RESEARCH WORK AS A PREPARATION FOR TEACHING HIGH SCHOOL SCIENCE

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On Wednesday, January 25, last, while the thermometer stood at zero, I received the following letter from the principal and teacher of physics in a high school in western Illinois.

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"Professor Barber,
Normal, Illinois.

Dear Sir:

Please be so kind as to write me which will freeze the quicker, hot or cold water. I am unable to find anything in reference to this in any of my physics textbooks. Thanking you, I am

Yours truly,

. . . .

"P. S. The problem I have in mind is this: If a pan containing boiling water is placed in a room 10 degrees below zero, and another pan containing water at a temperature of 40 degrees Fahr. is placed in the same room at the same time, which will freeze the quicker?"

Some of us are inclined to smile at this inquiry. In reply we are perhaps inclined to suggest that authority might well be dispensed with in seeking an answer to this question, and simple observation substituted. We are even inclined to advise personal experimentation and observation to the application of abstract reasoning based upon the abstract laws and principles of physics which we all studied in our high school days. We are inclined to advise the writer of the letter to fill two similar dishes, one with boiling hot water and the other with cold water, and place these two dishes north of the school house on a cold day and observe results.

Let us not be too severe in our judgment of the attitude of this teacher. In thus seeking what he considered a reasonably authoritative statement for the solution of his problem he was undoubtedly but following the path along which his high school training taught him to tread. Although the Weather Bureau records will show that the entire week from January 20 to 28 showed zero weather, still it evidently never occurred to him that it was possible for him experimentally to answer his own query. His attitude of mind was not exceptionally remarkable. A fair length of life and constant observation leads me to believe that many other high school graduates are as dependent upon authority in all scientific matters as he appears to be.

Naturally, I read this letter to an advanced class in physics, and the pedagogy of physics teaching was discussed. In that class no one appeared in doubt as to whether the hot water or the cold water would freeze the sooner. One of my physics students carried the question into an advanced class in pedagogy. That class was divided in judgment as to whether the hot water or the cold water would freeze first. Not being a science class, judgments were based necessarily upon knowledge of physical laws and upon reasoning formulated upon the remembered laws and principles of physics. I was told that the discussion was animated and the conclusion was about fifty-fifty in favor of the hot and the cold water.

One member of that pedagogy class, a man of middle age, a high-school graduate and a man of many years experience as a teacher, was much interested in the question. Like the writer of the letter, he wanted a statement from some authority. He could not find it in textbooks and so he appealed to me. I questioned him as to his own conclusion. He readily gave it together with his reasons for drawing that conclusion. He said the hot water would freeze first for two reasons: First, "Physics teaches that the molecules of hot water are in rather rapid motion, while the molecules of cold water are not. Therefore, the molecules of the boiling water would come rapidly and frequently in contact with the sides of the containing vessel or to the surface. Therefore, the molecules of the hot water would lose their heat much faster than the molecules of cold water." Second, "Hot water evaporates much faster than cold water and every gram of water which evaporates carries off 536 calories of heat.

On account of these two physical laws the hot water would cool much more rapidly than the cold water and consequently freeze sooner."

Another student went to her home near a thrifty, small city in central Illinois on Friday evening, January 27. On Saturday her father called an intelligent and experienced plumber to do some repair work on the farmhouse plumbing. The student put the question to the plumber, whether hot water or cold water exposed to zero temperature would freeze the quicker. The plumber quickly answered that the hot water would. He was certain because in his experience it was invariably the hot water pipes of the hot water heating systems which freeze and burst and not the cold water pipes of the water system. Accepting this plumber's observations as being correct, some of us may be inclined to seek knowledge relative to the location of the hot-water pipes and cold-water pipes, especially in reference to the outside walls of the house.

It is my experience that in a physics class where the practice is encouraged, hundreds of practical questions pertaining to the environment of the class and the community in which they live will be asked. Few, if any, of these questions are to be found in our ordinary textbooks or suggested in our manuals. In my judgment, in the course of the development of each unit of instruction students should be led to see and to study the relations of the principles involved as they are found in commonplace, everyday environment. From a class which has grasped this conception of the function of science study, practical questions will be forthcoming by the hundreds, and it is the most important function of the recitation or the laboratory period in a science course to answer such questions.

Illustrative of the type of questions I have in mind, permit me to state a few of them:

1. Where electric service is available, electric lighting has very generally displaced gas lighting. Generally, we also use the electric flatiron in preference to the gas or coal-heated flatiron. Why have not, likewise, electric stoves and electric heaters displaced gas stoves and coal

furnaces and coal or oil water- and steam-heaters for house heating?

2. How can an electric company supplying current to consumers afford to maintain the pressure upon the primaries of their transformers throughout the year, day and night, when frequently, especially during the summer months, little current is consumed? This condition is true especially in villages and smaller cities.

3. Why do shunt-wound motors, running without load, or with light load, usually speed up tremenduously when large resistance is placed in series with the field coils? Why do such motors usually develop their greatest power and efficiency, when moderately loaded, when a small amount of resistance is still left in the field circuit?

4. In freezing ice cream why does the ice continue to melt even when the temperature of the contents of the freezer approaches zero Fahrenheit?

5. If an injured man is being carried up a steep hill or up a flight of stairs upon a stretcher by two other men, supposing that the center of gravity of the injured man is at the center of the stretcher, midway between the supporting hands of the bearers, is the weight of the burden equally distributed between the two carriers, one of whom is, perhaps, at an elevation of three or four feet above the other?

6. The vacuum cleaner demonstrator delights to show the hesitating purchaser that even after a rug has been thoroughly beaten on the grass or line the vacuum cleaner will still remove much dust and dirt from the rug. It is equally true that the rug receiving ordinary use and being first cleaned by a vacuum cleaner and then hung upon a line and beaten will still yield an ample amount of dust and dirt. Why is this true?

7. Frequently the unqualified statement is found in our physics textbooks that no machine can be so constructed as to yield 100% or more of efficiency when operated doing work. Is this statement true? If some employees are sent from a music store to remove a piano from the fourth story of an apartment house and they use a block and tackel to lower the piano from the fourth story window, is the statement true? Is the statement

true when railroad men use the ordinary skids to unload a carload of barreled goods?

8. Is it true that a farmer using a very ordinary team of horses sometimes pulls a high-priced, guaranteed forty- or fifty-horsepower automobile through a bad strip of road or out of a ditch when the auto cannot make headway unaided?

A live, wide-awake high school class in physics, properly trained and actuated by a wholesome and entirely natural attitude toward their physical environment will, in the course of a year's work, ask and eagerly seek the answers to hundreds of questions similar to those mentioned. No textbook or set of textbooks can supply the answers to the legitimate questions which arise in the minds of properly trained science students.

How can a high school class in science be so trained that they naturally assume an attitude of openmindedness and inquiry concerning their environment; that they will presume that nearly every lesson will reveal the explanation of their natural surroundings? Such an attitude of mind rarely, if ever, results when the student is required to perform a hundred or so laboratory exercises as usually outlined in a manual and designed to demonstrate the laws and principles of physics. It has been my experience that but little of the apparatus usually described in our laboratory manuals or commonly found in our laboratories is patterned after or reminds the student of machines and utensils which he sees daily in use performing the necessary operations of modern life and industry. To a large extent the equipment of our laboratories is unlike the equipment of our homes and our industries. Is this necessary, to the extent that now prevails, and can we with such apparatus best teach the practical or commonly applied principles of science? If my laboratory is equipped with a Regnault's apparatus for the determination of the boiling temperature of water under pressures ranging from 2 pounds to 60 pounds, is it possible that I might substitute a common pressure cooker with a smaller range of pressure and temperature to the positive advantage of my class? Which is the more profitable experiment: To attempt to determine the calorific value of gas by means of an ordinary Jolly calorimeter with the usual resulting values falling far below the values required of gas companies by law, or to accept the legal calorific values and by using an ordinary gas stove determine the cost of operating that stove for one hour? Or, possibly, compare the cost and efficiency of the gas stove with an electric stove of similar size?

As I have passed through our laboratories during the past 10 or 15 years, I have been impressed with the thought that there is some tendency to substitute, to a certain extent, practical utilitarian appliances such as are seen daily in use in the ordinary walks of life for apparatus never met with outside the laboratory and used solely to illustrate or demonstrate the laws and principles of science.

I have recently been interested in looking through a new laboratory manual of physics. Of the first 25 exercises, 13 are instructions for setting up models of appliances in common use and involving physical principles. The author explains that each student is to be provided with a locker equipped with a supply of glass tubing, lamp chimneys, rubber tubing and rubber stoppers, pinchcocks, Florence flasks and such other raw materials as will enable him to construct models of useful appliances. Without counting them, I should say that about one-half of the exercises outlined are intended to be of this character. Probably the other half can safely be described as being of the old type, i. e. exercises planned to illustrate the truth of stated laws and principles and, in the main, using apparatus never used outside the laboratory.

While this laboratory manual interests me, and while I regard it as something of an innovation in laboratory practice, still I cannot approve of the method as a whole. Exercise 1 is "To construct a lift pump and explain its action". Materials required: "No. 50 Macbeth chimney; 12-oz. bottle; 12-inch, solid brass piston rod, diameter 6 mm. with cotter pins; 12-inch glass tube, outside diameter 7 mm.; No. 7 one-hole rubber stopper; No. 6 two-hole rubber stopper (one hole at the center); thin leather sheeting and tacks." Illustrations and description of the exercise are given. In closing, this statement is made: "The action of this pump is similar to that of the kitchen lift pump, Experiment 57. Examine the parts of this pump if the apparatus is in the laboratory." Turning to Experiment 57 we find a good, commonsense study of the "ordinary kitchen lift-pump" or rather *suction* pump. Why should any student spend time in the fitting together of glass tubing, rubber stoppers and other similar materials into a *model* of a kitchen pump when later he is asked to study the real article? Would there not be far more educational value in furnishing a group of four or five students with a real kitchen pump, a set of wrenches, and requiring them to dissect and examine the pump, sketch and describe it? In one corner of the laboratory there should be permanently mounted one such pump over a sink where its operation could be studied.

I am unable to get free from the idea that a practical course in physics for the high school should consist very largely of two parts, so far as laboratory exercises are concerned: First, we must continue to illustrate and demonstrate some of the important laws and principles of physics by means of special apparatus. Not every law or principle can be illustrated profitably, nor can all desirable quantitative relations be shown in any other way. Our laboratories must contain some equipment not found and not used in the ordinary walks of life. Second, Our laboratories should be equipped also with many of the available and commonly used pieces of machinery and utensils which involve physical laws and principles. We should banish models temporarily put together by the students and made out of glass tubing, rubber tubing, rubber stoppers, etc., playthings at best and time consumers all the while. Physics study is primarily thinking, not pottering with play stuffs.

No suggestions need be made upon the equipment of a physical laboratory to illustrate and demonstrate laws and principles or to determine such constants as should be determined. This custom is established. I think it is desirable to suggest that a laboratory should be equipped with many practical, rather small but life-sized, portable, and where possible, dissectable commercial appliances commonly used in the life of every community. What are a few of these commercial appliances? Cistern pumps, coal stoves, gas stoves, electric stoves, meters of every kind (gas, water and electric), water and electric motors, gasoline, gas and hot-air motors, pressure cookers, heat regulators, electrical transformers, rectifiers for changing ordinary 110 volt A. C. to low voltage D. C., ice and mechanical refrigerators, cameras, telescopes, opera glasses, transformers and X-ray outfits, some musical instruments, blood-pressure apparatus and such other appliances as involve physical principles and are suitable and available. The list should include eventually practically every appliance which is not too large or costly which is found in the community.

If some of our laboratory periods are to be spent in experimentally answering practical questions which arise in the class recitation and not to be found in text or manual, how much will our ordinary laboratory methods be modified? Suppose that the following question has been raised in the class during the discussion of why electricity has not so completely displaced gas in cooking and heating as it has in lighting: What is the relative cost and time required to raise a quart of water from tap temperature to the boiling point, first, by using a gas stove or hotplate and, second, by using an electric stove or hotplate? It is then the teacher's duty to plan an exercise which will answer the question. In my judgment it is neither feasible nor desirable that high school students make such investigations individually. Class or group work is entirely sufficient. This does not mean that the teacher should give this rather lengthy exercise as a clear-cut demonstration while the class looks on. If the group consists of no more than 10 to 15 students the teacher can stand aside and assign the duty of making the proper connections to certain students. Other students may be assigned the task of inspecting those connections. Still other students may later be assigned the duty of reading the meters and taking the temperature and time.

To conduct such a group experiment, perfect order and careful attention must be required of every student.

Frequent questioning should be the rule. Each piece of data must be clearly announced, or better still, recorded upon the blackboard. Each student should be held strictly for the proper recording of data as the experiment proceeds, and likewise for adequate sketches of apparatus and all connections. Such an exercise is justified only upon the ground that thinking and thoroughly understanding every detail of the exercise is an imperative requirement. I doubt if it is nearly so difficult to secure such results when conducting a group exercise as it is when overseeing 10 to 20 students at individual experiments.

Now as to the subject of this paper: Research Work as a Preparation for Teaching Science. If, as this paper assumes, about one-half, or thereabouts, of the laboratory exercises are based upon the study of situations arising out of the questions proposed by the class and not to be found, asked or answered in the text or manual, then the burden of determining just how those investigations are to be made falls upon the instructor. If such investigations are attempted, the instructor must plan many exercises. In my opinion the fitting of the laboratory work, as far as possible, into the environment of the class, making the laboratory investigations reveal the facts about the physical world about us, is a sure way of securing true values, lasting interest, and vital coöperation on the part of the students.

The science teacher who has received considerable training in research work is, in my judgment, much better fitted to conduct experimentation, suggested by class questions or class discussion, than is the teacher who has received no training in research work. Reliable judgment as to the soundness and reliability of methods to be used is a necessity. The teacher must also be prepared to defend the conclusions reached. Teachers of science who have been dependent, all their lives, largely upon the authority of the textbook for conclusions and upon the laboratory manual for the methods of experimentation are not well prepared to have the class ask questions not discussed in either text or manual. Such science teachers will continue doubtless to adhere strictly to the recitation of the laws and principles from the text and to the performing of only those exercises which are outlined in the manual.

Is it not possible that the writer of the letter quoted at the beginning of this paper lacked the self-confidence and initiative needed to stimulate him to investigate the matter as to whether hot water or cold water freezes first because his training has never included any work in research? This paper is no appeal for the injection of ordinary university research work into the high school curriculum. It merely makes the suggestion that if the spirit of the research worker and his attitude toward unsolved problems were frequently and skillfully injected into high school science classes and always applied toward clearing up situations found in the student's environment or in the community, there would be less stereotyped, uninteresting and unprofitable science teaching.

Is this picture of fitting at least a part of science study in the high school onto the environment of the students farfetched and visionary? Is there a science teacher in this audience who has not felt an immediately stimulating interest arise in the class when some student springs a vital question which relates the general topic under discussion to a concrete situation in which they are all concerned? Recently I had such an experience. We had studied the short-distance and the long-distance telegraph systems. One young man, without any suggestion on my part, went to a Western Union station and asked questions. When he reported to the class that the operator told him that the Western Union Telegraph Company had discarded the local circuit from many small stations on their lines and were largely using "main line" sounders, except at central stations, the interest of the class was much aroused. When the initiative for study comes largely from the science class itself, then we shall have more productive and more educative science teaching.