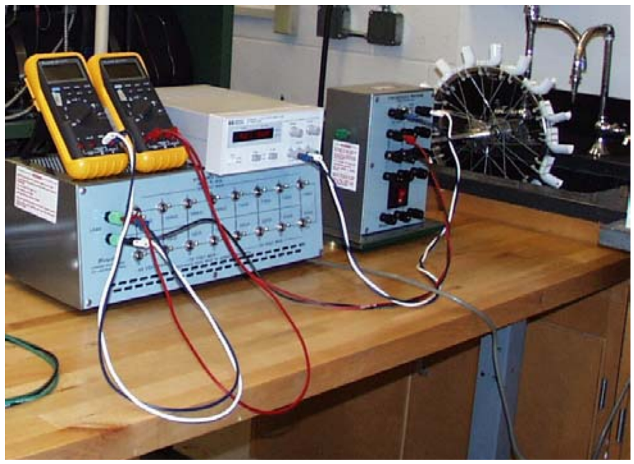

Figure 1. Energy conversion in the laboratory.
Water wheel in the background.

The afternoon sessions are held in the Thermal Systems Laboratory. The week-long objective for the afternoon sessions is to build a complete energy conversion system. The system we have used for the past two summers has converted the potential energy of the lab water supply into electrical power through a water wheel. The teachers have been in charge of building the water wheel, its installation, and characterizing the wheel's mechanical power output. Water flow through a nozzle creates a high-velocity jet stream, which is directed onto the water wheel buckets. Wheel shaft power is determined by measuring the time required for the wheel to lift a known weight through a known distance, allowing for a start-up distance. In plotting the resulting power/speed curve, the students see the power peak at half the unloaded speed, as predicted by theory during the morning sessions. Additionally, we spend time discussing experimental procedures, consistency in data collection, noise, and uncertainty. Once the wheel's performance characteristic is known, the generator is added and its losses quantified.

Those losses are measured after connecting a single-phase alternator to our water wheel using a rubber coupling device. The rotational losses are measured first by noting the reduction in water wheel speed (with zero stator and rotor current) and inferring the power loss using the previously generated power/speed curve. Rotor current is then applied and iron losses are measured by noting the reduction in water wheel speed and inferring the power loss using the wheel's power/speed curve. A resistive load is then connected to the alternator and the load is increased in steps until the wheel almost stops. Copper losses are calculated by using the previously measured stator resistance and the load current. A complete system power flow diagram is calculated for one of the system's operating conditions. The final analytical result includes a power loss assessment of the system, and a final efficiency associated with the conversion of potential energy to usable energy.

An overall intent of the laboratory sessions is always to reinforce the morning topics, but quite often the group gets side tracked with its own investigations that are carried out in parallel with the primary objectives. For example, one summer group became fascinated with a radiometer unit and spent significant time developing idea models for understanding of how it worked.

Fabrications Workshop

The participants in the student workshop came from private and public schools in surrounding school districts. We also have had some home schoolers. They learn about the program through their teachers and advisors, who have seen the TCU newsletter. We do not charge any registration fee for the workshop. The first workshop presented 3 summers ago had 7 student participants, 3 of which were TCU staff children. Last summers workshop had a full enrollment of 12 students, with a closed waiting list of 12. In fact, we had two no-shows the first morning and by the afternoon had replaced their spots with the first two wait-listed students. The instruction staff includes the four of us, which gives a 3-to-1 student-to-teacher ratio. We have found that working with middle school students in this type of hands-on setting requires close supervision.

The workshop meets Monday through Friday, from 9:00AM through 4:00 PM, with a break for lunch. Unlike the teacher workshop, there is a very limited classroom component. The hands-on activities begin almost immediately. When the students first arrive on Monday morning they sit down at the milling machines and lathes and start reading through the instructional materials. The excitement level is fairly high, and unfortunately, has to be reigned in with a lecture on safety. The workshop is held in a mezzanine above the Engineering Machine Shop, and students are made to understand that there are plenty of opportunities for accidents.

During the week the 12 students visit three project stations: the mill, the lathe, and the electronics project station. Each station visit is three half-days in length. We have 4 mills and 4 lathes, and everyone completes an electronics project, which means that each student is busy at a station at all times. The final half-day is spent on a field trip.

Mill projects

The learning curve is steep on the first machine the students encounter, whether the mill or the lathe. This is where we introduce proper techniques for installing the work piece and cutting tool, making measurements using the micrometer and calipers, and reading a blueprint with dimensions and tolerances. We have yet to have a student with any experience using this type of machinery, or have even been around a machine shop. Thus, basic machining principles have to be taught.

With both the mill and the lathe, the first project is completed with a Plexiglas work piece. From a safety standpoint, this is ideal. Additionally, it provides students insight into how they must change their machining techniques when they begin to machine metal, rather than plastic materials. The first mill project is a fitting plate, which introduces methods of facing, pocketing, and drilling. Another mill project is a screw sizing plate, on which students first finish the edges and then drill and tap a set of 6 machine screw holes. We use leaded brass material that is relatively easy to tap, does not have to be lubricated, and can also be polished to a nice finish.

Figure 2. Fabrications workshop. Students working on the mills.

One of the most frustrating tasks for the students on the mill projects is positioning the end mill at a specific location. For some, this is a mathematical stretch. We keep a small portable white board in the shop for quick explanations. Most students want to do it correctly, since they learn quickly the truth and wisdom of "measure twice – cut once."

Lathe projects

The students seem to enjoy the lathe most of all. They are fascinated by the cutting process for which a continuous material cutting is expelled from the work piece. Also, it's a bit easier for them to feel comfortable with the lathe in comparison to the mill because they're working with 2 dimensions (radial and axial) instead of 3 on the mill. The pieces are easier to measure on the lathe using the calipers, with the primary dimensions being diameter and length. On the lathe, students work with plastic, aluminum, and a mild steel. Projects include a go/no-go gage, a stepped shaft, and a centering punch made from 1018 carbon steel hex-stock. We have also left a couple of hours for available for free-form creativity using aluminum, which is easy to work with and shines brightly when polished.

Electronics project

The electrical portion of the *Introduction to Fabrication* student workshops begins with a discussion of how an electrical or electronic product comes to market. We review the sequence: idea => initial analysis => simulation => initial testing => breadboard circuit => printed circuit board. We then explain that the students have not reached the point in their education to be able to design a circuit but they can certainly understand the fabrication of a PC board and qualitatively understand the behavior of the circuit. We explain each circuit component and its symbol in the schematic diagram and then explain the behavior of the circuit to the students. We demonstrate the simulation of the circuit's behavior using a popular schematic capture and circuit simulation software package.

Each student then builds and troubleshoots a circuit using a breadboard. This reinforces the earlier discussions by letting the students verify the circuit behavior and allows them to translate the schematic diagram into a real circuit. Using a PC board layout software package, the students enter the schematic and manually route a small board. The pattern is printed on a commercially available product called PnP-Blue (manufactured by Technics and purchased from ALL Electronics) using a laser printer. The pattern is transferred to the circuit board using a household iron. The boards were then etched using a ferric chloride solution. Alternative methods of PC board fabrication (e.g., photosensitive film, milling, etc.) are discussed while the students watch the etching process. After etching, the boards are cleaned. Component holes are drilled using a Dremel tool drill press. The students then transfer their breadboard circuit to their printed circuit boards and solder them. After fabrication and troubleshooting is complete, the working boards are cleaned and taken home by the students. The projects during the past three years include a latching touch switch, an infrared "Theremin", and a simple LED color organ.

Conclusion

Learning science and engineering concepts should not be a passive process - to understand, a student must do. Learning should be a hands-on experience. American Chemical Society Priestley Medalist Harry B. Gray stated this quite vigorously "I ... would ... do away with introductory ... lectures completely, and build a first-year course entirely around experiments.''

We believe that these workshops are good examples of the types of active learning exercises that can be adapted by others to fit their teaching goals. We would be happy help others implement similar programs.

References

1. URL: http://www.exploratorium.edu/snacks/stripped_down_motor.html

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