Sharpening Pencils and Young Minds

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Abstract

The School of Technology at Purdue University has undertaken an ambitious project to increase the number of students who eventually pursue careers in science and technology. The "Techmobile" is an interactive traveling exhibit for Indiana eighth graders that introduces a wide array of scientific information in the context of manufacturing and sharpening a pencil. The events are flashy and fun, but force students to use basic math and science skills that are the foundation for any technical career. This project was made possible with the generous support of the CIBA Educational Foundation, who is an active supporter of the nationwide "School to Work" movement. This document is a useful case study for institutions considering similar projects.

Introduction

The School of Technology at Purdue University is working to increase the number of successful college students available for technical careers in Indiana. This goal is an ongoing challenge since relatively few Indiana residents have a four year college degree. In fact, Indiana ranks among the lowest of the 50 states in terms of the percentage of high school students who elect to pursue a four year college degree. One way to combat the status quo is to reach out to grade school and high school students before long term career decisions have been made. The short term goal of a successful outreach program is to show young students that technology can be fun. The anticipated long term impact is an increase in the number of well prepared students entering college.

The "Techmobile" is the School of Technology's newest and most ambitious outreach program. The project was made possible by a generous grant from the CIBA Educational Foundation, a strong supporter of the nationwide "School to Work" movement. With contributions from every department in the School of Technology, the project will take less than two years from inception to implementation. A large interdisciplinary group of volunteers developed the overall theme in the Spring of 1996. A smaller group designed, built, and tested six individual stations during the next year. Eighth grade students will evaluate the exhibit during the Spring of 1997 and refinements will take place during the summer months. Initial delivery to classrooms across Indiana is anticipated by the Fall of 1997.

The traveling road show has six sequential activities centered loosely around the theme of sharpening a pencil. At the first station, students simulate the harvest of a cedar timber by guiding a laser through a rugged forest maze. Before delivering the timber to the pencil factory, students decode a digital combination lock. Once inside the factory, students determine the maximum number of pencils that can be harvested from a single tree. At another location, students try to bake the graphite pencil lead as fast as possible. At yet another station, an electronic paint mixer determines the pencil color. The pencil finally gets sharpened after students determine a gear combination that achieves the required sharpening speed. A more detailed discussion of each station is given in subsequent segments of this paper.

The pencil sharpening activities eventually lead up to a friendly competition between groups of students. During the initial demonstration, tour guides show and explain the different events. It is important that students watch and learn the rules that govern each event at this time. A subsequent practice session enables students to complete each task at their own pace and become more familiar with the equipment. In the competition mode each event is scored, usually by keeping track of the time to complete the assigned task. Teams of students cooperate to earn the highest number of points while sharpening their pencils.

Station 1: Harvesting the Timber

In order to produce products, raw materials must first be acquired. In this case, selective harvesting of timber is the most basic starting point. Thus the rationale for this station is to initially gather the raw materials for use in production. To transport the timber to the pencil factory, the students use a small laser to plot a path from the felled trees, through the forest, around as many as two mountains, and to the pencil factory loading dock. Students compete to see who can map a path from the forest to the factory loading dock in the least amount of time.

Functional Description

Figure 1 shows the laser maze playing field that consists of an 18” X 27” aluminum plate. Trees and mountains are mounted on it to simulate the obstacles in a hilly forest. The forest consists of up to twenty trees. One or two mountains can be used. The trees and mountains are repositionable, depending on the desired complexity of the task. Each tree may be mounted anywhere on a 1” X 1” grid pattern, which covers most of the plate. A 2 mW Helium laser is mounted horizontally at the left side, approximately 2” above the plate and aimed longitudinally toward the factory loading dock at the other end of the plate. A photocell detector on the loading dock determines when the laser beam has arrived. Because the trees and/or mountain obscure a direct line-of-sight path from point to point, mirrors divert the beam on a path that circumvents any obstacles. As many as 10 mirrors may be mounted anywhere on the grid and rotated incrementally. Varying the number and locations of the mountain and tree obstacles allows a large number of paths to be generated.

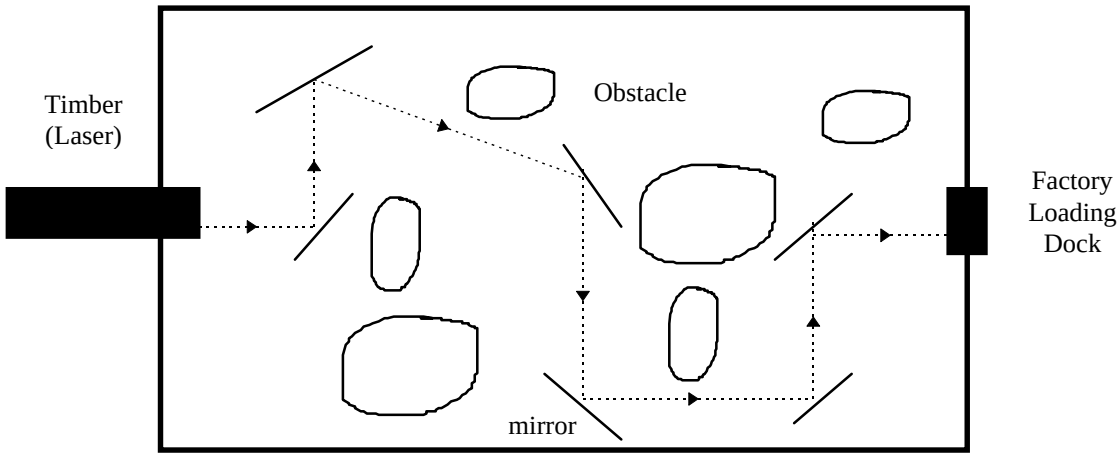

Figure 1. The Timber Harvesting Station demonstrates principles of physics and optics.

Learning Objectives and Applications

Beyond the excitement of using a laser on a fun project, the timber harvesting station introduces students to a number of important scientific and technical concepts. Principles of physics and optics, most notably that the "angle of incidence equals the angle of reflection", are applied to solve a real world problem. Lasers are commonly used in engineering technology for surveying and building construction. Similar instrumentation is also used for quality assurance in manufacturing assembly lines.

<u>Station 2: Unlocking the Factory Door</u>

After the raw timber is delivered to the factory, the door must be unlocked. The door is controlled by a combination lock based on weighted binary switches. The student's task is to unlock the door by discovering the combination. Students compete to see who can unlock the door in the least amount of time.

Functional Description

Figure 2 is a sketch of the workstation that students use to unlock the factory door. The digital circuit that controls this station (not shown in Figure 2) is housed in a transparent case so that the inner components are visible. At the start of the contest the computer generates a random 8 bit digital number that represents the door's combination and the "Locked" light is on. Students generate their own 8 bit digital number by manipulating the binary (on/off) switches. The switch configuration of Figure 2 is a digital representation of the number 56. To compare an answer with the secret lock number, the test button at the bottom of the display is pressed. The actual combination lock number is not revealed right away, but an indicator dial and lights show whether a student's guess is high or low. A five second time delay is incurred for each incorrect match. A correct match turns on the "Open" light and allows students to continue to the next station.

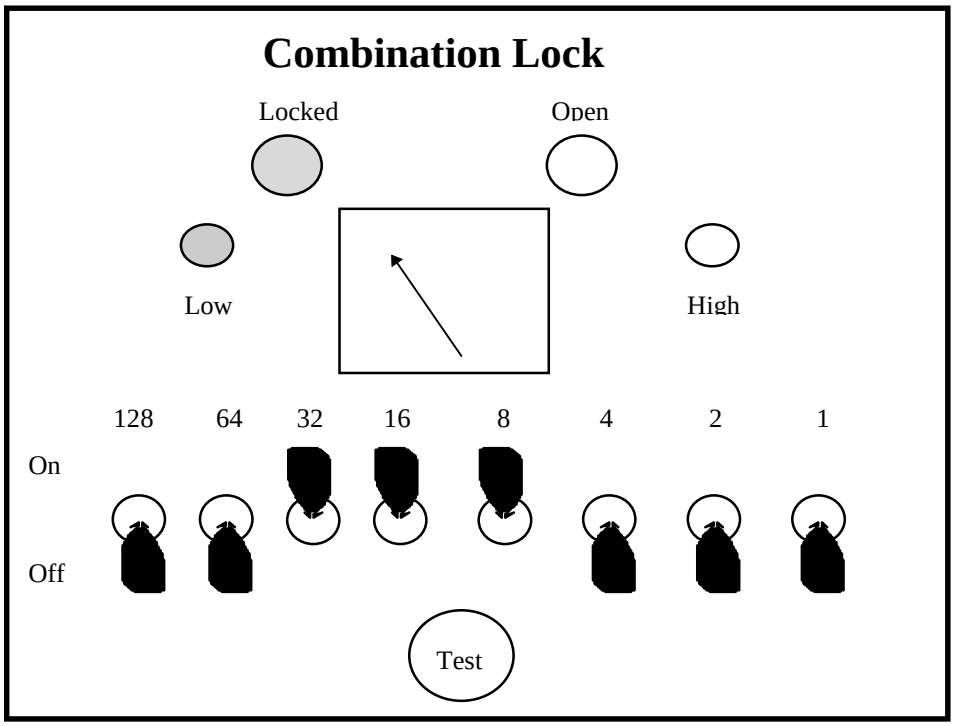

Figure 2. The Combination Lock station introduces binary number systems.

Learning Objectives and Applications

The station that unlocks the factory door offers a glimpse at the inner workings of modern computers, which operate on a binary logic system. In addition to exposing the actual integrated circuit, students learn that the position (1-8) and actuation (on/off) of each digit is important. Students could unlock the door with a trial and error approach, but a significant time penalty would be incurred. To be most efficient (and fast), students must master the concept that switches located further to the left have a larger impact on the final answer.

Station 3: Cutting the Logs Into Pencils

Once the students have gained access to the factory, the next step is to cut the raw timber into pencil-sized pieces. Initially the students must consider how many pencils can be cut from a given log. A second more subtle consideration is how to maximize the number of pencils (or minimize waste) from a given log. Not all log shapes are equally efficient at producing pencils. Students are timed as they compute how many pencils can be manufactured from a given cedar log during the competition segment.

Functional Description

There are at least two ways to estimate the number of rectangular carpenter pencils that can be manufactured from a cedar log. A physical model, made by stacking carpenter pencils to match the volume of a log, will almost certainly guarantee a correct answer. The drawbacks to

this approach are that it can be labor intensive and time consuming. The log cutting station has hollow Plexiglas "logs" to assist the development of a physical model. Figure 3 shows that approximately 25 carpenter pencils can be made from one circular log. A variety of Plexiglas sizes and shapes (circle, square, rectangle, triangle) are available to demonstrate the minimum waste factor as pencils are placed in the Plexiglas “logs”.

A math-based model is another valid approach. The dimensions of the log and a pencil are measured first. By applying geometry, the volume of both items can be determined. The ratio of the log volume to the pencil volume is a reasonable analytic estimate of the number of pencils that can be manufactured. Students may be surprised to learn that the physical and math-based models frequently yield different results. As suggested in Figure 3, a circular shape will always have wasted material when producing rectangular pencils. The potential for wasted material is even larger when the width of the saw blade is considered and is difficult to include in the math-based model.

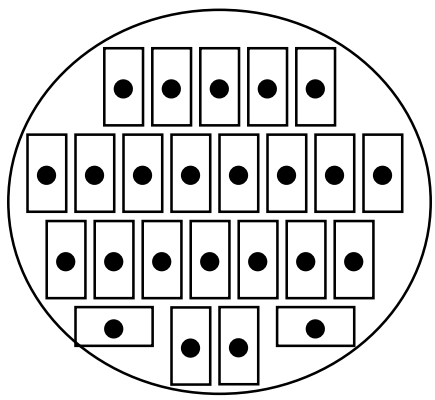

Figure 3. How many carpenter pencils can be made from a circular log?

Learning Objectives and Applications

The station that cuts logs into pencils incorporates a number of useful technical topics. The instrumentation includes a caliper for accurate length measurements, carpenter pencils, a ruler, Plexiglas “logs”, and a calculator for basic arithmetic. Students apply geometry to compute both areas and volumes. More importantly, students have the opportunity to compare physical and math-based methods of analysis. After completing the log cutting station students will recognize limitations of a mathematical solution to any physical problem.

<u>Station 4: Processing the Graphite</u>

Another significant step in pencil manufacture is processing raw graphite to a suitable consistency for pencil lead. Graphite is ground, washed, pulverized, extruded, and baked to a suitable level of hardness. The graphite processing station demonstrates some of the technology behind the baking process and along the way introduces a few basic heat transfer concepts.

During the friendly competition, students evaluate different heating options with the goal of baking the graphite as fast as possible.

Functional Description

Figure 4 illustrates the basic layout and operation of the graphite processing station. A single graphite container is placed inside a small industrial oven and heated. In reality the industrial oven is only a prop, it is simply a well-insulated container without a power supply of its own. An external heat source raises the graphite container temperature from ambient conditions to a target temperature of about 40 °C. Temperatures are maintained within safe limits by using a 1500 W hair dryer that has a maximum operating temperature of about 60 °C. An infrared thermometer monitors the container temperature during the heating process. The heat source, oven, and infrared thermometer do not change. The rate of heating for several different graphite containers is the focus of this experiment.

The material for the graphite container controls the rate of heating. Students can select graphite containers made of steel, stainless steel, aluminum, copper, brass, plastic, or wood that have the same size and shape. Copper, aluminum, and brass achieve the target temperature quickest. Steel and stainless steel are a little slower at achieving the target temperature. Students incur a significant time penalty for selecting wood or plastic graphite containers, which achieve the target temperature very slowly if at all. Fortunately, students do not have to select the containers at random. A basic heat transfer equation and a table of material properties helps predict which container will heat up the fastest.

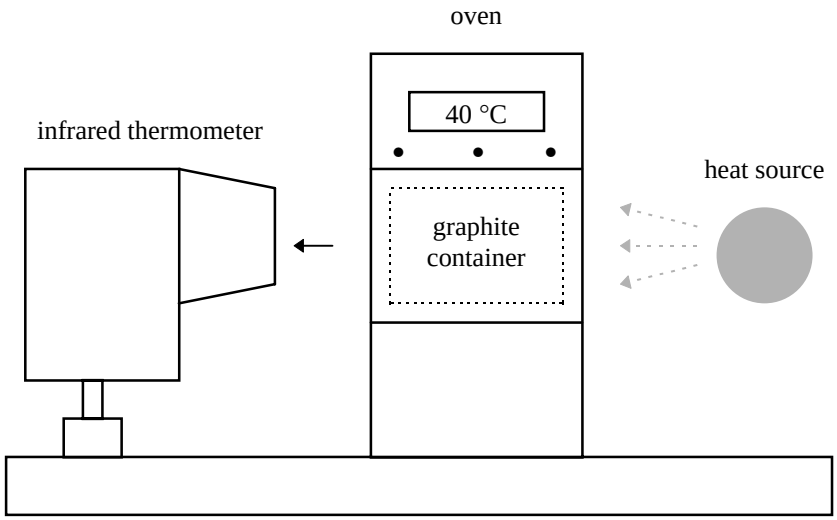

Figure 4. The Graphite Processing station illustrates heat transfer.

Learning Objectives and Applications

The graphite processing station presents a number of useful ideas. The infrared thermometer, which measures temperature without surface contact, attracts a lot of student attention. It looks more like a Star Trek phaser than a useful measurement instrument. The thermal performance of insulators and conductors as well as one dimensional heat transfer are among the important technical concepts. Finally, students are challenged to use basic algebra to evaluate engineering problem rather than relying on guess work.

Station 5: Painting the Pencils

Pencil manufacture is nearly complete at this point. Both the wood and graphite have been processed and assembled to appear like a finished product. Only the finishing steps, such as painting the pencil are left. Before the pencil can be painted, the paint must be mixed to match the color desired by the customer. The student task at the pencil painting station is to mix the paint to a specified color as quickly as possible.

Functional Description

Figure 5 is a sketch of the Color Proportion Controller at the paint mixing station. The circuit that controls this station (not shown in Figure 5) is housed in a transparent case so that the inner components are visible. The computer initially selects a random color that appears on a small multi-color LED labeled "Desired Color" and the "No Match" light is on. Students attempt to match the target color by adjusting the red, blue, and green proportion knobs in the middle of the display. Three indicator dials show the relative amount of each color in the overall mix. The cumulative student effort is displayed in real time on a second small multi-color LED labeled "Mixed Color". When students are satisfied with their answer, they press the "Test" button at the bottom of the display. A "Match" light indicates success, while a time delay is incurred for a "No Match".

Learning Objectives and Applications

In addition to demonstrating an application of computer circuits, the pencil painting station illustrates basic rules for proportions. For any paint color derived by the students, the percentage of red, blue, and green is shown on the indicator dials. The cumulative amount of color always equals 100%. In other words, the amount of red plus the amount of blue plus the amount of green always equals 100%. To work efficiently at the paint mixing station, students must recognize that changing the amount of one color directly affects the proportion of the other two colors.

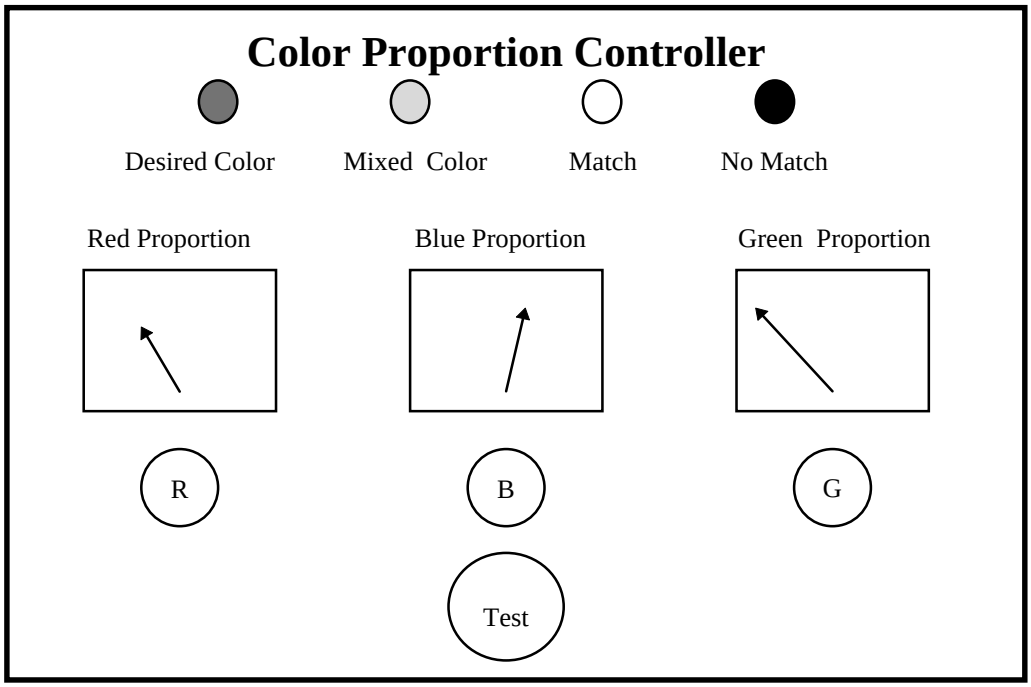

Figure 5. The Pencil Painting station demonstrates proportions.

<u>Station 6: Sharpening the Pencils</u>

The sixth station finally sharpens the pencil. Students must evaluate and build a simple gear-driven machine to power a pencil sharpener. The key parameter for this analysis is the gear ratio, which is the number of rotations of a driven gear for a single rotation of the drive gear. This event is timed during the friendly competition.

Functional Description

At the start of this event a computer randomly selects a gear ratio for optimum pencil sharpening. This target value changes each time the station is used. Students work to build a physical model that matches the target gear ratio. As shown in Figure 6, the pencil sharpening station consists of 4 circular posts mounted on a small sheet of Plexiglas. Small lightweight nylon spur gears fit over the posts and mesh together. A variety of gear diameters are available. The middle two posts of Figure 6 show that multiple gears can be stacked on the same post and linked with a shaft key. In this way, two gears on the same post always move together. Depending upon how the sizes match up, gear ratios from 1:1 to 5:1 can be achieved.

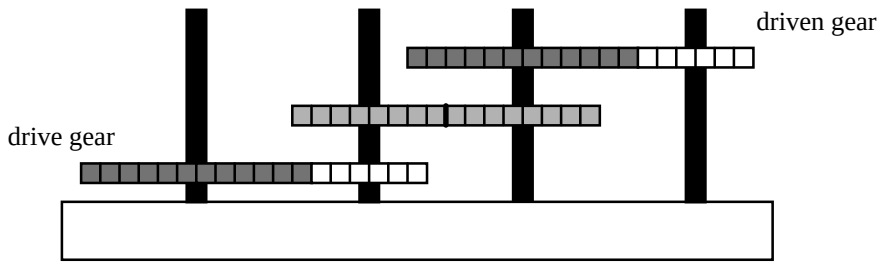

Figure 6. The Pencil Sharpening station introduces gear ratios.

The gear ratio for the simple machine of Figure 6 is the number of rotations of the gear on the extreme right with respect to the number of rotations of the drive gear on the extreme left. This value can be determined analytically by comparing the diameters of neighboring gear sets and combining the final answer. The two gears on the left posts have about a 2:1 ratio. The gears on the middle posts have about a 1:1 ratio because they are roughly the same size. The two gears on the right posts have about a 2:1 ratio. The composite gear ratio is about 4:1.

Learning Objectives and Applications

Gears are a fundamental mechanical device. Gearboxes are found in almost any machine that moves, from cars to jet engines. Students will be given the basic mathematical relationships that describe the performance of meshing gears and will creatively apply this information to solve a real world problem.

Ongoing Development

Although a great effort was made to make each Techmobile station simple and easy to use, significant computational resources are required to coordinate all the activities. As a simple example, log cutting (station 3) cannot commence until the factory door is unlocked (station 2). These types of project integration activities are transparent to the user and are carried out by a Programmable Logic Controller (PLC) that is linked to each station. The PLC was donated by Allen Bradley and monitors each station's performance, coordinates timing, and determines success or failure as students work.

Packaging has also received considerable attention. The workstation components must be protected as they are moved from place to place. Custom containers were fabricated to keep all work station materials together and prevent damage. Parts of the containers will be re-used to hang signs during an exhibit. Each container weighs less than 75 pounds or has built-in wheels. The containers are extremely durable. All the containers fit inside a single cargo van.

Faculty volunteers on the Techmobile project quickly found out that brainstorming about an innovative outreach program is one thing, but actually delivering an ongoing program of consistently high quality is a much bigger issue. Every detail must be planned in advance. Issues like providing supplementary literature, transporting the equipment from school to school, and

training the personnel who present the Techmobile were not apparent at first, but require a great deal of coordination. It comes down to time and money. Work on the Techmobile began in the Spring of 1996 and limited delivery will commence 1 1/2 years later in the Fall of 1997. The budget for the project is roughly $50,000, which does not include donated equipment or much of the time put in by volunteers. The cost for delivering and maintaining the Techmobile on a continuous basis has not been determined.

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