HANDS-ON PHYSICS PROGRAMS FOR MIDDLE LEVEL STUDENTS

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Abstract -- We describe a series of three female-targeted extracurricular physics programs that we have developed over the last ten years. The programs explore fundamental concepts of physics, relate them to applications, and culminate in student-built devices. Exploring Physics, an eight-session program for female students in grades 5-7, has eight units that explore different concepts in physics, and is used by about 300 students annually throughout Missouri. FEST, Families Exploring Science and Technology is a four-session program for grades 6–7, where students and parents work together to combine physics and engineering principles and build a movable drawbridge. Saturday Scientist is a three-Saturday program in collaboration with local industries, where 8-9 grade students visit industrial sites and learn about applied scientific principles and careers. We also describe evaluation results, related publications, and teacher development institutes. These programs were developed with NSF funding, and are currently working toward being self-sustaining.

Index Terms—extra-curricular programs, hands-on physics activities.

INTRODUCTION

Despite the efforts of the past three decades, the physical sciences are still sparsely populated by females. According to data from the National Science Foundation [1] 22% of females enroll in high school physics, compared to 27% of males. In 1996, women earned 47% of bachelor's degrees in science and engineering fields, including social sciences; however, only 37% of physical science degrees and only 18% of engineering degrees.

Much of the research on student interest in science documents that students lose interest as they progress through school. Using a multi-dimensional science interest instrument [2] it was found that [3] attitude toward science becomes less positive throughout grades six through ten and throughout each school year in those grades. Attitudes that were strongly positive toward science at the beginning of sixth grade changed to a neutral attitude at the end of tenth grade.

Several studies have documented gender differences in attitude toward science [4, 5, 6]. Females' attitudes toward science were significantly more negative than that of males. The negative attitude persisted (among eighth grade students, [7]) despite females achieving higher grades and scoring similarly on achievement tests. Moreover, significantly more males than females join mathematics and science extracurricular activities.

In order to positively influence both the attitudes toward and familiarity with the physical sciences among female students, we have developed and implemented a series of three extra-curricular programs that span the middle grades: Exploring Physics, for grades 5-7, Families Exploring Science and Technology (FEST) for grades 6-7 and Saturday Scientist for grades 8-9. The grade groupings were chosen to match the local public schools, and can be adapted for different school structures. The programs are targeted to female students, however, male students are not excluded.

Recruitment is a key concern for an extracurricular program with a targeted audience. Having teachers help develop programs gives us a jump on recruitment – teachers feel a degree of ownership and are eager to conduct the program. Several strategies are used to advertise the programs. Teachers actively invite female students whom they think will benefit from a physical science program. For Saturday Scientist, brochures are mailed home inviting the parents of targeted students to sign their child up for the program. At some schools participation in these extra-curricular activities allows students to earn "club" points toward a school letter. Our initial goal was to have at least 50% female participation. Our numbers frequently exceed the target.

Having teachers help develop programs has several additional benefits: they help keep programs at an appropriate intellectual level for the students, help choose materials and equipment that suit the hands-on skills of students, provide formative evaluation, and anticipate potential classroom management issues.

EXPLORING PHYSICS

The Exploring Physics program was piloted in 1993, and currently serves about 300 students annually. Exploring Physics focuses on hands-on activities that are concept oriented, fun, and sequenced to develop a given topic. Several of the activities are make-and-take projects. This voluntary, after-school program is targeted to female students in grades 5-7, but has often been used for grades 4-8. The program is conducted at the students' schools and is run by science teachers who receive content training at our Summer Teacher Institutes. It is currently available in the local (Columbia) Public School District and to other Missouri teachers who have taken the summer institutes.

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Each four-week program uses one of the units listed in Table I. Students attend 90-minute sessions twice a week. Typically 20-40 students attend a given program. The last session is a family evening; students show their families what they have learned, and also interact with hands-on style exhibits. Teachers often include popular demonstrations, for example, activities with a Van de Graaff generator. Eight units (e.g., Optics I) have been developed, each with two or three modules (e.g., Reflection) with six to ten activities in each module. The units topics are summarized below [8].

TABLE I.
EXPLORING PHYSICS UNITS

Matter and Mechanics I: Air and Stability	Matter and Mechanics II: Density and Simple Machines
Optics I: Reflection and Color	Optics II: Refraction and Polarization
Sound: Vibrations, Waves, and Resonance	Energy: Mechanical, Chemical, Electrical Energy; Energy Transformations
Electricity I: Static Electricity, Batteries, Bulbs & Switches, and Simple Circuits	Electricity and Magnetism-II: Magnets, Solenoids, Resistors, and Capacitors.

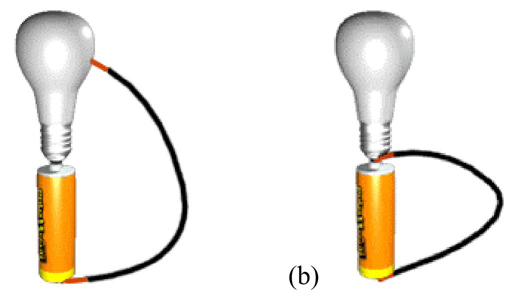
Each module of a unit focuses on a few key concepts (e.g., the reflection module explores the reflection of light by straight surfaces, multiple mirrors, and curved surfaces). The activity materials were developed using the 5E learning model [9], using the following guidelines to keep the "fun level" of the program high:

- A module often begins with a game or a puzzle based on the concept. The initial activities are designed to internalize the concept, rather than learn it formally.
- Concept development is done via activities that use commonly available materials and simple scientific equipment, such as digital voltmeters or ray boxes. Student see that science is manifested in everyday life, and also gain familiarity with laboratory equipment.
- Concepts learned are applied to build a gadget, game, art project, or toy, thereby developing students' building and mechanical skills. Common shop tools are used under supervision of the teacher. Many female students express awe at having handled an electric drill during the program.
- Quantitative analysis of data is introduced for students in higher grades.
- "Gee-whiz" exhibits are used on family night, and are handled with interactive explanations so that they are not regarded as "magic". Family night helps publicize the program to younger friends and siblings.

A Sample Exploring Physics Module

The *Batteries, Bulbs, and Switches* module [10], which introduces students to electrical circuits, explores the concepts of closed circuits, contact points, and various kinds of circuit elements: bulbs, switches, batteries, buzzers, motors, LEDs, and photocells. This module is suitable for grades 4-6.

The module begins with the classic activity where students are provided with one bulb, one battery, and one wire. They are first asked to draw two ways in which the circuit can be connected so that it does not work and two ways in which it will work. This activity highlights students' misconceptions about what constitutes a closed circuit. Examples are shown in Figure 1, where connecting to the glass envelope of the bulb (a) or a short circuit (b) is construed as a closed circuit. After students try out these circuits and do not succeed (and indeed, touch the hot battery or wire in (b)), a discussion of contact points and the importance of having metal-to-metal contact follows.



(a) (b)

FIGURE 1.
STUDENTS' MISCONCEPTIONS OF A CLOSED CIRCUIT.

Next in the module is a problem-solving activity, *The Bulb Challenge*, where students examine different diagrams of closed circuits, (like those in Fig. 1) predict whether the bulb will light or not, give reasons for their prediction, and then try them out. The next activity examines the inside of a bulb and relates it to closed-circuit concepts. In *Look at Those Bulbs*, students examine an assortment of light bulbs, make diagrams, and discuss how the filament in a bulb is connected to the outside contacts, allowing the circuit to be completed while simultaneously lighting up the bulb.

The next few activities utilize a puzzle board where different devices are mounted on puzzle pieces that can be mixed and matched (Fig. 2). *Light That Bulb* uses piece A. Students draw a diagram of the circuit, and then trace the path of the electrons, introducing the concept of a direction for the flow of current. They are asked to exchange the + and – terminals of the battery and observe what happens (no change), and queried on what they must do to turn the bulb on and off (pull a wire off a contact). This last question leads to the next activity, entitled *Enter The Switch*, which utilizes puzzle pieces A and B (Fig. 2). Students first draw a picture of how they will connect the circuit so that the switch turns the circuit on and off, and then connect the circuit. Invariably, a few students connect all terminals of all devices to each other, producing a short circuit! By this time students are usually comfortable using standard symbols for devices rather than cartoons of bulbs and batteries.

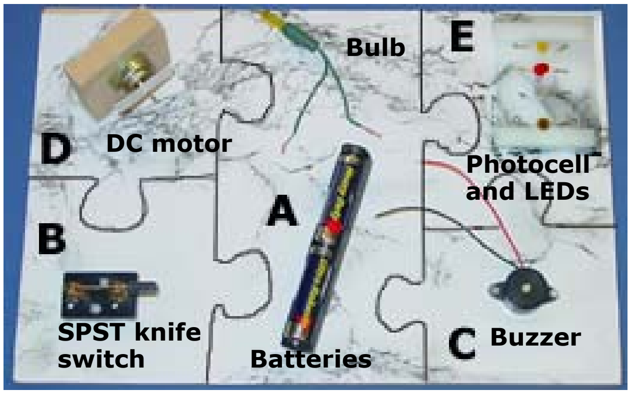


FIGURE 2
THE PUZZLE BOARD

In the next activity, *Look at All Those Switches*, students examine a variety of switches (SPDT, DPDT, DPST, push-button, etc) draw diagrams, figure out how they work and discuss where they may be used. A problem-solving *Switch Challenge* follows, where students examine several circuits with multiple switches and bulbs and predict how those circuits function.

The next activity is *Turn On the Buzzer*, (using puzzle pieces A, B, and C, Fig. 2). Students plan the circuit and connect the switch, battery, and buzzer. The buzzer works only in one polarity. Next is *Connect the Motor* (puzzle pieces A, B, and D). The DC motor changes the direction in which it spins when the polarity is reversed. Both activities reinforce the concept of the direction of current flow.

The next activity is *Adding a Photocell and LEDs* (puzzle pieces A, B, C and E). This activity introduces modern devices to young students. The photocell is connected in series with the buzzer, and students observe the change in the volume of sound when a finger blocks the light falling on the photocell. A discussion of the buzzer "not getting enough voltage" follows. The red and yellow LEDs reinforce the concept of current flowing in one direction. A bipolar LED surprises students by lighting up (in different colors) when the polarity is reversed. Students quickly figure out that it consists of two LEDs set back-to-back.

The advantage of using a puzzle board is that it allows the teacher to maintain some degree of control over the sequence of activities. In a pilot run where we had all devices on a single board, students were prone to just playing around and connecting devices to each other, frequently expressing frustration that things "didn't work." With the puzzle board, pieces can be given or taken away from the students as needed. After all the activities have been completed, however, students often play with the devices connected in creative ways, but this time they can answer their frustrations themselves, or create more efficient "teachable moments." We frequently provide a voltmeter when a student complains that a bulb and motor in series will allow the motor to work while the bulb does not light. This circuit also gives us an opportunity to address the misconception that the "motor is closer to the battery and therefore works while the more distant bulb does not." This discussion sets the stage for the next module, *Simple Circuits*, which addresses series and parallel circuits.

The final activity in this module is a student-built device entitled *My Own Car Door* (Fig. 3). The circuit is built in a transparent baseball card box. The light turns on when the lid is opened and turns off when the lid is shut. Students take this gadget home.

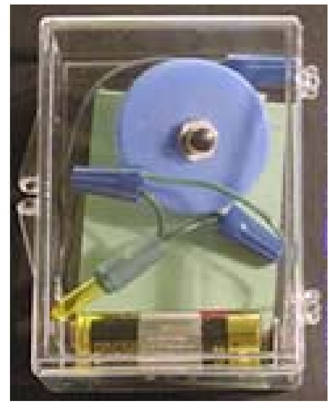


FIGURE 3
MY OWN CAR DOOR

The *Batteries, Bulbs, and Switches* module takes students about three 90-min sessions to complete. The written materials for this and other Electricity and Magnetism modules have been published as a CD-ROM [10] (discussed later in this paper).

FAMILIES EXPLORING SCIENCE AND TECHNOLOGY

Families Exploring Science and Technology (FEST) is an evening program designed to give middle level students and their families collaborative experiences in science and technology. FEST piloted in the spring of 1998, was developed in collaboration with industrial technology and science teachers. About 50 students in grades 6-7 participate annually. The most effective strategy for recruitment is to show students the final take-home project – the working drawbridge.

FEST is structured so that students work with an adult family member to learn science concepts through hands-on activities and construct the drawbridge. Students who cannot bring a family member are assigned a buddy who works with them. The four-week program meets one night each week for two hours. To make the program more convenient for families, low-cost dinners are delivered if the families choose this option.

The FEST program sessions are organized in the following manner. In the first session, after introducing the program, families examine a model drawbridge. Video clips of drawbridges in movies (The Blues Brothers, Annie) and other bridges (Tacoma Narrows Bridge Disaster, a.k.a. Galloping Gertie) are presented.

Families begin the first hands-on lesson on structures. The teacher discusses different types of stresses that engineers consider when building structures, and the audience often provides examples. Each family constructs a box made from basswood sticks from one of four structural designs: a plain box, a box with crosspieces, a box with gussets on the joints, or a box that has both crosspieces and gussets. The glue is allowed to dry until the following week's session. The class makes predictions about what they think will happen when they test the boxes for their ability to withstand stress. If there is time, families begin construction on the basic structure of the bridge sides. Families often check out the tools and supply boxes to continue the construction at home.

During the second session families test the strength of their boxes by loading and breaking them. They compile class data on which boxes held the most weight and evaluate the strengths and weaknesses of each design. Each family then decides which extras (crosspieces or gussets), if any, to add to their design of the bridge sides.

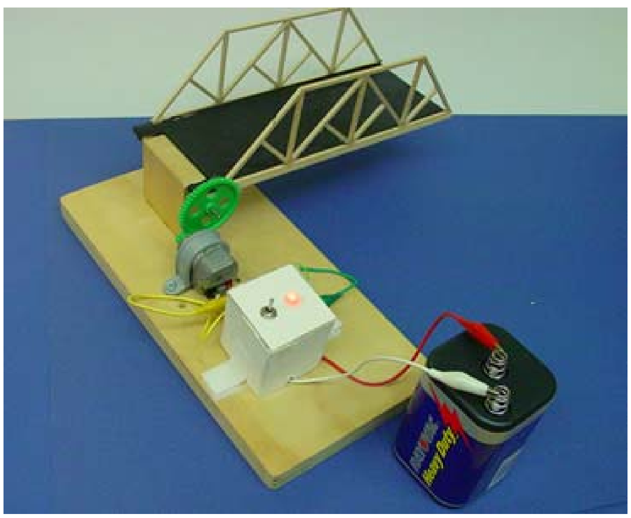


FIGURE 4
THE FEST DRAWBRIDGE

While individual families test their boxes, the rest work on a lesson on gears. Participants investigate combinations of gear sizes using a simple gear apparatus, and make conclusions about the resulting differences in input/output force and speed. The teacher also has a bicycle and stand for families to examine. Participants apply what they learn to the drawbridge situation by deciding how to arrange two gears most appropriately. Should the bridge move slowly with less power or quickly with more power? In the end the participants decide that it makes more sense to put the large gear on the bridge base and the small gear on the motor, letting the bridge raise and lower slowly while requiring less power.

Session 3 deals with electricity. In preparation for wiring their motor, families learn about the differences between series and parallel circuits made from Christmas bulbs. They use voltmeters to measure and compare voltage and discuss current in the circuits. Then they learn how to wire a double-pole-double-throw (DPDT) switch so that the motor can change directions, allowing the drawbridge to be both raised and lowered. A bipolar LED is included in the circuit to indicate the direction of motion of the drawbridge.

The last session of the program is spent assembling all the parts of the drawbridge. The families finish constructing the bridge sides, if necessary; reinforce the floor of the bridge using any design they choose; assemble the gears, axle, and motor; wire the motor and switch circuit; construct a switch box; and test the whole structure. It is impressive to watch the diligence with which the groups work to put everything together. No one ever leaves without a complete bridge. Of course, final decorative touches can be added later.

In addition to the science and engineering concepts learned in this program, students and their "buddies" leave with practical skills in using tools such as saws, drills, wire-strippers, hammers, and multimeters. Most importantly, the families have had the opportunity to spend some quality time working and learning together.

SATURDAY SCIENTIST

The Saturday Scientist Program is a hands-on, industry-based experience designed for junior high school students (grades 8 and 9). The goals of the program are to provide meaningful extra-curricular science experiences and to increase students' awareness of potential careers in the physical sciences. The pilot program was conducted in 1998. Each year three local industry sites host about 100 students from the three local junior high schools. The 3-hour programs are conducted for three Saturdays each spring, and each school rotates through the three sites. Several organizations have hosted Saturday Science over the past six years, including the City of Columbia Water & Light and Fire Departments, University of Missouri's School of Veterinary Medicine, Industrial Engineering and Computer Engineering departments, KOMU TV, and the Columbia Career Center's Laser Lab. Details and pictures of several programs are on our website [8]. We describe a few of them below.

The City of Columbia Water & Light Department, developed two programs on energy conservation and energy production. During the energy conservation program, students built tabletop houses from various insulating materials, including cardboard, cardboard covered with aluminum foil, foam insulation, drywall, and Plexiglas. A 100-W light bulb was placed in the house as a heat source and the students took interior and exterior temperature readings for 12 minutes. After plotting the data, the students estimated the steady-state temperatures to compare the effectiveness of the building materials., Students examined the thermal leaks using an infrared camera. The most counter-intuitive infrared picture was to see visibly transparent Plexiglas opaque while cardboard was virtually transparent. Students then attempted to further insulate the houses by sealing leaks, applying window treatments and trying other creative ideas.

During the energy production and usage program, students measured the power usage of appliances in a tabletop house. By modifying LED-based lights with added resistors, the Water & Light engineers came up with an ingenious plan that used safe 12V supplies, yet appear to use energy comparable to air conditioners, stoves, and refrigerators. Students then used an energy bike to produce electricity and power the devices.

At the Career Center (Columbia Public Schools), students made holograms and worked with optical materials. The Career Center has a collaboration to train optical technicians for 3M, and has a state-of-the-art holography apparatus.

At the Robotics Lab, University of Missouri CSCE Department, students programmed two simple mobile robots that were designed and built from Legos [11]. "Freddy" is built with treads. "Willie" has two active wheels and one passive wheel. Both are controlled with two motors and a differential drive strategy, which is explained to students. Three bump switches are included as binary touch sensors – two in the front and one in the rear. The "brain" of each robot is a Tiny Tiger micro-controller programmed in BASIC. Low-level subroutines were written prior to the students' visit and provided a form of high-level interface. A handout provided exercises to familiarize the students with the robot functions, after which students were encouraged to write a program that used all of the sensors to escape from obstacles. A maze was provided that made the task interesting and required some strategizing.

EXPLORING PHYSICS – THE CD-ROM

A dissemination product of our Exploring Physics program is a CD-ROM entitled Exploring Physics-Electricity and Magnetism [10]. The CD is intended for teachers and students in grades 5-9, and for professional development. We are currently using the CD (with minor modifications) for a physics class for preservice elementary education majors.

Over 100 hands-on activities are organized in six modules, entitled Batteries, Bulbs and Switches (described previously in this paper), Understanding Batteries, Simple Circuits, Static Electricity, Resistors & Capacitors, and Magnets & Magnetism. Within each module the activities are sequenced to develop a few chosen concepts. The kinds of activities vary – there are hands-on activities, inquiry-based experimental design activities, challenges (problem-solving activities), projects that students can build, and student reading pages for important background information.

The activities are designed so that the same activities are used for professional development of teachers and for use with students in their classrooms. The additional depth required for teachers is built into the embedded links. While the original Exploring Physics program was targeted to grades 5-7, the CD was expanded for use in grades 5-9, with some segments useful for 3-4 and 10-12.

The CD was written not only as a compilation of hands-on activities, but also to serve as a reference. Teachers who took our summer institutes routinely asked for written materials that would provide the content background needed for the hands-on activities. The CD was therefore written with a vast repertoire of links that provide appropriate conceptual information, a rich collection of animations and figures, useful instructions on equipment, several quantitative activities, handy teacher hints, quick-check answers, and several activities usable for assessment.

Teachers who had previously taken the summer institutes and those who were running the Exploring Physics programs served as formative and summative reviewers as we wrote the CD. Following their input, we emphasized visuals over text, favored bulleted text over long passages, and kept linked background information relatively short (with a few notable exceptions).

SUMMER TEACHER INSTITUTES

Soon after we started the Exploring Physics program we realized that we needed to provide inservice professional development for teachers who would teach the programs. These inservice summer institutes, piloted in 1993, have evolved to be three weeks long. They run in a three-year cycle: Matter, Mechanics and Energy; Electricity and Magnetism; and Optics and Sound. Teachers learn using the same materials that we use in the Exploring Physics program, but with additional depth. The Electricity and Magnetism institute uses the CD-ROM described previously in this paper [10].

The institutes are funded by state Eisenhower grants, now entitled Improving Teacher Quality, which provide tuition, room and board, and a kit of materials that is split-funded by the grant and the teacher's school. As of this year the grant also provides a stipend. Many teachers use the materials in their classrooms, and several offer the extra-curricular program.

EVALUATION DATA

Much of the evaluation focused on testing the efficacy of our programs, and on attitude changes. All evaluation instruments are available on our website [8].

A confidence instrument was administered (pre-and post-) to female students taking Exploring Physics, and to comparison groups of female and male students who did not take the program. The females who took Exploring

Physics had about the same confidence pre-test scores as those who did not take the program. The males (who also did not take the program) had higher confidence levels than both female groups. After the Exploring Physics program, however, the confidence level of the female students taking the program increased, and was equal to or higher than that of the male students for 11 out of 12 items. The overall evaluation by the students and the families who visited at family night has remained very positive regardless of the Exploring Physics unit.

FEST evaluation data were collected from site visits at the three middle schools, analysis of a modified Science Experience Survey [12] (SES), buddy survey, summative evaluation, and limited follow-up telephone interviews. From the data collected over four years, it is evident that students and families especially enjoy building the bridge together, working with electricity, and taking the final product home (66% enjoyed these areas the most). Almost all participants would recommend FEST to others. The high mean scores and low standard deviations are consistent across all schools.

The overall rating of Saturday Scientist was also very positive. Students especially enjoyed operating lasers and making holograms, programming robots, and wiring electrical circuits in the tabletop houses. As far as careers related to their experiences, students cited a very diverse list of skills they perceived to be necessary in each field. Students ranked the ability to do math as being a high-necessity skill for all industry sites.

Summer Teacher Institute qualitative (interviews, surveys) and quantitative (pre- and post- test) data indicated that the Institutes greatly expanded the knowledge base of the participants. Teachers liked the CD and felt it would be a wonderful resource. Several had good insights on how to incorporate the CD into their own classroom activities. Overall, the participants indicated that the material of this Institute would be retained much longer due to the expectations of the course, the usage of material learned, the hands on re-enforcement of the concepts, the real world applications, and the many homework problems. They also felt they would be able to better able to facilitate a similar knowledge gain in their students due to the pedagogy of the Institute. Having the kit of equipment helped them implement the hands-on activities in their classes.

SUSTAINING THE PROGRAMS

Since grant funding for these programs ended in March of 2002, we have had to modify some aspects of the programs to ensure their sustainability. Some teacher stipends have been shifted to the public school's extracurricular budget as a science club or as part of the Career Ladder. For Saturday Scientist, junior high school teachers applied and received a locally disseminated Links to Learning grant to cover not only stipends, but transportation costs to the industry sites. Exploring Physics and FEST now both charge a fee to participants to cover materials costs, but make scholarships available for those who cannot afford the fee. Some schools have also received funds from their PTA or have conducted fundraisers to cover the cost of materials. The industrial sites for Saturday Scientist have been very generous in providing expertise and materials at their own expense. Stipends for graduate students who helped with the program at University sites were provided under the original grant, and may be written into the application for the Links to Learning grant in the future.

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