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Experimenters in the Schoolroom

Research scientists and imaginative teachers join to construct a new program in science for primary schools.

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Since the year of the Boston Tea Party, everybody has known, from the work of Scheele and Priestley, that the breath of life is some 20 percent of the air we inhale; free oxygen. This simple and incontroverted fact constitutes, with the formula H_2O, a large part of the total quantitative scientific inventory of most nonscientists. Its truth has been popularly demonstrated to students by generations of satisfied science teachers. They have used a simple scheme (not due to Priestley!). A jar is inverted over a shallow trough of water, the water seals the air in the jar, and a candle burning within the jar is seen to gutter out in some seconds. Up rises the water in the jar, standing a couple of centimeters higher in the spent air of the jar than it does in the trough open to the atmosphere. An estimate yields the result that a quarter of the original volume of gas, more or less, is missing. No one doubts that a little more careful work would yield the desired and freely quoted 20 percent. The oxygen burns out, plainly, and the residual nitrogen, now at lower pressure, admits water to the jar.

It was a small surprise last summer when, as participants in a study-project in elementary-school science education at Newton South High School, near Boston, we learned that this time-honored "experiment" has no bearing on its famous conclusion. It simply doesn't work that way. A candle affects the pressure of the spent air in which it has burned mainly by producing a transient rise in temperature; a true account of the demonstration would emphasize the leakage of hot air out of the jar mouth—when the spent air cooled, its volume, and hence its pressure were in fact less. The "20 percent" is simply an artifact of the usual scale of the crude experiment. You have only to recall what happens when wax and wick burn to see that no important net change in the number of molecules can have occurred, especially under conditions of water-vapor saturation. Almost any variant of the experiment will make the facts clear: sealing the mouth of the jar with plasticine against the bottom, or using, instead of the jar, a tube sealed on top with a balloon.

The "experiment" is worth describing because it bears more on science education than on chemistry. Its properties are plain: it is performed by the teacher, not by any student; the answer is known, and forced on the data; there is no sense of inquiry, no analysis of how the measurement is to work. What is seen as most important is not the experiment, for it proceeds without controls or analysis, but the familiar result. Words, not experience, rule in the end. This is not science. Should we accept it as science teaching? We heard it defended: "But it does get the point across, doesn't it?"

An alert teacher of chemistry, Paul Merrick, exposed the old fraud of the burnt candle. He was one of the 70-odd people—machinists and mathematicians, chemists and classroom teachers—who formed the enthusiastic Elementary Science Study Group this past summer at Newton South High School. We sought, under National Science Foundation support, to combine the skills of research scientists and their supporting teams with skills of teachers who have successfully taught children in the first eight or nine years of school. We were all there to take an intensive look at ways in which real science might be brought to all children. We had real science, we think, and we certainly had real live—and lively—children to try it on. We came away with a sense of having made a genuine entry into the problem, a feeling of elation over the prospects of success and of what success would mean for our schools, and a clear recognition of the magnitude of the task ahead. It is my purpose in this account, let me say in all candor, to let the community of scientists hear what we believe we have learned and in that way to engage a great many more research people in undertaking a share of the work.

The direct ancestry of the summer study is easy to trace. The study grew out of two or three years' work, beginning with the decision of Francis Friedman and Charles Walcott to try a new way of teaching science in the fifth grade. Friedman, late M.I.T. physicist whose taste and devotion have a worthy monument in the increasingly successful Physical Science Study Committee high school physics course, supported the Harvard biologist Walcott and his teacher colleagues at Educational Services, Inc., in the design and trial of a "cell unit" with children. Here the 10-year-old student, with his own cheap but adequate microscope, is led to find for himself, with that microscope, that life is built of living cells; he can watch and modify the growth of yeast cells and perform simple and lively experiments. The unit has been used with encouraging results in schools in the Boston area, typically by teachers who brought no scientific training to their classrooms but did

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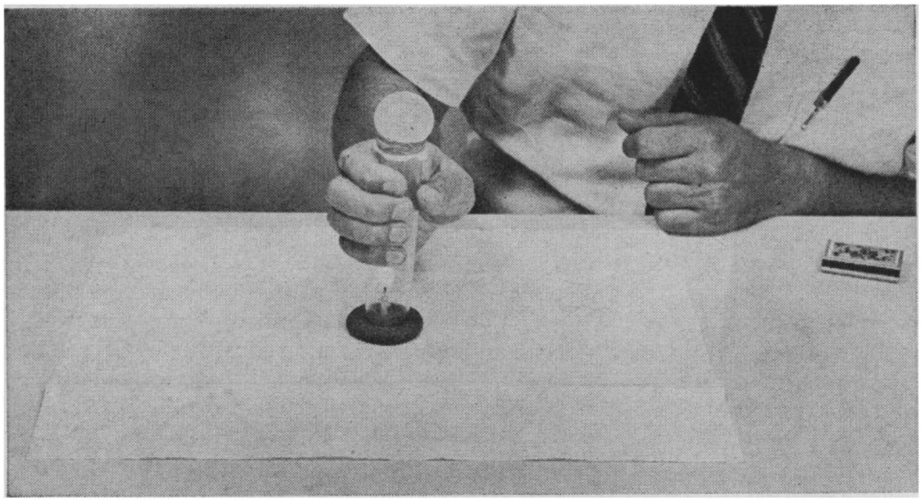


The expansion of air, demonstrated here, is overlooked in the usual candle experiment.

bring a willingness to learn from what they saw.

These years of experience in testing the cell unit, and a few other, related units, led to the belief that the time had come for a larger-scale effort of this kind, spanning many fields of science. The summer study was the beginning of that effort.

Of course, this work in the Boston area was not the only forerunner of the effort. In Berkeley, research people such as the physicist Karplus and the herpetologist Stebbins had for years been working out a number of such activities for children, in collaboration with classroom teachers. Leaders in science education, such as Paul Brandwein of Harcourt Brace, the writer Herbert Zim, Fletcher Watson of Harvard, and Gilbert Finlay of Urbana, have spent careers in the same endeavor. The new currents of school mathematics, associated with David Page of Urbana, Robert Davis of Webster College, and Robert Christian of the University of British Columbia are freshening rapidly the stagnant pool of drill which has barred so many people from full mathematical literacy. Inspired teachers such as Dave Webster at Educational Services, Inc., Phylis Singer of Far Brook, and Lore Rasmussen of Miquon School have for years sought new ways of bringing a creative quality into the classroom. All these people were present and at work.

The paper output of this one summer's hard work is bulky; drawings, protocols, lessons, essays, circuitry, questions, lists and all, it fills a dictionary-size volume called the "Twelve-pound Book" (accuracy ± 10 percent!). The book is not for publication; it will be a starting point for the years of work ahead. Nor is it for summary; sampling can present only a little of the texture and the flavor of this rich feast that is in preparation. The cooks themselves are still only tasting from the cook pots.

It seems necessary, before the samplings, to try to catch some generalities of the point of view. This cannot be easy, for, as should now be plain, the project pins no simple motto to its banner and offers no aphorism for its aim. Science is diverse; so are children. Bringing all science to all children is not a task to be fitted to a list of six purposes and five means. Indeed, most of us believe that not even a list of the great unifying concepts is to be taken as a canon of what the children ought to learn. Learning how to learn, learning to want to learn, learning how it feels to learn are perhaps more appropriate rubrics for a small part of a child's school career than any big but vague ideas. Children know many names, but they see too few animals (*1*). The word and symbol are indispensable, but they are not sufficient. Many children need other channels to knowledge; do we not often say it is the *feel* of things which marks the successful investigator? One teacher wrote: "It is another style of looking at the nearby world with more curiosity, greater thoughtfulness. It is a kind of warp, and children put it down with joy." She wrote of nursery-school model making, but the words fit what we want: "left-handed" thought—intuition, inquiry, playfulness, learning from error. Do not fear; we shall never lose sight of the right hand—discipline, content, analysis, precision. They belong. They do grow out of real experiences. The hands on the apparatus, the close observation of the insect, the pencil making notes and drawing a little graph. But they ought to grow, and not merely leap full-blown from the textbook, without embryo or blemish. We think that the fabric of science can be woven by anyone, to the degree of mastery of which each is capable, in such guided ways.

In that weaving, more than the fabric of science can be fashioned. The child can learn of the nature of human knowledge itself, its partial and its changing quality, its rewards and its difficulties. It is not only the clever who will catch on; something of this learning can and should be brought to every child while he is young enough to try to take part and not merely to watch. For the multiple-channel way of science, appealing to the hands and to all the senses, offers a road to occasional success even to the least bookish, if only by chance.

For such reasons, then, we do not compactly list either the great heuristic methods, such as approximation or estimation, the great issues, such as continuity or discreteness, or the great concepts, such as conservation or evolution. We hope that some of these can become real for some children out of real experience; the short school years and the youth of the children surely preclude an attempt to impart the full wisdom of these big ideas. It is much better to lay down the warp well than to figure the cloth with great designs; we proceed from the accessible to the general, at a rate which the child can himself set. And it is not the summary work but the act, the stuff, the feel of the thing that is the warp of science.

Sample Presentations

In what follows, then, I describe a few of the schemes we saw devised last summer. There are and there will be many more. Each item used is safe, and cheap, and it can be provided not for the teacher alone but for many children, working in unequipped schoolrooms. Each scheme is presented to the children not in isolation but as part of a branching sequence, a tree of growing sophistication and detail—presented in word and in picture, in metal or plastic, or by means of a bug crawling about in a small box, as the subject matter decrees. The experiments are designed for different sorts of children, or for differing aspects of one child; the stage of maturity where each is appropriate will in the end be found by trial. Generally, topics can be introduced earlier than you would expect; generally, a good topic will retain its interest longer than you would expect, as the child matures. (Indeed, in the study group, it was always almost too easy to catch up the research people, the artists, and the gifted teachers in a new presentation of even the most familiar phenomenon.)

Let us look at some sample presentations.

1) Down a long vertical tube of transparent polyvinyl, filled with water or syrup, a marble slowly falls. At each loud tick of a metronome the experimenting child marks the position of the marble on a strip of masking tape with a marking wick. The tape is removed and cut at the marks. The pieces placed side by side graph the motion; the relation between derivative and integral is built in. Variants of damping liquid, slope, even shape of tube are introduced to build up a real start on dynamics.

The "metronome" is a yardstick pendulum, with two bricks for a bob, swinging between two chair backs on a piece of dowel. It ticks away for a matter of minutes by striking a thin bit of index card against a needle glued through the bottom of a paper cup mounted upside down below the swinging bricks. Demonstration of the independence of rate and amplitude is a wonderful result of using two such pendulums together.

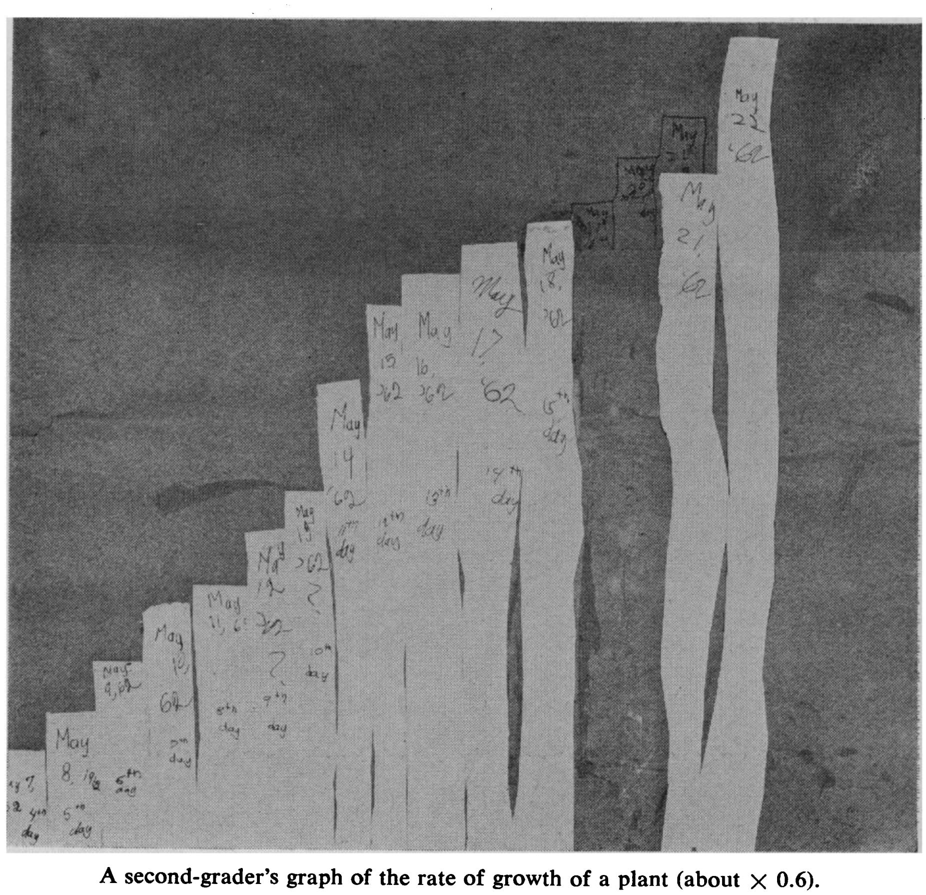
2) Organisms move, and move in diverse ways, but all—a turtle, a caterpillar, a goldfish, a fly, a June bug, a toy car, a child—are shown to move forward only at the price of pushing backward the medium of their motion. The turtle throws up little wakes as he walks on sand; the fly, temporarily and harmlessly fixed to a straw, blows a jet of air behind and down; the child causes a board to roll back as he walks across it. This graphic bit of physics (or is it biology?) is presented in a context even larger than that of the motion of animals.

3) A lens, made of a polyvinyl bag, filled with water, held between a Lucite plate and a flat piece of masonite with a round hole in it, focuses at many distances, depending on how tightly its covers are squeezed. The nature of a lens, as a controlled shape, becomes clear; the analogy to the eye is pretty close, and the "tuning" can be related to the curvature that the bag is seen and felt to have. This optical device is part of a long sequence that begins with shadow play and ends with the building of telescope and microscope from wonderfully clear Lucite marbles. A theory is presented as well, unifying geometrical optics on the basis of the postulate of least time; the presentation can be managed at various levels—from a special racing game to the graphical search for a stationary point.

4) The green alga *Chlorella* can easily be grown by children and serves as a tool for a study of light and life. Oxygen can be taken up quantitatively by many systems in the familiar jar (but not by the burning candle). Rusting steel wool, activated with vinegar, does, in fact, reduce the volume of air. A burning candle can indicate oxygen take-up, not by change in volume but by the length of time it burns. Gases have differing densities, which falling balloons filled with carbon dioxide, helium, and freon strikingly exhibit.

5) The totally balanced aquarium—not as common as the tanks displayed in its name — is only one charming microcommunity. A simpler one is a miniature lake bottom, made with an inch of lake mud and two inches of lake water placed in a polystyrene freezer box on the window sill. The sequence, from the busy *Tubifex* worms to the gnat larvae, the little crustaceans like Daphnia, and the surface bacteria and algae and associated small fauna, can be seen in a month or so; the end point in sand and water will probably be revealed by the end of the school year. A good many other ecosystems can be made in miniature and studied at many levels, from simple presentations in the earliest school years to the sophisticated level of the microscope and the pure culture.

6) Cells made of whole lemons (better ones made with Kool-ade) introduce the indispensable dry cell, which makes possible cheap circuit work in complete safety. Children set to causing two bulbs to glow with one cell can move swiftly to the level of the slide-wire potentiometer, and for the familiar "cook-book" building of circuitry we can substitute experiments that lead to genuine understanding. Some day soon transistors may be as cheap as flashlight bulbs, and really powerful circuits may be built by students for detecting radio, light, sound, and bio-



A second-grader's graph of the rate of growth of a plant (about $\times$ 0.6).

(Left) The hole in the shadow was bigger a few minutes before; why? (Right) Archimedes revisited. The two blocks are balancing three on the other side of the fulcrum.

electric potentials, or for computing. All of this seems possible for students in the upper primary school.

There is not enough space here to show the real texture of this sort of work, to discuss its elaboration and the results of trying it with children. One finds, to his surprise, that many young children understand the minimal property of a straight line only if it is horizontal or vertical. Anyone who has taught college freshmen will know something of the problems of apparatus, but perhaps he would not have guessed that children do not see how simple the function of the lamp socket is. The laboratory for this kind of study must boast of two components: the devices of instruction—simple, cheap, artful—and the children, more complex and diverse than any apparatus.

Not everything should be done with sealing-wax and string. A durable cheap microscope, a cheap supply of pressurized gases such as oxygen and freon (*à la* bug spray), a flashlight cell with handy terminals, a Polaroid-like film pack without fancy camera back, aerial photographs of the school in question, and many other products of modern industry will do marvels for a science curriculum. The need for such products sets a challenge before the scientists, engineers, and manufacturers of our wealthy society which we hope will not be left unmet.

We are talking about 30 million young people, and a million teachers. They should become the concern not merely of the specialists in education but of the departments of our universities whose domain is a subject—physics, zoology, electrical engineering. Most such departments do not now regard elementary education as within their sphere of interests. Yet every big physics department, for example, surely thinks of itself as having at least peripheral and potential expertise in the manufacture of transistors and cryogenic machinery, even if it has no intention of beginning actual production. One looks forward to the time when every such department contains some men and women who are aware of the needs and the problems of elementary education in its field, even though the actual running and planning of schools and the design of teacher-training courses will remain the primary responsibility of professional educators. Only when research institutions, especially the universities, recognize that all learning, at every level, is partly their business can a self-sustaining educational system come into being, a system not cursed by intrinsic obsolescence. How important that is in the world of today I need not argue.

Our psychologist colleagues this summer set some children this question: "Suppose one of your friends does not know what a scientist is. How would you describe a scientist to him? What would you tell him a scientist does when he is working?" One 8-year-old boy answered tersely and eloquently, "He thinks." Professional workers in science who feel, with us, that the ideal in that boy's answer imposes an obligation on science and gives all men hope for the future are invited to take part in the large-scale work of bringing real science to the schools. The Elementary Science Summer Study at Newton South High School in the summer of 1962 was an early step in that direction (*2*).

References and Notes

1. The canonical allusion is to A. N. Whitehead's great work, *Science and the Modern World* (Macmillan, New York, 1926), p. 285.
2. Any interested reader wanting to be placed on the mailing list for additional information should write to Elementary Science Study, 108 Water Street, Watertown 72, Mass.