



THE TOOLS OF THE PHYSICS TEACHER *by Richard M. Sutton*

A sense of humor and love for the subject are among the basic virtues of the physics teacher writes the author, who has both. He gives a few of his ideas on the subject here.

The author, set to demonstrate a chain reaction with mousetrap-cocked cork neutrons.



A physicist has been described by Eddington as a pointer-reading creature. If that is so, then the physics teacher must be a "pointer-reading creature with an attachment for students." And there may be some pessimists who think that all students are resistance coupled!

Whatever may be the aim of the physicist in his research laboratory, his object in the classroom is to improve the quality of the inhomogeneous supply of thinking animals entrusted to his care. This is a process that cannot be reduced to the use of instruments, although one could imagine several instruments that would be helpful in the classroom. For example, there ought to be a Geiger counter that would tell when ideas penetrate and click in the student's mind, some instrument to tell the professor when the student is on the beam. Conversely, each student should have under his control a knob which he could turn to let the professor know whether ideas are coming too fast or too slow. If these knobs were connected to an integrating meter, the instruc-



tor could watch the pointer on the dial and keep his class continuously at the proper level of activity. Individual students might still lag behind or be way ahead; but if each knob were connected to its own recording potentiometer, the instructor could readily pick out those students who are consistently slower than their classmates or those who are exceptionally fast. Diagnosing and correcting the faults of the classroom could thereby be hastened. No doubt such instruments will become standard equipment in the electronically controlled lecture room of the future. Most instructors who are honestly interested in doing a good job would welcome another instrument to help them assess their own work. It might be classified as a recording hygrometer to give a continuous check on the classroom atmosphere to tell the instructor whether a lecture is too dry or all wet. And, finally, an Oersted Medal should go to the man who invents a satisfactory bypass for steaming up students whose intellectual thermostats are permanently set for 70!

By Head and By Hand

The most valuable tools of the physics teacher are the intangible ones, but they are none the less important. They are tools which become more and more useful as the teacher acquires skill in using them, and skill usually comes from experience. The effective teacher must not only have sound knowledge of his subject, but he must be able to convey that knowledge to his students and to inspire them to go forward on their own. The concepts of physics are often complex, or at least they are likely to strike the student as being complex, and the teacher must be prepared to present them clearly by a variety of approaches so that if one approach fails another may succeed. I once knew a high school teacher who had exhausted his resources in an effort to teach Ohm's

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law. Judging from the glassy stare on the faces of his students, he had failed. In some exasperation he asked, "Why can't you get this stuff? I learned it once; why can't you?" To this one member of the class replied, "But you must have had a very good teacher!" Flexibility of attack and alertness to the student's individual stumbling blocks are among the necessary tools of the teacher. Imagination is a priceless adjunct to flexibility. Another valuable tool is the ability to enliven mathematical formulations. Patience and a lively sense of humor are like lubricants in the machinery of education and have much to do with a smoothly running classroom. Last but not least is enthusiasm for physics. The teacher who is not sold on his subject is not likely to sell it to others.

But turning now to the more tangible tools and instruments, we find the teacher of physics ready to use anything that the market offers, and when the market doesn't offer what he needs, he may have the resourcefulness to create his own teaching devices. Throughout the past two centuries there has been a close interplay between the teacher and the manufacturer of scientific instruments. Joseph Henry, when he was still a professor at Albany Academy, could not buy suitable wire for his work on magnets because there had never been a need for such a commodity; he made his own insulated wire by wrapping bare wire with silk tape. What he found out about magnets was basically important to a great new industry. When Heinrich Hertz undertook to verify Maxwell's equations at the Technische Hochschule in Karlsruhe, he had to devise his own apparatus. What he found out was fundamental to the whole radio industry. When J. J. Thomson sought by experiment for the nature of the electron about fifty years ago, he somewhat incidentally designed the cathode ray oscilloscope. Where would radar and television be without that by-product of Professor Thomson's laboratory? Oersted, who is reported to have been "all thumbs" when it came to performing experiments, nevertheless brought forth the first evidence of the magnetic field produced by an electric current, and the account is clear that this discovery took place before a classroom full of students. It is scarcely possible to overestimate the importance of his discovery which stimulated Faraday to look for a converse effect and so to discover electromagnetic induction. Without these two discoveries, there would be no electric industry.

In the Laboratory

In the laboratory, the teacher can employ an endless list of instruments. Every instrument for measuring mass, length, and time, and all of the physical quantities derived therefrom is fairly within his field. He is faced with the responsibility for instructing students in the fundamentals of physical apparatus, and the more examples of equipment he can place at the student's disposal, the better prepared will the student be to understand the instrumentation of modern technology. But whereas the manufacturer may improve his sales by building instruments in fancy black cases, the physics instructor should take it upon himself to remove the case of an instrument to disclose its fundamentals of operation. There once was a National Research Fellow who expressed interest in knowing what was inside a transformer case! The sad part of his plight is not that he was still in ignorance and had such curiosity, but that his curiosity had not been satisfied long before, preferably in high school.

In the elementary laboratory, the teacher is dependent in large measure upon standard apparatus produced primarily for instructional purposes by a large number of manufacturers. There are many physics professors who would gladly express their thanks to the manufacturers for the variety and quality of such apparatus now available. In turn, the teachers themselves have frequently contributed to the design and improvement of such apparatus so that it does its job more effectively. For the advanced laboratory, again, there is available a good selection of precision scientific equipment commercially produced—somewhat expensive, to be sure. Even the 20 million volt betatron has now become a standard product! Favored institutions can offer their students a great variety of such equipment, and few are so poor as to be devoid of at least a few pieces in which they can take pride. The importance of these refined pieces in the instruction of students can scarcely be overestimated. From working with them and understanding their operation, the student gains not only sound knowledge of principles but an appreciation of fine workmanship and precision of design. In the graduate research laboratory, the student reaches the state where apparatus is often produced in lots of one-of-a-kind, where he himself becomes the designer and often the producer of new equipment; and although he may use a large amount

of standard equipment as adjunct to his own self-designed apparatus, he has the thrill of creating something that has never before existed. It should be possible to prepare an impressive list of practical devices and instruments that have sprung from the work of individual students engaged in creating new equipment at this advanced level. Not least in such a list would stand the Van de Graaff generator, Lawrence's cyclotron, and Kerst's betatron.

In the Lecture Room

Finally, let us consider the use of instruments and apparatus in the lecture room. In an elementary or intermediate laboratory course, a student may perform during one year perhaps twenty to forty experiments. If these experiments are wisely chosen, the student secures first-hand experience with a large number of types of apparatus, and there is no good substitute for this firsthand experience. But laboratory time is limited; the student may observe ten times as many important phenomena if they are discussed and illustrated in the lecture room. There is no better way to impress a new principle upon the student, no better way to clear up complicated concepts than to bring in a sample. It is here that the demonstration experiment has its value, and it is here that the physics teacher has full scope for the exercise of his imagination and inventiveness in the design and use of apparatus. In the course of a lecture he may be able to show half a dozen good experiments, often contrived with the simplest of equipment. The function of the teacher is to assemble, to organize, to rearrange, and to modify standard apparatus to meet his needs. Commonplace phenomena shown in uncommon ways, rare phenomena shown by ingenious methods,—these are the experiments which enliven physics and make it unforgettable. They are by no means a substitute for solid driving on principles, but they serve to accent principles and make them more palatable and attractive. A student who has not observed a physical phenomenon under discussion has but a hazy background on which to build his thinking.

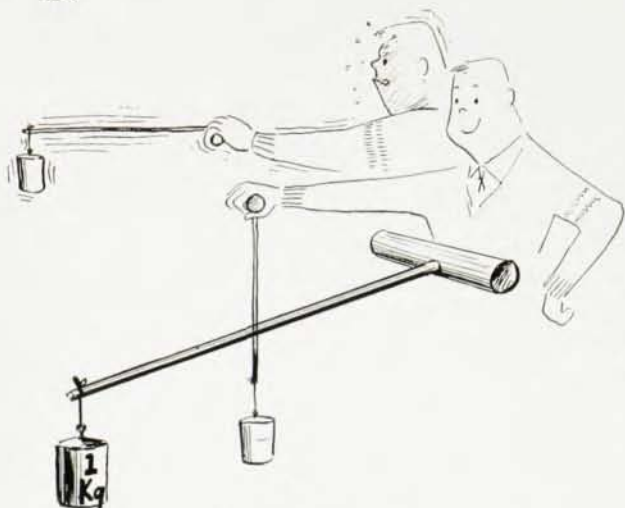
My own philosophy of the uses of the demonstration experiment includes the employment of the simplest kinds of equipment shown with as great dramatic effect and emphasis on principles as can be mustered; it includes the use of deliberately conceived paradoxes to tease the wise and initiated; it

includes the use of an occasional hoax just to keep the students awake and wary. Good analogues are fair game. Six examples out of six hundred that might be described will suffice to illustrate my meaning.

First, for teaching physics through the muscles. I illustrate the principles of torque by asking the student to hold a one-kilogram weight at the end of a steel rod one meter long. The rod is set at right angles to a short piece of broom handle which the student grasps. A strong grip is required to produce sufficient tangential friction on the handle to exert one kilogram-meter of torque, whereas the weight and rod may be readily suspended on one finger when the lever arm is zero.

Second, the strong dependence of water vapor pressure upon temperature is strikingly illustrated by making water run uphill into a spherical flask from which air has been driven out by steam by boiling a tablespoonful of water in the flask. The flask is then stoppered with a long protruding tube and the system is inverted with the free end of the tube lowered into a vessel of water. As the flask cools, water rises into the tube and finally spurts into the flask. Then with an impressive rush, the water gushes into the flask. This is the modern coffee maker in reverse, and in many respects it resembles Newcomen's early steam engine. The best students will be challenged to explain where the energy required to raise the water comes from. From heat? Yes, but how?

Third, as an example of a paradoxical situation on which students are not likely to guess right, I use a system of two spring balances, a one-kilogram weight, and a light wooden frame. The upper balance is adjusted to read zero when the lower balance and frame are suspended from it. Then when a one kilogram weight is hung from the lower balance by a string attached to the base of the wooden frame and passing over a pulley fastened to the lower balance, the upper balance reads one kilogram, but the lower balance reads two kilograms! As both of these forces act upon the connecting hook, the student may be hard pressed to find the missing kilogram of force. I find that, by vote, the class usually expects the lower balance to read one-half kilogram and only the bold vote for two kilograms. Such paradoxical results are best introduced after the student is already complacent in his knowledge.



Teaching physics through the muscles

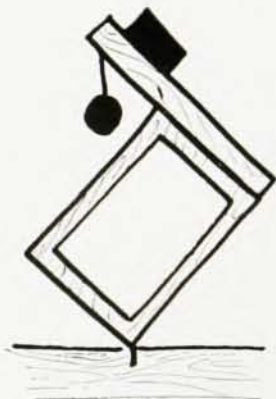


Using the unexpected



Teaching by paradox

Teaching by hoax



Fourth, as an example of a simple hoax, I use a crude wooden frame which is propped up on the lecture table by some blocks under its corners. One of its edges rests on the table. After discussing center of gravity and the two important principles of static equilibrium, I proceed to illustrate those principles by removing the stabilizing blocks and causing the frame to balance in an evidently unstable position. The students begin to get suspicious when, after changing the load on the frame and going through two or three careful efforts to rebalance the structure, I release it and it stands. Their doubts of the instructor's honesty are fully confirmed when he carelessly touches the system and disturbs its equilibrium and it doesn't topple over but begins to oscillate! In this case, equilibrium is assured by passing a long finishing nail through the frame and into a hole drilled in the lecture table at the point of contact. The moral is that the laws of physics are illustrated, not violated, by hoaxes. Furthermore, in unexpected situations, the student instinctively looks beyond outward appearance to underlying causes.

An example of an analogue: when a few dozen mousetraps are set and spread out on the table and each trap is topped by two ordinary cork-stopped "neutrons," what more could one desire to illustrate the physical principles of an atomic bomb? It "explodes" and demonstrates the neutron-perpetuated chain reaction simply and effectively.

Some years ago I learned a neat trick from a former student. It illustrates dramatically the phenomenon of real image formation. The instructor waves a long white wand vigorously up and down at an appropriate spot in the room. The wand sweeps rapidly and repeatedly over the position in space where the real image of a lantern slide or cut card bearing a few words would be cast upon a screen. Persistence of vision does the rest. The projection lantern is hidden from view and unwanted light is directed through an open doorway or against a dead black backdrop far behind the image. Suddenly there appear in bold letters, right in midair, such words as

