THE TEACHING OF SCIENCE

WOODHULL

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TORONTO

THE TEACHING OF SCIENCE

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New York
THE MACMILLAN COMPANY
1918

Set up and electrotyped. Published July, 1918.

Norwood Press
J. S. Cushing Co. — Berwick & Smith Co.
Norwood, Mass., U.S.A.

PREFACE

The addresses and papers collected in this volume were written for special occasions and delivered to various audiences during a period of more than twenty years. They all however bear upon one general theme, science teaching, and indicate a consistent trend of thought. In a measure, they constitute the history of a movement in education.

The title of the book requires a word of explanation. The addresses were, for the most part, delivered to teachers of physics and chemistry. Why then should not the title be The Teaching of Physical Science? Although the illustrations were of necessity chosen mostly from physical science, the addresses were a constant appeal to all science teachers to teach science rather than special sciences.

The addresses are arranged in chronological rather than logical order. Although the same theme is often repeated, the treatment is progressive as befits the history of the growth of certain ideas among teachers.

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I

THE EDUCATIONAL VALUE OF NATURAL SCIENCE [1]

In this paper I have undertaken only to state the case; the limits of space will not permit the presentation of arguments to defend it. It will be understood that I have not attempted to state the value of science as it is now taught in the schools, but rather as it might be taught. In mentioning values I have omitted several considerations, such, for example, as the giving of useful information, and dwelt rather upon what seems to me to be the chief value of the study of science, viz., the training in certain habits which may be characterized as scientific.

Through the study of science the habit of investigation is acquired. As soon as one begins to explore by the methods of natural science — and a pupil in the primary school is not too young to begin — he feels a strong impulse to investigate further. He finds that his field of knowledge has been extremely small, and that he has been entertaining fantastic ideas concerning that which lies outside of his little

[1] Paper read before the Harvard Teachers' Association, March 9, 1895.

circle. Very many of his ideas break down when he begins to investigate, and correct ideas must be established in their place. Children are generally eager to investigate, but a notion has long prevailed that if they become wise through their own explorations they are not so likely to be good. As a result of this it has happened that nature's feasts have been spread in vain, while we have with one accord made it our excuse that we think it safer to take our knowledge only at second hand. Some one has said, "In this world a large part of the business of the wise is to counteract the efforts of the good." It is the undoubted mission of science to enable the good to become the wise. Dr. Josiah Strong in the *New Era* says:

"Generation after generation has repeated the mistakes of its predecessors at a dreadful cost of suffering and loss, which was as needless as it would be for ships, in clear weather, to split on rocks known to sailors for centuries."

Professor Brinton says:

"The good which we endeavor to attain is scientific truth, the one test of which is that it will bear untrammeled and unlimited investigation. Scientific truth is absolutely open to the world; it is as free as air, as visible as light, there is no such thing about it as an inner secret, a mysterious gnosis, shared by the favored few, the select illuminati, concealed from the vulgar horde or masked to them under ambiguous terms. Wherever you find mystery, concealment, occultism, you may be sure that the spirit of science does not dwell, and what is more, that it would be an unwelcomed intruder. Such pretensions belong to pseudo-science, to science falsely so called, shutting itself out of the light, because it is afraid of the light."

The scientific mind investigates for the sole purpose of finding out the truth, and to the truth all preconceived ideas are subordinated. "It does not assume to know what ought to be, but finds out what is. On this line all the victories of modern science have been won."

Through the study of science the habit of observing relations is acquired. Persons may have the habit of observing to the minutest details things in which they are interested, without practicing scientific observation. Scientific observation is always organized observation. It relates one thing to another, lighting up one fact by another, searching for the relation of cause and effect. The unscientific mind is insensible to the lessons which its observations and experiences would teach. I have discovered a large number of persons, old and young, who have not learned the lesson that when they look into a mirror obliquely they see objects not from their own immediate vicinity, but those situated upon the opposite side of a perpendicular to the surface of the mirror. I have also discovered that it is possible for persons to have much learning and still be oblivious to such an obvious fact. Professor Wesley Mills says:

"I have known children who did not go to school till seven years of age, who prior to that period had learned to be good observers of what was going on around them, to lose all love for natural objects after being at school a couple of years; and I do also know to my sorrow that many of the young men that enter our colleges neither know how nor care to observe. They prefer not to look nature directly in the face, but try to see her through the medium of books, lectures, etc., and for this our school system is largely responsible."

A college graduate and a candidate for the degree of Ph.D. was asked what evidence he had that air makes a fire burn, and he made a pitiable spectacle trying to recall what the authorities said upon the subject. A boy of twelve when asked the same question said:

"We close the stove draughts to shut out the air when we wish to check the fire, and with a bellows we blow in more air when we wish to quicken the fire."

The *Popular Science Monthly* in an editorial says:

"If there is a fact that experience has overwhelmingly illustrated and established, it is that mere book-teaching of science is void and of none effect, nay that it is worse; that it has an actively injurious effect on the mind, which it deadens with meaningless jargon and befogs with ill-comprehended notions. How hollow, and often how fantastically absurd, are the ideas children acquire of things of which they are told but which they have never seen or handled. Let us turn children out of the public schools ignorant, if need be, of many things that are taught to them now, but let this idea at least be rooted in their minds, that this world is made up of real things; and this further idea, that words are worse than useless unless they can be applied in the most definite manner to well-understood objects of sense or of thought. What a blessing it would be if we could inspire the rising generation with a real horror of vague and meaningless language. It would mean nothing less than an intellectual revolution in the world."

Scientific observation means seeing with one's eyes and having, as a result, a train of thoughts start in one's own brain. Professor Tyndall said that

"Faraday never could work from the experiments of others, however clearly described. He knew well that from every experiment issues a radiation, luminous in different degrees to different minds."

The following is presented as an example of scientific observation. We built a fire in the furnace which smoked much. After it had burned a few minutes we opened the door and found it covered with drops of a dark brown liquid as thick as molasses and having a characteristic odor and taste. A piece of burning paper or wood was dropped upon a white plate. Drops of the liquid appeared upon the plate afterward which resembled closely those found upon the furnace door. A paper tube was burned at one end and the smoke passed through the full length of the tube. The walls of the tube were found afterward to be saturated with a liquid like that already mentioned. A similar liquid was found to drip from the joints of a long stovepipe in a building where wood was burned. A similar liquid appeared to saturate the rind of some ham which had been smoked. A scientific imagination is required to assist in correlating these observations, and a scientific conservatism must be used in drawing conclusions from them.

The study of science is valuable for the purpose of developing a constructive imagination. The scientific imagination is similar to that which enables a sculptor to see a statue in a block of marble, or which enables a painter to imagine to himself the picture he is to make upon the canvas, or that which enables the architect to form an idea of the building he is to construct. The scientific mind uses imagination, not only for discovery, but for appreciating facts. Teachers who suppose that a school laboratory is useful only for teaching the inductive method sometimes say that life is too short for pupils to spend much time discovering truths which have been already discovered. The fact is that very little discovery can be expected to take place in a school laboratory, but nevertheless the laboratory furnishes the only means by which the pupil can reach an understanding of the truths of his science. Through the microscope one sees only minute portions of an object at one time. The constructive imagination needed to form a conception of the whole is slowly developed by working with the microscope. By laboratory experiments we illustrate in a small way the great phenomena of nature — phenomena which are too large to be presented as a whole to our observation. A constructive imagination is needed to make the transition from the laboratory experiment to the natural phenomena. For the purpose of developing a constructive imagination illustrative experiments have a high value, and should be mingled with all quantitative work. Scientific observation and a scientific imagination were developed to a high degree in Laplace to enable him to conceive the nebular hypothesis; and scientific observation, together with scientific imagination, is requisite to all who would appreciate how the nebular hypothesis explains the way in which worlds are made. Scientific observation and a scientific imagination enabled Darwin to do his work, and without scientific observation and scientific imagination we shall never be able to appreciate evolution.

A person who has acquired the habit of making use of scientific investigation, scientific observation, and scientific imagination will surely become well informed. Most of us are ignorant when we might be wise if we would give attention to the phenomena which are daily presented on every hand.

Science teaches conservatism in making and accepting conclusions. It begets a desire to examine the evidence for everything. It propagates a wholesome skepticism in a world which has a passion for being hoaxed. If the scientific mind were cultivated more widely, newspapers would not find falsifying so profitable, advertisements would not be so palpably untrue, and history would not need to deal with exaggerations in order to be readable. It is probable that all the available history that would be useful in the education of such a mind might be gathered into a very brief course. Science is largely a matter of common honesty. The first thing a person has to do when he wants to begin to be an honest man is to take an inventory of his stock of knowledge, or what he has considered knowledge, and throw much of it overboard, following the advice of that eminent sage who said: "It is better not to know so much than to know so many things that are not so." It cannot be doubted that the dishonesty of those people who disregard evidence does more harm than the dishonesty which we call lying and cheating. Certainly the first kind of dishonesty is far more prevalent than the second. What one gains by being dishonest with himself in respect to the stock of knowledge which he possesses, it would be difficult to say; yet there are no possessions to which one is apt to cling so tenaciously as to that mass of knowledge which he has adopted either without evidence or contrary to evidence. The scientific mind enthrones reason above authority. The world has suffered too much from authority. Ignorant and unreasonable authority has forced into submission an ignorant and unscientific world, and thus resisted the progress of truth. Even a child has an inalienable right to an explanation whenever any course he is required to pursue seems unreasonable to him. It is tyranny to require unquestioning obedience if an explanation is possible.

Painstaking habits are developed by the exercises of a well-conducted scientific laboratory. Teachers of science should require carefulness in performing experiments, carefulness in taking observations, and carefulness in drawing inferences. Careless, slipshod experimenting will always go hand-in-hand with careless observing and with hasty inferring. Most of the knowledge which really is worth while has to be dug out by dogged persistence. Perhaps our education cannot be too extensive, but it certainly is too little intensive. We are sure of nothing. We do not take time to connect and correlate. We do not digest and organize our knowledge. We are smatterers. We have a newspaper education. We deal in snap judgments. We hold opinions upon profound questions without any study whatever. Real science study cannot be looked upon as a diversion or a device for getting the attention of a weary class. If it is worthy the name of science, it must be quite as disciplinary as the study of classics or mathematics. It may be pleasurable, but the pleasure should be that which comes from a sense of increasing power. The student of science will not be satisfied with vagueness. He will require that his knowledge shall be very definite, and he will, as a result of training in science, acquire the power of giving expression to his knowledge in very definite language. Such masters in science as Huxley, Spencer, and Tyndall are masters also in the art of saying what they mean. It is chiefly in this respect that science furnishes a training in the use of language.

"Common sense" is not a natural heritage; it must be acquired. To this end the study of science may be made a most potent agency.

The study of science should develop the capacity for earning a living, and at the same time give one reasonable ideas about what constitutes good living. It should act as a moral ballast. Its devotees are not subject to petty vices. It cannot be said of them that "they are more afraid of doing things conventionally wrong than of doing things morally wrong."

Science furnishes a basis for true religion. Professor Huxley says:

"True science and true religion are twin sisters, and the separation of either from the other is sure to prove the death of both. Science prospers exactly in proportion as it is religious; and religion flourishes in exact proportion to the scientific depth and firmness of its basis. The great deeds of philosophers have been less the fruits of their intellect than of the direction of that intellect by an eminently religious tone of mind. Truth has yielded herself rather to their patience, their love, their singleheartedness, and their self-denial, than to their logical acumen."

Herbert Spencer says:

"So far from science being irreligious, as many think, it is the neglect of science that is irreligious — it is the refusal to study the surrounding creation that is irreligious. Take a humble simile. Suppose a writer were daily saluted with praise couched in superlative language. Suppose the wisdom, the grandeur, the beauty of his works were the constant topics of the eulogies addressed to him. Suppose those who unceasingly uttered these eulogies on his works were contented with looking at the outside of them; and had never opened them, much less tried to understand them. What value should we put upon their praises? What should we think of their sincerity? Yet, comparing small things to great, such is the conduct of mankind in general, in reference to the universe and its Cause. Devotion to science is a tacit worship, a tacit recognition of worth in the thing studied; and, by implication, in their Cause. It is not mere lip homage, but a homage expressed in actions; not a mere professed respect, but a respect proved by the sacrifice of time, thought, and labor. Doubtless to the superstitions that pass under the name of religion, science is antagonistic, but not to the essential religion which these superstitions merely hide. Doubtless, too, in much of the science that is current there is a pervading spirit of irreligion; but not in that true science which has passed beyond the superficial into the profound."

The study of science is humanitarian. Professor Brinton says:

"The aims of science are distinctly beneficent. Its spirit is that of charity and human kindness. Its mission is noble, inspiring, consolatory; lifting the mind above the gross contacts of life, preserving aims which are at once practical, humanitarian, and spiritually elevating."

Coleridge said that

"Sir Humphry Davy would have established himself in the first rank of England's living poets, if the genius of our country had not decreed that he should rather be the first in the first rank of its philosophers and scientific benefactors."

Goethe found nothing inconsistent in the spirit of science and the spirit of poetry. Some people give their idea of a scientist in the expression "a cold-blooded scientist." If they think that the study of science makes one incapable of love, they should read the lives of Agassiz and Faraday; and if they think that the scientist is incapable of enthusiasm, they should visit him in his laboratory or follow him through the fields.

Mr. Spencer says:

"The current opinion that science and poetry are opposed is a delusion. On the contrary, science opens up realms of poetry where to the unscientific all is a blank. Is it not indeed an absurd, and almost a sacrilegious, belief that the more a man studies nature the less he reveres it? Think you that a drop of water, which to the vulgar eye is but a drop of water, loses anything in the eye of the physicist who knows that its elements are held together by a force which, if suddenly liberated, would produce a flash of lightning? Think you that what is carelessly looked upon by the uninitiated as a mere snow-flake does not suggest higher associations to one who has seen through a microscope the wondrously varied and elegant forms of snow-crystals? Think you that the rounded rock marked with parallel scratches calls up as much poetry in an ignorant mind as in the mind of a geologist, who knows that over this rock a glacier slid a million years ago? The truth is that those who have not entered upon scientific pursuits know not a tithe of the poetry by which they are surrounded. Whoever has not in youth collected plants and insects knows not half the halo of interest which lanes and hedgerows can assume. Whoever has not sought for fossils has little idea of the poetical associations that surround the places where imbedded treasures were found. Whoever at the sea-side has not had a microscope and aquarium has yet to learn what the highest pleasures of the sea-side are. Sad, indeed, is it to see how men occupy themselves with trivialities, and are indifferent to the grandest phenomena — care not to understand the architecture of the heavens, but are deeply interested in some contemptible controversy about the intrigues of Mary Queen of Scots! — are learnedly critical over a Greek ode, and pass by without a glance that grand epic written by the finger of God upon the strata of the earth."

II

THE ENRICHMENT OF THE HIGH-SCHOOL COURSE IN PHYSICS[1]

A LEADER in education has said:

"The education and training afforded by our schools is too greatly influenced by the requirements of college entrance. Thus the majority are unprovided with the most efficient and most useful training for the lives they are to lead. The schools teach facts without practical and useful ends in view and without instruction as to how these facts are to be applied."

He says further with reference to the particular school under his charge, which sends eighty per cent of its pupils to college:

"There is no alternative. Our efforts must be directed to making as good a preparatory school as the colleges will permit; the ideal secondary school must await a more enlightened age of higher education."

Accepting this as the best statement of the situation that can be made, it is probably wise to work harmoniously with the present order of things while using every effort toward a better order.

Such an association as this can do much toward bringing on that more enlightened age when the relation between the college and secondary school

[1] Paper read before the Eastern Association of Physics Teachers, November 5, 1904.

shall be similar to that which now exists between secondary and elementary schools. This will mean that the secondary school will give the pupil what he needs and the college will accept a pupil who has been educated according to his own needs rather than the supposed needs of the college. The needs of high-school pupils are much better understood by high-school teachers than by college professors, and they should determine what should fit them for college. Elementary school teachers are acknowledged experts upon the educational requirements of their own pupils. They would brook no interference from high-school teachers were it offered. How does it happen that high-school teachers have no professional status? To an outsider it would appear that high-school physics teachers are badly priest-ridden, since they have a syllabus made out for them prescribing their work in the minutest detail, and they are themselves the only persons who know how great a misfit this requirement is when applied to the high-school pupil. No other department is so throttled.

Let it be conceded that the high-school teacher's task for the present is both to fit for college and at the same time to make his physics teaching as good as he can in spite of college requirements.

The best plan for accomplishing this result seems to be that which has already been adopted in a few schools, namely, to give first a course in physics planned wholly with reference to the needs of the pupils, and follow this by a brief course intended to present the specific things which will be likely to appear on the college entrance examination papers. The first course is taken by every pupil who can get it on his program. The second is taken only by those who are intending to offer physics for college entrance.

I cannot agree with those who would restrict physics to the select few who are mathematically inclined and have perhaps a technical course in view. Physics appears to me to be a subject which all pupils need. The community is now demanding it for their children. Teachers of other subjects adapt their instruction to the needs of the majority of their pupils. Physics teachers must do likewise.

The college entrance course in physics is too meager in general information and in the applications of physics to daily experience. If the high-school teacher of English were given a syllabus which directed the teaching of grammar alone without literature, his case would be quite parallel to that of the physics teacher.

The course needs enrichment by the addition of large measures of information. Some teachers with excessive allegiance to the inductive method not only refuse to give information, but also to use simple and direct means of illustration. Why should the department which has the most interesting and most valuable information — information which bears directly upon the common life and happiness of every one — be so chary of giving it to the pupils? Other departments give information freely, and they take a strong hold upon the pupils; but some teachers of physics appear to conduct the course as though they would say to a pupil, "You may have only such knowledge as you can find out for yourself *first hand.*" Getting knowledge first hand is not an elementary process. Postgraduate students when sifted down to the few candidates for the doctor's degree handle it with indifferent success. No individual, however expert, has by the arduous labors of a lifetime been able to get first hand any considerable amount of knowledge. If we teach high-school pupils that they can acquire knowledge first hand without appeal to authority, we are deceiving them and we are in danger of making prigs of them. What goes on in a high-school laboratory is neither *induction* nor *verification*. It is simply an attempt to get a realizing sense of things by coming in contact with them. Without the laboratory the pupils would get only inklings; with the laboratory they get some appreciation of what you are trying to teach them. Without the laboratory they become dazed and soon tire of the subject; with the laboratory properly conducted they get that taste of physics which makes them want further information with an eagerness which is irresistible. A good deal of information in the field of physics is due them, and the course should be greatly enriched in this direction. High-school pupils are not able to receive information in the brief, formal statements of the text-books. They need prolixity. The statements of principles need to be very much amplified. Tyndall's book of six hundred pages on Heat is more comprehensible to them than the forty or fifty pages of the high-school text-books on the same subject.

The reading of articles from books of reference and the current magazines is quite as necessary in physics as in English or history.

It has been the fashion to decry the lecture as a means of teaching physics. This is probably due to the prevailing idea that one must not give information, but must leave everything for the pupil to find out for himself. The skillful teacher, however, conducts his course so that no restraint needs to be put upon either of these processes. The more information he gives the more he stimulates the self-activity of the pupil, and with a broader understanding of his subject the pupil works more intelligently at his appointed tasks. Davy, Faraday, Tyndall, and hosts of others have made good use of lectures.

Lectures illustrated by many experiments skillfully performed and skillfully explained; illustrated by lantern slides, charts, and blackboard sketches; illustrated by constant appeal to daily experiences; illustrated by graphic word pictures and the use of analogies, — such lectures in the hands of a teacher of science furnish not only information, but several other essential features of instruction not covered by the forty quantitative experiments.

College professors in physics habitually complain that students do not generalize. They may have been trained to experiment accurately, but they do not relate facts. The biographers of Sir Humphry Davy characterize his investigations as *brilliant.* He reached conclusions in incredibly short time. They speak of his wonderful power of generalization and call it "genius," "insight," "instinct." They speak of his constant use of analogies, of his fertile imagination. These traits have characterized all successful scientists to a greater degree than some of us like to admit. It cannot be the business of certain departments to encourage these things and of others to kill them. The processes of education must be better correlated than that.

Even if all high-school pupils were being trained for original research, it may be claimed for the lecture that it has equal value with laboratory work. Our chief difficulties at the present time, however, arise from the very erroneous idea that they are being so trained. In pursuance of this idea a portion of the college course in physics is crowded into the high school, and together they are intended to lead directly toward graduate courses in research. Since, however, few will follow that course to the end, few are disposed to begin it in the high school. There is no good reason on any ground why methods of research should be linked to high-school instruction. It would be a sad fate if, after fighting hard to get some science into the high school; and having secured the introduction of physics very generally throughout the country; and having forced the majority of pupils out of physics, contrary to their needs and desires, so that you might fit the minority for college; and having introduced into this college preparatory course, at the suggestion of the college professors, a kind of work so ill adapted to the high-school pupil that it does not even fit him for college, you should at last be discredited as educators and some other subject be put in the place forfeited by physics. Yet this, we hear on every hand, is upon us unless some radical change occurs soon.

The kind of physics which enabled us to win the fight for introduction into the high-school course twenty years ago was that which was well represented by the first edition of Gage's *Elements*. For fifteen years that sort of physics made exceedingly good progress in the high schools. It undoubtedly had much to do with bringing on public interest in scientific matters. But in spite of the fact that public interest in physics is still on the increase, we have, inside the schools, turned the tide against physics and are slowly driving the pupils from the subject. I cannot believe that the public, whose interest in the schools is also on the increase, will long permit this state of affairs to exist.

I believe that high-school physics should be the study of phenomena, and physical principles should be taught solely for the purpose of explaining the phenomena. Learning principles should not be the end of any study. Formulas, definitions, and laws are misplaced and misused. They do not belong at the beginning, but at the end of the subject. They are the crystallized forms of statement useful to engineers and others who have digested the principles and need them in that shape for ready reference. They are also useful for those who are going up for examinations, for which purpose they are best crammed the night before. It would be a waste of energy to carry them throughout the course. The text-book should be more than a dictionary of physical principles and a glossary of physical terms.

It should be a book of information written in a readable style. It will serve its purpose better if it leaves all descriptions of experiments and problems to the laboratory manual. The criticism, therefore, that a text-book is not sufficiently quantitative or does not pursue the induction method should be irrelevant. These things belong to the laboratory manual.

The forty quantitative experiments can be very much abridged and lose nothing either in educational value or in effective preparation for college. Quantitative problems upon data given might very well take the place of many of them. These could be worked out at home just as the problems in algebra are. If physics is to hold its own among the other high-school studies, more home work must be devised for it and it must absorb more of the daily attention of the pupil. When physics is made easy and interesting, there is often a large compensation in voluntary outside effort. Unless we are sure that we are sufficiently wise doctors in education to safely prescribe a dietary distasteful to the pupils, it would seem to be better to give them bread than a stone, because their appetites demand it. They receive more, they work over it more diligently, and they digest it better. We might let them have more of electricity and not compel them to take so much of mechanics. They might spend less time on electrical measurements and none at all on measurements from a battery cell. They might omit the calibration of a thermometer and "double weighing" with the balance.

A quantitative experiment or problem should be the goal toward which several qualitative experiments, or perhaps personal experiences, point. To illustrate: The kitchen stove cools off more quickly than the hot-water tank. A teaspoon taken out of a cup of tea cools quickly, but a teaspoonful of tea does not cool quickly. The sand on the seashore both heats more quickly and cools more quickly than the water in the sea. A few teaspoons taken out of hot water and put into cold water will convey very much less heat than an equal weight of the hot water added to the cold water. Bodies of water modify climate by giving out large stores of heat in cold weather and absorbing large stores of heat in hot weather. Thus it happens that islands in the sea and lakes on the mainland have equable climates. High-school pupils are familiar with these facts, but they have not related them. When they have been led to do this it adds much to their appreciation of the whole matter to determine the specific heat of some substance by a quantitative experiment; and, if the quantitative experiment is allowed, say, one-quarter of the time spent in the study of specific heat, it may be the cream of the whole matter, but if it is the only thing taught under specific heat, it is pretty nearly valueless.

High-school pupils come to the study of physics with a large number of experiences which bear upon the subject, but their experiences have been largely of the unconscious type. If therefore "science is merely organized common sense," the teacher must call up these experiences and organize them. In this matter the teacher who deals with country pupils is thought to have the advantage, since country pupils are reputed to have had more experiences in the line of physics; but let us consider what the city has to offer.

A well-equipped city school building contains many applications of physical principles:

The furnace and boiler.

Direct and indirect heating systems.

Ventilation.

Automatic control of temperature.

Steam used for power.

Hydraulic and electric elevators.

The plumbing of the building.

Filters.

The lighting of the building.

Electric motors.

Electric bells, telephones, and clocks.

The piano, illustrating the various principles of sound.

A great variety of machines which are superior to the laboratory apparatus for purposes of instruction.

Some pupils have observed these things and thought much about them, others have noticed them but thought little about them, and still others have neither noticed nor thought of them. Excursions about the building will enable the teacher to supply to all some of the necessary experiences upon which to found his instruction, which will take the form of correlating and interpreting these experiences in the light of physical principles.

The home, and the city outside of the school building, are full of the applications of physics. The citizen must square his life according to physical principles whether he wishes to or not. It is our privilege and duty to conduct this study so as to enable him in some measure to make his life more peaceful and more successful.

III

MODERN TREND OF PHYSICS AND CHEMISTRY TEACHING [1]

THE excellent paper on College Entrance Examinations [2] which was read at your meeting one month ago contains one suggestion which I heartily adopt as the central theme of this paper. It is *more descriptive and less mathematical physics* and (I may add) *chemistry.*

The history of physics teaching in secondary schools for the past 25 years naturally divides itself into two periods. During the first 13 years of this period physics was taught without help or hindrance from the colleges, and it progressed against fearful odds until 24 per cent of all secondary school pupils were studying the subject; during the last 12 years the colleges have dominated the physics teaching in the secondary schools through their syllabi, interpreted and enforced by their examinations, and it has declined until the number of pupils in physics has been reduced to 10 per cent. Twelve years ago 24 per cent of the students selected physics voluntarily; now a considerable portion of the 10 per cent study it only by compulsion.

[1] Paper read at meeting of New York Schoolmasters Association, December 9, 1905.

[2] By Mr. Wilson Farrand. See *Educational Review*, January, 1906.

The kind of physics which was taught during the first period is well represented in the earlier editions of Gage's and Avery's text-books. It was descriptive of matter of universal interest and abundantly illustrated by experiments exceedingly well adapted to make the subject real. I have been collecting testimony for the past 18 years from persons all over the country who studied physics then, and I find that the general feeling is that it was both interesting and profitable. Such testimony has been steadily changing into adverse criticism of the physics teaching of the last 12 years.

In recent years physics teaching in the colleges also has been growing more unsatisfactory to general students. It is becoming more and more deficient in both the humanitarian and the practical elements. It does little for general culture and less for common sense. It is good preparation for neither investigators nor engineers, and least of all for the ordinary citizen. In recent times college men have set out to *know only one thing*, and have omitted to conquer a sufficient field of related knowledge to understand any one thing well enough to teach it. We have witnessed the attempt to force the worst features of college instruction upon the secondary schools, and we have in many cases seen young men come directly from such a régime of college physics to teach in our secondary schools. They confine themselves to that disjointed skeleton of dry bones, the forty quantitative experiments. They use them as simply isolated, detached mathematical problems. They make no logical connections. They know little of an articulate whole. They know nothing of practical applications of physical principles, and they know nothing of the correlations of physics and chemistry with botany, zoölogy, physiology, geology, geography, and the like. Of course they cannot clothe their skeleton of forty experiments with symmetry and beauty, for they have never been taught any such thing in physics. They deal in academic discussions about per cents of error. They present nothing as organized common sense, which was Huxley's idea of science. It is not because these college entrance requirements are difficult, but because they are a misfit, that they are uninteresting; and the pupils have the good sense to dislike them. Until the makers of the physics syllabus exhibit a greater knowledge of the science of teaching, we may conclude that the desires of the great majority of high-school pupils furnish us the safest guide to what is pedagogically correct. As one of your members said here last month:

"These college entrance requirements have been shaped by specialists whose interest has been in the subject rather than in the student."

They do not understand high-school pupils. How can they understand what will fit them for college? The chief trouble with high-school pupils when they pass into college is not that they are deficient in mathematics or in the art of making accurate measurements, but that they do not generalize, and the work prescribed is not calculated to help them learn how to do so. The claim has been put forth by certain teachers that theirs is a "good stiff course in physics," that it is equivalent to Greek forsooth, and every other course has been characterized by opprobrious titles. Their favorite expression of contempt is "sugar-coating the pill" and the favorite expression of satisfaction with their own work is that they are giving "a self-respecting course in physics." Now I cannot discover why their course should be called "good" or "stiff" or even "physics." (One professor of mathematics says he is willing to accept it as algebra and geometry.) I presume no teacher ever has or ever will get what may properly be called "good work" from a student except by the force of a "compelling interest." Let us consider what there is in these experiments which a reasonable high-school pupil could object to.

A considerable number of them are clumsy, tedious ways of getting results which the pupils know they can get by more direct means. A great ado is made about getting the specific gravity of wood. All wood is heavier than water, but they set out to prove that a certain block is half as heavy as water. It floats on water for the same reason that an empty bottle floats. If we let the water enter and drive out the air, both sink. It makes a difference whether the wood comes from inland or seashore; from the north side of a hill or the south side; whether it is green or dry or kiln-dried; whether it is summer or winter. In winter our closet doors shrink so that we can poke our fingers through. In summer they swell so that we cannot shut them. The teachers try to coat the block of wood with paraffin so that air shall not get out nor water get in. No one has yet learned how to keep wood from shrinking and swelling. The pupils, who are often wiser than doctors of philosophy, know that their teachers are making a pretense of getting the specific gravity of this block of wood merely for the sake of an academic discussion. Now note how the instructors proceed. They simply want the weight and the volume of that block. The weight is procured directly, but the volume, which might be procured directly by measuring a regular-shaped block, is thought to be more accurately found by measuring the amount of water which it will displace. And instead of sticking a pin into it and thrusting it down into a vessel full of water and measuring the overflow, they tie a lead sinker to it so as to introduce more mathematics into the problem. They spend weeks finding the specific gravity of various things by various methods; finding the breaking strength of a wire; comparing wires in breaking tests; finding how much a wire will stretch; bending laths by varying loads; bending laths of varying dimensions; twisting laths — all to no purpose. Such procedure has no connection with anything else either in the course or out of it. Nearly the whole of the first half-year is spent on this work which is related to nothing. Meanwhile the students are eager to get into electricity, but when at last they reach that subject they are cruelly disappointed because everything that has a practical bearing is carefully eliminated and academic discussions are substituted about things never met outside the school laboratory. The experiments in electricity are such as no electrical engineer would have any patience with.

Teachers who watch every opportunity to nip in the bud any symptom of interest or enthusiasm select the coefficient of expansion of iron as a subject worthy of a whole week's study. The sole aim of the work is to have the pupils determine whether a rod of iron will expand by one twelve-millionth part of its length for one degree rise in temperature. They first consider at some length the sources of error, and discuss the efficiency of the apparatus. The whole rod must be brought to a uniform temperature. It must therefore be surrounded by a hot-water or steam jacket. The thermometer must be placed in such a position as to get the true temperature of the rod itself. There must be some sort of multiplying apparatus to measure such slight increments of length, and this will introduce some mathematics which will exercise a wholesome restraint upon enthusiasm. The experiment is performed and the results are discussed again with reference to sources of error. The class average is taken and compared with standard figures, etc., etc. Now if that is the end of the whole matter (as it very often is) it seems to me not worth while. It is not "stiff." It is stupid. The pupils are not complaining of hard work, they are objecting to stupid work. They are capable, and willing to do much harder work if it appeals to them as worth while.

Suppose now we treat the expansion of iron by first performing some of the many simple, ingenious, and beautiful experiments which illustrate it. Let some of these be lecture experiments and some individual laboratory experiments. Let the question arise what will happen to a steam pipe 1000 feet long when the engineer puts on steam and raises its temperature from, say, 60° to 212°. It will lengthen about one foot. The class will be interested in calculating that from data given in the text-book, and certain pupils will want to verify the data by a quantitative experiment on the coefficient of expansion. A few optional experiments are always needed to give to the brightest pupils in order to keep the class abreast. The whole class want to go on an excursion about the building to see what provision is made for this expansion of the steam pipes and hot-water pipes. They want to know what provision is made for the expansion of the iron work of the Brooklyn Bridge between winter and summer. And they would be glad to calculate how much that expansion might be; how much a wagon tire 5 feet in diameter is stretched by heating it 500° for purposes of setting it. Illustrations of this sort can be multiplied until a week is thought by the class to be all too short for the subject.

I do not believe that high-school pupils are lacking in either willingness to work or ability to work. They are patient sufferers with what they know to be poor teaching.

Secondary schools are not dependent upon the colleges. They depend directly upon the public, and the colleges are equally dependent upon the public. Certainly no subjects are nearer to the public mind than physics and chemistry, and public sentiment will in time settle these questions for both colleges and secondary schools. It will undoubtedly determine that the secondary schools shall teach such physics as all girls and boys in the schools may pursue with profit to themselves. (Some teachers are now congratulating themselves that they have crowded out of physics the great majority and have left only the mathematical elect, and some teachers of physics avow it to be their purpose to kill enthusiasm wherever they find it.) Public sentiment will further determine that the colleges shall receive any pupil who has been taught according to his own needs, and that the colleges shall learn how to continue his instruction according to his own needs. I presume that in both the secondary school and the undergraduate college, physics will in time be humanized. It will be taught with reference to its practical applications, not solely for commercial reasons, but also because of its universal human interests.

As indicating the modern trend of thought on this subject, I will present numerous quotations from various writers and speakers.

Professor Hall of Harvard is doing us the great service of reproducing in the *Educational Review* considerable portions of the report of Professor Karl Fischer of Munich on his studies of the prevailing condition of instruction in physics and chemistry in the secondary schools of various countries. The articles contain much of what appears to be a consensus of opinion from many countries. They abound in such phrases as these:

"Mathematical developments [in physics] are to be avoided . . . more stress is to be laid on the spirit of the method than on technical details . . . the calculations kept as simple as possible, should be based on actual relations. . . . Numerical problems, in and for themselves of little profit, should not be given in greater number than is necessary to insure the insight of the pupils into the relations exemplified in the problems. . . . The striving after too great precision is a mistake . . . demonstration instruction should be made as practical as possible . . . theories without interest, calculations which have nothing to do with realities, are to be dropped. . . . The object is not to make of the pupils accomplished physicists but to make them acquainted with the great laws of nature and to lead them to give account to themselves of the operations which they see going on about them. . . . Official programs prescribe too exactly the matter to be taught."

Professor H. E. Clifford, of the Massachusetts Institute of Technology, said a few months ago before the Eastern Association of Physics Teachers:

"In any course of physics the fundamental instruction should be by classroom work which should be made more vital by the laboratory. The classroom comes first in usefulness and efficiency in instilling the fundamental ideas, and the laboratory second. A well-illustrated course of lectures is more valuable than a well-equipped laboratory. The laboratory work should be qualitative, not quantitative. It should aim at accuracy in observation, not accuracy in measurement. The explanation of everyday phenomena is the true function of high-school physics."

Professor W. S. Franklin, of Lehigh University, one of the examiners in physics for the College Entrance Board, said recently at a meeting of the New Jersey State Teachers' Association:

"It is not important that high-school physics should be quantitative or mathematical, it should be *phenomenology*."

President Stanley Hall, as quoted by Professor Charles Baskerville to the New York Chemistry Teachers' Club:

"The finest expression on the face of a child seems to me to be that of open-eyed and often open-mouthed curiosity and wonder. The objects of nature charm and entrance the soul, which for the moment becomes almost one with her. . . . This divinest thing in childhood, which only bad school methods can kill, which prompts the primeval experiments of infants in learning to use their senses, limbs, and minds upon nature, is the root of the spirit of research, which explores, pries, inquires, so persistently, and often so destructively in older children, and comes to full maturity in the investigator behind the telescope or microscope, in the laboratory, seminary, library, or on exploring expeditions."

To which Professor Baskerville adds:

"Each one of us has done his little research in college or university, and knows that it was but an extension of his experience as a boy. . . . Having once breathed that fragrance of the new, having once been allowed to pluck a seed from the unknown storeroom of the Almighty, having once nursed it into a flower, however beautiful or unattractive, I fail to see how one, by the very fever of the thing, could look on that one creation and not be swept along by the desire to make a garden of such joys, for each birth is a happiness, not solely for selfish pleasure, but that the world might also look in and rejoice."

Professor Louis Sherman Davis, Indiana University, says:

"Interest in a science is proportioned to the immediate bearing which its subject-matter has upon the life of the student. Hence the matter and processes with which chemistry deals should touch the student's life as closely as possible."

In accordance with this view he arranged his text-book so as to teach chemical principles in their relationship to industrial purposes, such as preparation of iron and steel, explosives, artificial ice, illuminating gas, baking powder, petroleum, butter, soap, sugar, glass, paints, etc.

Professor C. R. Mann, University of Chicago, in *School Science and Mathematics*, October, November, and December, 1905:

"If an instructor has once clearly grasped the fact that the so-called principles and laws of science derive their final accuracy from our powers of abstraction, can he confine the student's attention so assiduously as is often done to a per cent and half a per cent of error? Far be it from us to decry the importance — nay, the vital necessity — of such considerations of accuracy in advanced research work. But do we not sometimes forget that the high-school pupil is not a research specialist, and that he is as a rule not enamored of great accuracy? Do we not then develop rather his manual dexterity than his reason and his imagination? . . . do we not often fail to make use of the vast fund of physical experiences which every one necessarily possesses simply because he has lived on this planet? Yet we often reject in whole or in part this fund of real experience and expect to develop a system that shall be comprehensive and exact on the basis of comparatively few rather clumsy stock experiments with half a hundred percentages of error thrown in for good measure.

"But the real vitality of physics is not in these external signs and symbols, but rather in the human part — the scientific imagination; and any student who leaves his physics class for the last time without ever having felt an inspiration to ponder over and try to form images of the operations of the world forces amongst which he lives, has been filled with husks and empty forms and dwarfed in soul and mental growth. . . . When we 'fix' [physical laws] into a system of dogma, develop them into a logically perfect series, and then dole them out to growing, living, thirsty souls . . . we are but exhibiting to them a veritable 'physical mummy' and should not be surprised if the children turn from it chilled with indifference rather than warmed with enthusiasm.

"He [the student] usually has a large amount of qualitative personal experience with the subject-matter of science, and can generally obtain a large store of personally observed facts in the routine of his daily life. . . . It is an interesting fact that children trained to observe carefully and to reason from these observations clearly and in freedom, remember both the facts and the conclusions better than if they are taught the conclusions as a matter of authority. Though it may seem paradoxical, it is yet true, that if we make it our aim to teach the facts and principles of science, we fail; but if we have as our sole purpose the development in the children of this scientific attitude, they not only acquire that most valuable possession, but also learn the principles better. Moreover, by the adoption of this aim, the sciences become truly correlated. . . . A vast advance over the methods at present in vogue in science teaching could be made if each teacher would try to present his subject more from the historical and concrete side and less in the purely logical and abstract one — if he would try to connect the history of his special subject with the grander general history of thought — and of human activity.

"We need to get closer to Nature and to absorb the warmth of the greater human life about us. We do not need new and more ingenious apparatus in our laboratories; nor yet novel and elegant methods of demonstrating this or that principle; but greater outlook and wider sympathies — in a word, less *impedimenta* and more human life."

Professor Mann has written a high-school textbook of physics "to meet," as he says, "the new demand that has been made on the subject by the general public. . . . The aim has been to show the student that a knowledge of physics enables him to answer many of the questions over which he has puzzled long in vain." He aims, as he says, to "appeal to students on the humanistic side." The numerical examples are free from mathematical intricacies, and are based largely on the practical problems of everyday life. "The latest discoveries and theories in science are presented, both because young people are known to be interested in them and because they serve as nothing else can to develop the scientific imagination. . . . The mastery of principles and methods in scientific study depends on the awakening of interest and self-activity more than any one thing."

Before the New England Association of Chemistry Teachers Professor F. L. Bardwell, of the Massachusetts Institute of Technology, said:

"Instruction [in chemistry] should be along qualitative lines. It may be wise to introduce some quantitative work, but he who loses sight of the qualitative side of quantitative experimentation loses sight of rare beauties in Natural Science and causes in his pupils the sort of distorted mental vision which cannot see beyond the cross hairs of a telescope or discern any phenomena which are not connected with the swing of the pointer of a balance . . . don't forget the one essential thing in laboratory work — *observation*, which must be qualitative before it is quantitative . . . let laboratory experimentation be employed to drill the pupils in careful manipulation, not necessarily highly refined and accurate measurements — and then above all in observation and inference. Pupils should be encouraged to discover principles — to generalize; and it is well to arrange certain experiments which are not complicated and which have not been preceded by special instruction so that the beginner may have opportunity to generalize without prejudice."

Professor F. W. Clarke, in *Science*, October 23, 1903, says:

"The man who could not see the forest because of the trees was a good type of that scholarship which never rises above petty details. It may compile encyclopedias, but it cannot generalize."

Some one has said:

"Avoid formulas. Most high-school pupils work with formulas in a very mechanical way and fail to get the rationale of the matter. It is only to mature minds that formulas represent the gist of the whole matter."

Professor H. H. Goddard, State Normal School, Oshkosh, Wis., *School Science and Mathematics*, October, 1905:

"A great company of the great men of science is open to our acquaintance among the leaders and investigators of the past. . . . Their names cannot fail to excite the wonder and admiration of all who have followed the achievements of science and can be moved by the attainments of the human mind. . . . These men live in the triumphs of their investigations into the mysteries of science and in the heritage they have left us from the secrets of truth. . . . Every student of science should learn something of the great difficulties which have been overcome in the progress of this line of study. . . . The story should be known of how Scheele subjected himself to deprivation and even poverty in order that he might give his time and talent to scientific discovery. . . . The story of Roger Bacon should be told, — of his splendid talent, of his untiring efforts to illuminate the darkness and ignorance of his time by the searchlight of truth, and of the persecutions which he endured as a result. . . . The lessons of self-sacrifice and of loyalty to truth which are shown by these and many others are of great educational value. The opportunity for such lessons can scarcely be excelled in any other line of study outside of the field of science. And such lessons are especially needed in these days of commercialism and self-aggrandizement, when it is so common to associate successful careers only with the accumulation of wealth.

"What we as teachers can do is to acquaint our students with the fundamental principles of the subject, let them see a few of the interesting applications of these, and then not neglect to inspire them with the splendid story of the growth and development of the science, how it has moved forward little by little, now retarded by error, but again pushing forward with tremendous bounds under the guidance of truth, until with the dawn of the present century its achievements are the wonder of the world."

Professor Sedgwick, on Physiology, in *Science*, September 18, 1903 (his words may very well be applied to physics and chemistry):

"Not only in childhood but throughout life we do not care greatly about the parts of a machine unless we know or can guess their use. The instruction in physiology should aim at the outlines of the more important functions. . . . The pupil should understand that the heart is a force pump, but it is not necessary that he should understand the exact structure or mechanism of the auriculo-ventricular valves. We must teach less about anatomy and histology and more about the germ theory of disease, about polluted water and polluted milk. We must simplify every statement and eliminate the unimportant. We must not seek to make of physiology a training in the precision of measurements or in scientific method. We must keep steadily in view the practical object . . . the rational conduct of physical life. We now teach history and economics and civics with some reference to the future life of the public school pupil as a citizen."

He speaks of "arousing a *compelling* interest in the subject." He also has something to say about "arid osteology."

For the relief of high-school pupils and teachers I propose:

(1) That the teaching of physics and chemistry in

secondary schools should be less mathematical and more descriptive.

(2) That, in order to secure greater freedom in the teaching of high-school physics, the official list should be increased by the addition of qualitative experiments, and that teachers should be free to choose from the whole list any thirty-five to present for college entrance.

IV

THE INTENSIVE METHOD IN CHEMISTRY[1]

In nearly every presidential campaign we are called upon to hold opinions on some difficult problems. We feel obliged to vote when we have only inklings of the truth. It may take two or three campaigns on a particular subject to enable us to acquire knowledge that we may clearly define. Questions which puzzled the most astute minds a few years ago are clearly understood by the average mind of to-day.

This is the way we have gained our knowledge of the principles of chemistry. First came inklings of ideas. They may have been ruminated upon, but they were forgotten as much as we ever forget anything. After a time we again met these ideas and were startled perhaps to find that we comprehended them much more clearly than before, as though the mind had been doing some unconscious work upon them meanwhile. This experience may recur many times with regard to the same idea until finally, after several years perhaps, we see the truth with clearness.

This seems to be a law under which the mind must work, — a law which we must reckon with in teach-

[1] Read before the New York Chemistry Teachers' Club, May 12, 1906.

ing. We speak contemptuously of our modern newspaper civilization with its smattering of ideas, but is there proof that men of any other age ever did or ever can acquire knowledge by any far different method?

Now it sometimes happens that men, who have spent several years passing through this sort of experience in the study of chemistry and who have arrived at pretty clear ideas themselves, undertake to teach these ideas full-fledged to beginners. Thoroughness and accuracy are their aim. To go slow and cut a clean swath is their method. They are champions of the *intensive* as against the *extensive* method. They demand of beginners definiteness, sureness, and completeness of knowledge, and they attempt to make a few quantitative experiments furnish what time and extended experience alone can supply.

Teach chemistry to beginners — old or young — for one year, by whatever method one may choose. When they are examined upon the subject the next year, their ideas appear to be exceedingly hazy. This is of necessity so. It is a law of the mind, and teachers should not be ignorant of it. College professors undertake to examine these products of the high-school chemistry class and are amazed at the results, and their judgments of the pupils and their teachers are very unjust. To mitigate as far as possible the severity of these unjust judgments, pupils are put through the senseless but very effective process of cramming the answers to questions used upon recent examination papers.

It happens that a large number of students take their first year of chemistry work in college and the assistants, whose duty it is to read the papers, can testify that college students at the end of their first year's work in chemistry have a phenomenal faculty for giving vague and strange answers to examination questions.

If one teaches a topic three times over, (1) as completely as he can in a lecture, (2) as thoroughly as he may in the laboratory, and (3) by the study and recitation of a text-book, even though he may succeed in making the pupil understand each step, he will find a few weeks later that the pupil has no realizing sense of the matter. He is like a person who answers questions correctly when half asleep.

Pupils in the kindergarten and elementary school like repetition. It is the only means by which impressions are made upon their brains. High-school and college students have not passed beyond the operation of the same law. The justification for carrying along simultaneously the three methods of instruction — lecture, laboratory work, and study of the text-book — lies in the necessity for reiteration. This also furnishes ample justification for giving college students a course in general chemistry even though they may have had an excellent course in chemistry in the high school.

A year's course of laboratory work consisting of thirty-five experiments, mostly quantitative, with little lecture work and little text-book work, furnishes too little repetition and too little perspective. When each experiment by itself is intended to establish one principle, it fails by its meagerness. Better have thirty-five groups of experiments, each group containing experiments which are closely allied, mostly qualitative, and all calculated to give different points of view of the same subject. Some experiments should be quantitative but generally each quantitative experiment should be preceded by several of a qualitative nature upon the same subject. Some quantitative experiments should be assigned to the lecture and some qualitative experiments should be made laboratory work. Induction and verification may play a minor part in the course, but all experiments, whether used for lecture or for laboratory purposes, should have the main purpose of making the subject *real*. I do not object to intensive work nor to quantitative experiments. We may admit that they are the cream of the whole matter and yet insist that, like the nutritive part of food, they must be mixed with a large bolus if digestion is to proceed. Certainly "the notion that an experiment is a vehicle for training in accuracy primarily is a very harmful superstition."

We teachers of chemistry need to take courses in applied science, we also need courses in biology, physiography, and other allied sciences in order that we may give a practical turn to our teaching of chemistry. The time must come when we shall give the higher degrees in education at the university for such broad work as that quite as much as for the more narrow specialization.

There are at least three reasons why we should teach principles always with reference to their applications:

1. Our pupils get no correct appreciation of the principles themselves until they see their applications. A subject becomes a science only when its principles are related to something.

2. The subject must be taught with reference to its practical application not only for commercial purposes but also for the sake of human interest and culture. That is a very preposterous claim that our friends who call themselves humanitarians make — that their subjects alone contribute to human interest and human culture. It would be easy for us to establish chemistry in the hearts of the people as *the humanity par excellence*, and it is our duty to do that.

3. We must make our subject practical for commercial reasons. It is our duty to do all in our power to help our pupils to earn a living and become useful members of society.

Chemistry is the best of all subjects to lend itself to the logical and scientific development of principles. The topics may be so arranged that each one shall present further illustration of foregoing principles while adding new ones. In this way the last half of the year may be almost wholly reiteration of principles with increasing power to predict their applications in new conditions. This is where our training in induction comes in.

As for the main results to be sought I should say that, if a pupil understands his text-book in chemistry as well as the average pupil understands his history, we ought to be satisfied. I do not agree with those who speak slightingly of text-book work in general or of the existing text-books. There are a dozen or two text-books for high-school use which are very good indeed, and it would be a distinct gain if we should abandon the practice of making syllabuses and admit to college students who have been certificated as having completed any one of these text-books with appropriate laboratory work to make it *real.*

V

SCIENCE FOR CULTURE [1]

If there is anything the matter with science teaching one may be very hopeful that the difficulty will be cured when he considers the number of associations and clubs of science teachers formed to discuss plans for improving present conditions.

My subject needs a little definition.

Probably every one who is teaching science is attempting to cultivate something. One aims at accuracy, skill, honesty of thought, discipline; another aims to cultivate imagination, power of generalizing, information, etc.

I have no disagreement with either party, except that they ought not to exist as parties. They should combine. The different departments of education should work toward one end. Certainly it cannot be the duty of one department to tear down what another constructs.

It is my purpose to speak of culture as we generally use the term when we speak of culture courses, liberal education, etc.

No one needs imagination more than the investi-

[1] Paper read at the annual meeting of the Central Association of Science and Mathematics Teachers, University of Chicago, November 30, 1906.

gator, and no one has a better opportunity to cultivate it than the teacher of physics. The scientist and the humanist have not conflicting duties — indeed there is no occasion to make a distinction between them. Humanism which is not scientific and science which is not humanistic are worthless.

Professor Cooke says:

> "Science culture differs in its methods from the old classical culture, but it has the same spirit and the same object." [1]

Professor Burr, speaking of the fundamental idea of the humanists, says:

> "It was their open purpose in which they gloried to treat of things as they actually existed, to get as near to the life of the community as the best knowledge would bring them; in other words, to touch human life intimately and at the greatest possible number of points." [2]

Let it be conceded that it is very desirable to cultivate accuracy, self-dependence, mental honesty, etc. There is no short cut — no royal road to these results. Such fruits do not come out of forty laboratory exercises. They are a slow growth of many years. Quantitative work simplified, made direct, and put in its proper sequence with qualitative work may profitably occupy, say, one quarter of the effort of a high-school pupil in physics. But science is something more than measurement. To be sure when men began to measure they took great strides forward, but it is equally true that research comes to a standstill when information and imagination

[1] J. P. Cooke, *Science Culture,* p. 20.

[2] W. H. Burr, *Science,* October 26, 1906.

are wanting. The chief difficulty with science teaching to-day, both in the high school and in the college, is that we do not give sufficient information.

Culture courses, or information courses, are often spoken of scornfully as a "smattering of all the 'ologies."

We have the mistaken idea that we can cut a clean swath in education; can teach a subject thoroughly; can treat a few principles and teach the whole truth about them first hand. But this is to attempt the impossible. Neither the immature nor the mature human mind works that way.

Dr. Simon Newcomb says:

> "The plausible system of learning one thing thoroughly before proceeding to another, and taking things up in their logical order only, should be abandoned. Let us train the pupil as rapidly as possible in the higher forms of thought and not be afraid of his having a little smattering of advanced subjects before they are reached in regular course. Let us remember that thoroughness of understanding is a slow growth, in which unconscious cerebration plays an important part, and leave it to be slowly acquired. A teacher aiming at thoroughness might have kept Cayley or Sylvester working half his life on problems of advanced arithmetic without reaching his standard of thoroughness."[1]

The teachers of De Morgan, the mathematician, found him dull in mathematics.

Let me recall the scene from that charming little book, "Philip's Experiments," where Philip and his father are surveying in the field when the Schoolmaster is introduced.

[1] Simon Newcomb, *Educational Review*, April, 1906.

"Philip's schoolmaster pointed out that after he had a systematic training in geometry and trigonometry, he would have little difficulty with the problems which arise in surveying. He also said that the plane table should have a telescope instead of rude sights, and he described various accurate instruments, and intimated that I was cultivating habits of inaccuracy in Philip. Training in science which was not highly accurate he believed was worse than no training at all. I listened, but I remembered that this teacher had kept Philip at work making highly accurate measurements with a delicate balance. The boy had not appreciated the construction of the balance, for he had never made weighings with a rough instrument, and his mind had been kept so fixed upon the third place of decimals, that he did not appreciate what specific gravity really means. I could see that the schoolmaster in his endeavor to refine had forgotten the difficulties of an immature mind. Philip was on one contour line and he on another, and it would take more than a megaphone to put them into communication." [1]

"In obtaining quantitative work, exactness must be demanded, but exactness is a quality that comes relatively late in youthful minds as in that of the race. We are attempting to force nature; we are anticipating maturity of mind when we crowd into a curriculum subjects in advance of the time when the mind of the average boy or girl is able satisfactorily to pursue these subjects. . . . Probably the fault is not with the subject physics, but with the method. Too much quantitative work is demanded of both boys and girls; too little attention is given to the great names who have developed the subject and made inventions household words." [2]

We are too much afraid of teaching some things which have to be modified or even unlearned later. "Unlearning" is quite as educational as learning and does no harm to a reasonable being, indeed it may be a cure for bigotry. It is more important

[1] John Trowbridge, *Philip's Experiments*, p. 79.

[2] William L. Felter, *Educational Review*, April, 1906.

to cultivate openmindedness than it is to be correct.

Professor Hopkins, in giving a simple, provisional definition of an acid, says:

"At that stage of instruction this simple working definition is sufficient. More would be an enormity. What though the definition be untrue? The instruction, it is to be remembered, demands simplicity and progression — not truth. . . . It shows the subject presented not as a carefully completed, rounded and exact definition . . . but as a part-truth at first which grows with his capacity for understanding."[1]

We are too sensitive about being up to date with our facts and theories. Since it has become impossible for any man to keep up with the literature of more than one subject, men have become timid about teaching more than one subject. But it is not difficult to show that the man who keeps himself moderately well informed upon the progress in several sciences is better prepared to teach than the one who knows only one subject. The weakest thing about research to-day is that our men are not *widely* informed.

One who has traveled much and become familiar with types of country may find his way through an unknown territory and readily suspect it when he is approaching a spot sought for. The ant studying his grains of sand does not get this view of a country. It is the "bird's-eye" view. Sailors by extended experience become accurate observers of weather phenomena. Miners and farmers and horse dealers and experts of all kinds acquire their accuracy of knowledge chiefly by the extensive method.

[1] Arthur John Hopkins, *School Science*, April, 1904.

Professor Trowbridge says:

"The natural progress of our study of any subject is from the qualitative, or the comparatively rough evidence of our senses, to the quantitative."[1]

He says we need the countryman's habit of "hefting" a thing before weighing it.

Teachers in languages are everywhere insisting upon the advantages of reading at sight and reading widely. Why should teachers of science be slow to learn the science of teaching?

We talk about trying to rid ourselves of preconceived notions, but preconceived notions are quite essential to progress, and the ability to preconceive notions is absolutely essential to research. It is no argument against a gift that it is capable of perversion. We want to be put in control of our faculties, not deprived of them by education.

We have reversed the natural order and tried to train high-school pupils in induction. Using the forms of induction in the high school may be a species of dishonesty. After all, the pupils learn not from the experiment but from the teacher or the text-book. We teach them to test carbon dioxide gas with limewater, but we have to inform them that nothing else will turn limewater milky, and so it is only a roundabout way of telling them the whole story. We have great satisfaction in calling this the heuristic method, and we make the children prigs by leading them to think that they are acquiring knowledge first hand.

[1] John Trowbridge, *New Physics*, Preface.

The self-activity that high-school pupils need is that which they may get in the laboratory by doing experiments merely for the purpose of coming in contact with things — making their knowledge real — acquiring "a certain balance of judgment which comes from actual contact with things."

"The mind must rest upon physical laws for a comparative long period in order to understand their true significance." [1]

Pupils learn by imitation chiefly. Professor Trowbridge recommends performing in lectures by experiments which the students afterwards perform themselves in the laboratory.

In many schools throughout this country one may find eminently successful teachers of physiography who proudly acknowledge that they learned *by imitation* of Professor William M. Davis both their subject and their method of teaching. I should characterize Professor Davis' method as an exceedingly skillful way of *giving the information* which his students could not acquire first hand in a thousand years, and his method is equally successful in preparing students for research or for teaching.

The teaching of science should accomplish the greatest possible good to the greatest possible number. The time was when education proceeded without much reference to the public. It was intended for the select few. A rapid change is in progress. Within recent years the public high schools have become the most important educational institutions in the country. They surpass

[1] John Trowbridge, *New Physics*, Preface.

the colleges in buildings, laboratory equipment, and teaching force — not only in quantity but in quality. In the rapid growth of colleges, the available funds have not increased in proportion to the increase in number of students. The result is that the classes have been assigned inferior instructors.

The growth of research, by diverting funds and diverting men, has caused college teaching to deteriorate.

The general testimony of students is that they work much harder in the high school than in the college. Who knows how it might affect the intellectual and moral character of college students to have courses of instruction which were capable of absorbing their chief interest? So that they would not feel ashamed to say they were more interested in their studies than in their diversions.

Theoretically the pursuit of research ought to enrich one's teaching, but in actual practice attention to the art of teaching wanes as attention to research increases. The first requisite of a teacher is to be actuated by a desire — a fervent desire — to instruct others. If one can work at research and not have that ardor dampened, it is well. But to hold a teacher's position and to scorn the work of teaching is simply dishonest, and even though one's researches may be more valuable to the world than his instruction, those who have paid tuition for instruction have a just claim against him. Probably most of the money received from tuition fees and from endowment by undergraduate colleges was given for purposes of instruction, but after diverting much of this to the support of research, and after giving the students very indifferent instruction, we tell them that their tuition fees do not cover the cost of their education.

These college students have a starvation course in measurements called physics. Their tutors, having just passed through the same course with excessive specialization, are suspicious of that expansive thing called culture. They affect to despise, not only the public, but all departments of learning other than their own. They surpass the theologians in narrowing down their lines of orthodoxy. Some teachers of science are like polarizers. The truth which gleams in all directions is narrowed down to one plane when it is transmitted by them. Their standards would unclass Davy, Faraday, Tyndall, Pasteur, Humboldt, Maxwell, Huxley, Agassiz, Cooke, Shaler, and the like, for these men all preached the doctrine that science is good for culture and should be given to all. Those who interpret science as cold blooded and exclusive have not only nine-tenths of mankind against them, but a majority of the men of science and particularly the leaders of all time.

Davy was a poet and his high literary abilities made him a great teacher and likewise aided profoundly his researches. All of the men mentioned above were Natural Philosophers with all the diversity of interests which that title indicates. All were humanists and many of them devoutly religious.

The influence of the college in all departments, classical as well as scientific, is toward driving culture, in the sense in which I am using it, out of the schools: first, by narrowing the education which it gives to those who go out to teach in the schools; and, second, by prescribing a syllabus for the schools narrowly interpreted by examiners and bigotedly enforced by readers of examination papers. The schools cannot even give a cultural course in music. The brevity of life makes it necessary to have everything count toward entrance into college, and the college accepts only musical mathematics. There is not a department which is not handicapped in this same way. It is impossible to teach anything as a culture when it is necessary to prepare for examination — particularly an examination set by another person. No one can justly estimate the progress and the proficiency of a class except one who has been with them throughout their study. If a supervisor's examination is thought to be necessary, let the teacher prepare the questions and submit both questions and answers to the supervisor. A "reader" in four minutes passing upon a year's work of a student wholly unknown to him is an absurdity.

I cannot look upon a syllabus as a blessing even though it may be prepared by a majority of the teachers. Why should uniformity be thought necessary or desirable? The "New Movement among Physics Teachers" is very helpful so long as it keeps in a state of solution, but we may regret its crystallization. One may hope that if we must have a syllabus, it may be extensive enough to include all that may be desired by any considerable number of teachers, and that each teacher shall be allowed great freedom of choice within the syllabus.

The high schools are coming nearer in touch with the public mind every day. They are powerfully influencing public sentiment and are in turn being profoundly influenced by public sentiment. We have lately had evidence that science was in the ascendancy in the minds of the people by their vast gifts for equipping schools and colleges for teaching science; but unless our teaching is adapted to the needs of the majority, we shall soon see the funds drifting in other directions, or what is more likely, we shall see ourselves drifted away from our moorings by the resistless tide.

In the ultimate analysis the same public supports the colleges and the schools. The college looks to the public for its funds, whether they be legacies or legislative grants or tuition receipts; it looks to the public for exemption from taxation; it looks to the public for the patronage of its sons and daughters. The public in turn demands of the colleges better service in the matter of giving instruction.

People have recently learned that they must square their lives according to physical principles, and they and their children have turned to educational institutions for information with an eagerness that is irresistible.

Their children have increased the attendance upon the colleges fivefold in recent years, and they themselves have entered university extension courses in countless thousands. In some cases, the extension courses furnish quite as good instruction as any given at the university. Faraday was started on his course as a scientist by Davy's public lectures, and Cooke[1] says that he got his first taste of real knowledge from the lectures at the Lowell Institute, although he was a pupil in the Boston Latin School at the time — and that taste awakened an appetite which was never satisfied. Cooke says he eagerly sought the popular science of the day, which was vastly inferior to what we have to-day. We may now rank a few of the daily newspapers among our better teachers of Science. Huxley said, "Science is not solely for the men of science but for the people."

General courses in college should be culture courses. They should be what their name indicates — general surveys. A majority of the students in such courses will not and ought not to pursue the subject longer than one year, when we come to balance up the claims of all the subjects in a liberal course. Why then do the instructors persist in giving them that which is absolutely meaningless, unless it be joined to a protracted study of one subject for several years, and why do they give them that which properly belongs not so much at the beginning as at the end of the course in that particular subject? Such general-survey courses are quite as important to those who will go on to specialize in the subject as to the students who will pursue it no farther. Large knowledge acquired by gen-

[1] J. P. Cooke, *Scientific Culture and Other Essays*, p. 72.

eral surveys in many fields is necessary before one can select and organize. During his career in high school and undergraduate college a student should be encouraged to take general cultural courses in each and all the sciences whether his aim is to specialize or not.

"The time has already come when to know any one of the sciences thoroughly it is necessary to know the rest; in fact, all the so-called natural sciences are different branches of one great science."[1]

It is not possible to get an elementary knowledge of any one science except by this process of browsing among many.

[2] "We have a duty to our children which we cannot avoid, if we would, and for which we shall be held responsible by our posterity. These children are entering life surrounded not only by all the wonders and glories of nature, but, also, by giant conditions, which, whether stationed on their path as a blessing or a curse, will inevitably strike if their behests are not obeyed. So far as science has been able to define these giant forms, it is our duty, as it is our privilege, to point them out to those we are bound to protect and guide; and in many cases it is in our power to change the curse into a blessing, and to transform the destructive demon into a guardian angel. After that command of language which the necessities of civilized life imperatively require, there is no acquisition which we can give our children that will exert so important an influence on their material welfare as a knowledge of the laws of nature, under which they must live and to which they must conform; and throughout whose universal dominion the only question is whether men shall grovel as ignorant slaves or shall rule as intelligent servants.

"It is perfectly possible for a child before fifteen years of age

[1] Elisha Gray, *Nature's Miracles*, p. 170.

[2] J. P. Cooke, *Scientific Culture and Other Essays*, p. 81.

to acquire a real and living knowledge of the fundamental facts of nature on which physical science is based. This is not a question of natural endowment or special aptitude.

"To arouse a love of study in any subject is to take the first step toward making your man a scholar (I want to emphasize scholar), while to fail to gain his interest in any study is to lose the whole end of education."

[1] "We greatly wrong a pupil if we leave him unfitted to enter into the great inheritance of scientific truth obtained by past and present research. In striving to work out this problem let us, first, inculcate a habit of scientific thinking, second, give as wide a knowledge as possible, and third, awaken an interest which shall be lasting."

Mr. Roy Fryer says:

[2] "That course is best which contributes most to general information and culture by acquainting the pupil with a wide range of chemical facts, while at the same time it trains his powers of observation and of reasoning from those observations."

We make a great mistake when we shape our courses so as to eliminate all except those who are mathematically inclined and ready for specialization.

[3] "No educated man can expect to realize his best possibilities of usefulness without a practical knowledge of the methods of experimental science. . . . It is not to be expected or desired that many of our students should become professional men of science . . . (yet) any system of education is radically defective which does not comprise a sufficient training in the methods of experimental science to make the mass of our educated men familiar with this tool of modern civilization.

"The elementary principles and the more conspicuous facts of chemistry are so intimately associated with the experiences

[1] J. H. Denbigh, *School Science and Mathematics*, October, 1906, p. 635.

[2] Roy Fryer, *School Science and Mathematics*, December, 1906.

[3] J. P. Cooke, *Scientific Culture.*

of everyday life, and find such important applications in the useful arts, that no man at the present day can be regarded as educated who is ignorant of them. . . . Physical Science has become a great power in the world. Indeed, after religion, it is the greatest power of our modern civilization. Consider how much it has accomplished during the last century toward increasing the comforts and enlarging the intellectual vision of mankind. . . . It is frequently said, in defense of the exclusive study of the records of ancient learning, that they are the product of thinking, loving, and hating men like ourselves, and it is claimed that the study of science can never rise to the same nobility because it deals only with lifeless matter. But this is a mere play on words, a repetition of the error of the old schoolmen. Physical Science is noble because it does deal with thought, and with the very noblest of all thought. . . . The ancient logic never relieved a moment of pain, or lifted an ounce of the burden of human misery. The modern logic has made a very large share of material comfort the common heritage of all civilized men."

Teachers in their zeal for maintaining their standards often lose their missionary spirit and act as though they would exclude the large majority of students from the department of knowledge over which they preside. Their love for a particular science has overshadowed their love for their fellow men. Such are not true representatives of the men of science.

"No teaching is of any real value that does not come directly from the intelligence and heart of the teacher and thus appeal to the intelligence and heart of the pupil. . . . There is no nobler service than the life of a true teacher; but the mere taskmaster has no right to the teacher's name, and can never attain the teacher's reward.

"Value scientific studies not simply because they cultivate the perception and reasoning faculties, but also because they fill the mind with lofty ideals, elevated conceptions, and noble thoughts. Indeed, I claim that there is no better school in which to train the æsthetic faculties of the mind, the tastes, and the imagination than the study of natural science."

The history of science tells of a "multitude who have worked in faith for the love of knowledge" and "made themselves and their fellows more noble men."

VI

HOW THE PUBLIC WILL SOLVE OUR PROBLEMS OF SCIENCE TEACHING [1]

In this prognostication I have thought it necessary to reënforce my views with the testimony of a score of witnesses. I beg leave therefore to act as the editor rather than the sole author of this paper. Its composite authorship will be found duly set forth in the various footnotes.

In this country we need not fear a revolution in matters of education both because democracies are proverbially conservative and because educational administration is now well organized. Changes are therefore sure to be a matter of development and growth, and he who would work most effectively may prepare for what is before him by studying the history of the past and the trend of the present.

A very casual survey of history reveals the fact that education in this country has always been an exponent of the times.

When one considers the changes that have come over all educational institutions in the past generation, it is impossible to escape the conclusion that the public determines what shall be the nature of

[1] Paper read before the Wisconsin State Teachers' Association, November 12, 1908.

education. And this seems to be equally true whether we consider the so-called private or public institutions, and whether we consider elementary, high-school, or university education. All must be largely conventional and partake of the character of the times. This fact has been often recognized and commented upon both by those who regret it and by those who take satisfaction in it.

It should be noted that the college community is a part of the public and not apart from it.

I. The public will take greater control of educational institutions and the number of pupils will greatly increase.

Fifty years ago there were only forty high schools in the United States. Now there are about twelve thousand. Ten years ago there were about half a million high-school pupils and now there are about twice that number. The rate of increase in the number of pupils naturally is much greater than that of buildings or of teachers. A similar state of affairs exists in the colleges, universities, and technical schools. All this has occurred in spite of the attempts of some of the colleges to "put up the bar" and deny education to all but a relatively few. The methods of selecting those upon whom the fruits of education may fall are likely to be revised by the public, who feel that the money spent upon education should make better citizens rather than a proletariat.

It has been shown that the academic methods do not select the most efficient candidates.

It has also been shown that of those who enter the high school two-thirds drop out chiefly because the instruction is not adapted to their needs.[1]

"The real difficulty lies in the lack of adaptation of the instruction in the high schools to the need and opportunities of the pupils. . . . The instruction should be made as far as possible to serve the needs of the great mass of the pupils. . . . The high school (as now administered) is essentially a 'select' school . . . the real and imperative needs of the many are sacrificed to the doubtful satisfaction of the needs of the few . . . what the whole system requires is the skillful provision for the real good of the greatest number."[2]

Dr. Edward J. Goodwin, President of Packer Institute and recently Assistant Commissioner of Education of the State of New York, as quoted in the *New York Times* for October 25, 1908, says:

"We are gradually coming to recognize the injustice of organizing our high schools in the interests of the few alone. Our high schools contribute in New York for example less than 2 per cent of the men who yearly enter the so-called 'unlearned' professions."

It is inevitable that all educational institutions will become much more crowded in the near future, for the public is moving toward a greater control of the schools and colleges; and a still further increase of attendance upon our schools and colleges will forthwith compel us to make some modifications in our methods of instruction, so as to deal with larger numbers of pupils. For instance, it will

[1] Professor E. L. Thorndike, Columbia, "The Future of the College Entrance Board," *Educational Review*, May, 1906. Also "The elimination of pupils from school," Bulletin of the Bureau of Information.

[2] The *New York Times* in a recent editorial.

make it difficult to talk seriously of "laboratory divisions limited to twelve."

"The real voice of the voters who have lately so multiplied high schools has not yet been clearly heard, and their unformulated purpose has not yet been accomplished. . . . The evils of college dominance are now so great and manifest that they must be transient." [1]

"The people know what they mean by education after all really quite as accurately as we do, whose peculiar business it is to define the term." [2]

The conditions of our modern life are driving every one to the study of science. Evening classes, extension classes, correspondence classes, are multiplying. Books and periodicals give increasing space to scientific subjects The development of machinery has made the study of physics not only a matter of interest but a necessity to all persons. The automobile, the motor boat, and the like are not only rivals of the schools in the teaching of physics but they are at the same time the most potent cause for the reform in that teaching.

From Sir Humphry Davy, whose inaugural address at the Royal Institution sets forth the services of science to humanity and science as an agent in the improvement of society, through the long line of masters down to the present, there comes a complete and overwhelming condemnation of Cavendish's exclusiveness in science.

[1] President G. Stanley Hall, Clark, *Adolescence*, Vol. II, p. 515.

[2] State Supt. Henry C. Morrison, New Hampshire, *Educational Review*, October, 1908, p. 247.

"The subject matter of physics is far more closely connected than that of any other science with daily life . . . the things we need to know most are the physical things . . . there is no other science except chemistry, which touches common life at so many points."[1]

II. The public will no doubt require that science instruction shall be practical, or as Professor Bailey puts it — applicable.

Unless it is applicable it can neither be scientific nor humanistic.

The high schools of the future will without doubt be more closely allied to schools of applied science than to those of pure science. There will be more of the study of processes than of principles; more of physiology than of anatomy; more of agriculture, nature study, natural philosophy as Faraday understood it, than of physics and chemistry as the terms are now sometimes understood.

Faraday thought that physical science was a most appropriate study for children and mentioned *light* as a particularly good subject for that purpose.

Professor William Conger Morgan of the University of California has an article in *School Science* for November, 1908, on the "Relation of the Technical World to School Chemistry," in which he shows admirably how the high-school course in chemistry might be enriched, and he completely justifies the substitution of "practical" illustrations for the usual academic treatment when he says:

[1] Professor William F. Magie, Princeton, "Boyle and Townley, on Observation and Reflection," Proceedings of the Physics Club of New York, January 29, 1904.

"The best reason for introducing experiments from the industrial world is to illustrate the general principles of chemistry."

This is not materializing or commercializing; it is the most effective way of teaching science for its own sake.

But let us put special emphasis upon the next division of our subject.

III. Science teaching will be more humanized.

"Nothing is of real worth unless it can be directly connected with some result of conspicuous benefit to mankind.

"This attitude has profoundly influenced educational theory. This is a change of attitude of the world at large.

"Society wants the things of practical moment taught, and it is the task of education to do it.

"Science has the confidence of the people, before whose court it must justify itself. Science teaching has every natural advantage in its favor, including the keen interest of the pupil, and no excuse will be accepted for its failure.

"Science teaching has its mission in general education. It may be taught so that it throws light on almost every phase of human interest.

"The lives of the great scientists are just as significant for education as the things which they stand for. The more students learn about personality the larger men they become." [1]

"It is gradually becoming clear that for purpose of teaching, science must be treated as a part of human experience. It must be so closely linked with the interests and problems of the daily life as to become part of it. It must be shown to have arisen for the purpose of meeting human needs and to have played a very important part in the development of our present social life." [2]

[1] Dr. A. S. Dewing, Harvard, *School Science*, October and November, 1908.

[2] Professor C. R. Mann, Chicago, *Educational Review*, June, 1907.

"The call to life, and to life in this world, is the first and fundamental call of the scientific age, it is a call to sacrifice and to service, and the call to service has been the deepening undertone of the call to humanism." [1]

IV. The status of the high-school teacher will be greatly improved and we may hope that great teachers will arise as of yore.

If we are to meet the needs of the public, we must again have great teachers.

"The great teacher is the man of great personality, in whom nobility means more than attainments, and therefore the man whose personal touch upon the student is sure to be quickening and ennobling. He must know surely and clearly the subject he is teaching, but he must know even more profoundly and sympathetically the object he is teaching, namely, the other human beings, his pupils, for whom he is guide and leader.

"The greatest students of this world have been formed one by one by great masters.

"Give me a good teacher, of noble nature, and I am comparatively indifferent to his or her scholarly attainments. The attainments will follow. Of what use for educating our boys and girls would it be to have the most gifted if that teacher is himself a small-natured, mean-natured, close-natured, little-natured, soul?" [2]

"The educational process is not the mechanical impact of text-book or even of ideas upon the intellect, but the impact between living beings; and in the interaction of these vastly more is given and received than is ever formulated. What the teacher is expresses itself; and always the teacher's personality is the greatest educational influence." [3]

[1] Professor W. T. Sedgwick, Massachusetts, Institute of Science of Teaching, *Science*, August 14, 1908.

[2] Professor Andrew F. West, Princeton, *Educational Review*, September, 1908.

[3] *Educational Review*, October, 1908, p. 295.

The high-school age is the most important for education, and the public will there place its greatest teachers. They cannot be specialists, for as intelligence increases in one direction ignorance becomes more dense in other directions. The specialist seldom measures up to the average intelligence of his own pupils.

The greatest teachers of the future, like the great teachers of the past, will teach not one but many sciences and these with reference to their applications.

"A generation ago . . . the work was usually in the hands of one of those admirable all-round pedagogues who were capable of teaching with equal facility every subject in the curriculum; and it may be said in homage to their talent that the best of them taught every subject as well perhaps as some of the specialists of to-day teach the one subject to which all their time is given." [1]

"And we all praise famous men —
  Ancients of the College;
For they taught us common sense —
Tried to teach us common sense
Truth and God's Own Common Sense
Which is more than knowledge." [2]

"A well-rounded mind rather than the mind of one idea is the general purpose of teaching." [3]

Teaching is a "high and sacred calling" and we might expect it to react upon the personality of the teacher.

An Englishman writing of his visits to American schools says:

[1] Professor Nichols, Cornell, Proceedings of the Eastern Association of Physics Teachers, December, 1905.

[2] *Stalky and Co.*, Kipling.

[3] Dr. Dewing, *School Science*, November, 1908.

"I have found teachers the most attractive class in the nation, because more than any other class, not excepting the clergy, they are free from sordid aims." [1]

We may expect that such teachers will maintain sympathetic relations with their pupils.

At present teachers appear to be divided into two camps with reference to their mode of treating the pupils. One party feels that there can be no education without coercion, the other feels that it is possible to win students to voluntary efforts which shall count for more. The first party accuses the second of using "kindergarten methods" and of entertaining and interesting pupils until they lose the capacity for work. Work, they claim, is their watchword, and play, they claim, is the watchword of the second party. But the second party has never agreed to this claim. On the other hand, it says to the first party, you boast of work but you really administer sedatives. Your quantitative laboratory exercises and your mathematical treatment of physics is not hard, it is stupid. Its only justification is that it is the easiest thing for an overworked teacher to administer, particularly if he be a teacher who lacks the power to hold the attention of a class and therefore dreads qualitative experiments. Furthermore the second party claims that it secures a *compelling* interest in the subject which insures voluntary effort not only in school, but out of school, and through life. These two parties have never been able to get together by argument, and I take it that it is a hopeless case of lack

[1] *Educational Review*, October, 1908, p. 295.

of affinity. Unless I am greatly mistaken, these two parties in education would also be found to be two opposite sects in religion and for similar reasons. The first requisite of a great teacher is that he retain a vivid recollection of himself as a child, that he may be able to appreciate fully the pupil's point of view.

V. As the high-school teacher increases in dignity the domination of the college will cease and the evils of uniformity will disappear.

"High school physics has problems all its own to which its representatives should address themselves with courage, resolution, and above all with independence, or else the present decadent tendencies due to college control will continue.

"College entrance requirements as now enforced are almost an unmitigated curse to the high schools, exploiting them against their normal interests and the purpose of the people who support them.

"The high school should be master not servant.

"Perhaps no institution in modern times needs inspection, visitation, and scrutiny so much as the private endowed American colleges themselves." [1]

We can never have a truly educational treatment of any subject so long as it is studied solely with college entrance examinations in view.

In England and on the continent entrance examinations have been abolished on the ground that they are no test for power.

"The function of secondary schools is distinct in itself and will one day establish its independent right when it has rid itself of the vicious term and still more vicious idea of college preparation." [2]

[1] Hall's *Adolescence*, Vol. II, pp. 157, 510, 520, and 527.

[2] F. Whitton, *School Review*, 1900, p. 261.

The high-school teachers of this country have their subject matter and method of treatment minutely prescribed for them by those who understand neither the subject nor the pupils as well as they do.

Some persons, unconscious that physics is a living subject, that every man, woman, and child has his own physical world to study, varying with persons and with localities, demand that these high-school pupils shall be fitted to the Procrustean bed.

They assert that physics is a quantitative subject; that it presents the greatest difficulty to all except those few who have special gifts. They say that this is predetermined in the nature of the subject. All this, however, has been explicitly denied by some of the greatest natural philosophers and the greatest educational philosophers.

In the hands of the great teachers few subjects are difficult; in the hands of some teachers all subjects are not only difficult, but utterly incomprehensible.

"Any of the Sciences can be made impressive if taught by a full mind which alone can elementarize,"[1] and the ability to simplify is one of the marks of true greatness.

"We must distinguish between the teaching function and the research function. It is our business as teachers to open the minds of the young to the facts of science. . . . Nature study is not a new subject; it is a new mode of teaching and is just as applicable to the college as to the common school."[2]

[1] Hall's *Adolescence*, Vol. II, p. 202.

[2] Professor L. H. Bailey, Cornell, Proceedings New York Science Teachers' Association, Albany, 1907.

"The craze for uniformity more than any other one thing has led to the great success of our schools in the development of mediocrity." [1]

"Even more harmful than overcrowding is the over-systematizing which characterizes our present-day methods. The tendency nearly everywhere is to reduce teaching to a routine and thus to deprive both teacher and pupil of the chance to do and think for themselves. A committee is appointed to draw up a syllabus and to outline the Physics teaching for a whole state or for the entire country. Every school equips itself to follow this program, and every Physics teacher goes through the prescribed course in the prescribed manner with section after section, day after day and year after year, until Physics to him, instead of being the world-wide glorious science that it really is, is comprised within the scanty pages of the syllabus. Some spirits there are that refuse to be thus confined, but the tendency to uniformity levels down as well as up and the hilltops from which one may look out and view the true beauties of science are cut down in order that we may have a plain, easily traversed and easily cultivated." [2]

"The interests and needs of the pupils should be the determining factor in the arrangement of courses and the choice of methods.

"It follows that a high degree of uniformity in teaching physics is neither practicable nor desirable.

"Physics should be taught not as a preparation for college but as a preparation for life." [3]

[1] Professor Stanley Coulter, Purdue University, *Nature Study Review*, January, 1908.

[2] Professor E. L. Nichols, Cornell, Proceedings Eastern Association Physics Teachers, Boston, 1905.

[3] Mr. F. B. Spaulding, Boys' High School, Brooklyn, *School Science*, 1908, p. 674.

VI. As attendance upon the high-school classes in science increases, individual laboratory work will of necessity be somewhat curtailed and more importance will be attached to the lecture.

To begin with, the so-called inductive work will be eliminated from the laboratory.

High-school pupils are sometimes taught to "test" and to "verify," in short to learn things "first hand" when they have neither capacity for nor ground upon which to draw conclusions.

"I am an enemy of the inductive method in the school course. It is utterly absurd to expect an immature boy of fifteen or sixteen to perform that intellectual feat of generalization that is considered the most mature effort of the human mind. . . . It is supposing a mental endowment that only comes late in life to most of us and often never at all. . . . Bad as this method is in the hands of an experienced teacher it is confusion worse confounded when a novice attempts it." [1]

The laboratory at best is a very artificial means of supplying experiences upon which to build physical concepts. While it is useful and needful it cannot take the place of an appeal to life's experiences and the phenomena of nature. The charge that pupils may read about nature in books and not recognize her out of doors is quite as applicable to laboratory work. In physics it is too unreal; too much devoted to statics — too many things are presented which are never found outside of a laboratory and which are not parallel to or explanatory of anything found in ordinary human experience.

[1] Professor Perkins, Trinity. Proceedings Eastern Association Physics Teachers, December, 1905, p. 25.

Professor Mann, Chicago, says that "for the general student college laboratory work is neither essential nor desirable." [1]

"Too much time is given to so-called laboratory work with elaborate and expensive apparatus. Too little attention is paid to simple and effective illustrations of physical phenomena and simple applications of fundamental principles to be found in every school room and its immediate environments." [2]

Professor W. S. Franklin, Lehigh, says:

"My experience is most emphatically, that a student may measure a thing and know nothing at all about it, and I believe that the present high-school courses in elementary physics in which quantitative laboratory work is so strongly emphasized, are altogether bad."

. . . .

"I believe that the physical sciences should be taught in the secondary schools with reference to their practical applications. I cannot endure a so-called knowledge of elementary science which does not relate to some actual physical condition or thing, and I believe that the only physical things that are sufficiently prominent in a young man's mind to be brought into the field of his science study are the things which have been impressed upon him in everyday life. Say what you will, you must do one of two things to be able to teach physics in any school; either you must create an actual world of the unusual phenomena of nature by purchasing an elaborate and expensive equipment of scientific apparatus or you must make use of the boy's everyday world of actual conditions and things." [3]

The public has expended lavishly for laboratory equipment in physics, doubtless in the expectation

[1] *Education*, December, 1906.

[2] Mr. J. W. MacDonald, Agent, Massachusetts State Board, Report for 1907.

[3] Professor W. S. Franklin, Lehigh, Proceedings Twelfth Annual New York State Science Teachers' Association, Albany, 1907.

that their children will be better instructed thereby to cope with the new conditions of modern life. There is no department of education which the people have more at heart and there are abundant signs that they will not long permit their purposes to be thwarted.

Education is not wholly a process of training. It is in considerable measure a matter of acquiring the mass of information which it is conventional to have at any particular age.

The lecture is the only means by which we may bring in all the good things that we feel moved to introduce. The great teachers of the future will be able to instruct large classes by "talks, which is the method of the real teacher." This is to-day the method of the German teachers, who are notoriously the best teachers in the world.

Large portions of science should be merely touched upon; made understandable for a brief moment and then forgotten, not even retained for recitation, much less for examination.

"Curiosity and interest are generally the first outcrop of intellectual ability. Youth is normally greedy for knowledge and that, not in one but in many directions.

"Never is the power to appreciate so far ahead of the power to express and never does understanding so outstrip ability to explain. Over accuracy is atrophy. Mental acquisition sinks too deep to be reproduced by examination. With pedagogic tact we can teach about everything we know that is really worth knowing, but if we amplify and moralize instead of giving great wholes — if we wait before each methodic step till the pupil has reproduced all the last we starve and retard the soul.

"The nature of youth demands that science should be taught in a large all-comprehensive way. We must have an introduction to science that touches rather lightly on nearly all the great hypotheses over the whole field.

"The boy in his teens needs great wholes, facts in profusion, but few formulæ. He has a native gravity toward those frontier questions where even the great masters know as little as he.

"The college should stand for extensive more than for intensive study.

"It should stand with doors hospitably open to those who have time to pause for it on the road to a profession, or to spend a period of culture and acquire an avocation before entering a career. It should let teaching have its perfect work.

"The teacher should forage widely and incessantly, and bring everything within reach in his field to his class. The lecture method should be made the most of, being conversational and designed to provoke reactions. He should teach every topic broadly and comprehensively, and instead of disparaging mere information, it should ooze from his every pore.

"Every great expert should feel it his duty to put the best that is in him in a form most interesting and profitable to a cultured lay audience." [1]

The lecture room is the place for presenting the history of science and the biography of scientists; the story of inventions and how they have transformed society; the rise and development of modern scientific theories; the linking of the history of science with general history showing how the evolution of science was both helped and handicapped; the contributions of science to our comfort, our health, and our general happiness.

Mr. B. M. Jaquish of Erasmus Hall High School, Brooklyn, New York, in an unpublished paper has very effectually shown that countless references

[1] Hall's *Adolescence*, Vol. II, pp. 85, 453, 151, 156, 528, 548.

in all our literature require for their interpretation a general knowledge of science and this is rapidly becoming a *sine qua non* for current literature.

The lecture should show the application of science in the occupations of the particular community in which the school happens to be located.

Hence no syllabus can be made to fit the whole country. If the school is in a large city and is located in one of our most modernly equipped buildings the lecture in physics will often be devoted to an explanation of that equipment which will be found to illustrate every chapter in physics far better than any laboratory can.

VII. We may undertake to frame a platform for future science teaching as follows:

1. Science for high schools consists of a well-organized mass of useful information.
2. In order that the amount of information may be considerable it is given for the most part "second hand."
3. The three means for giving this information, stating the more important first, are: (*a*) Illustrated lectures. (*b*) Study of text-book with recitations, and reading many references in books and magazines with written and oral reports. (*c*) Laboratory work, a small portion of which consists of exact measurements.
4. This mass of useful information being acquired at the hand of a competent teacher involves discipline and training.

5. While the science teacher has a peculiar part to perform in the process of education which the teacher of no other subject can do so well, his task is not absolutely unique and the methods of instruction which are best in the treatment of other subjects are for the most part best for science.
6. A quantitative treatment with whole numbers, so to speak, runs through much of the instruction in lectures, recitations, and laboratory work — giving concreteness and therefore interest to the subject — but this is only incidental and of minor importance.
7. Science is not presented as a catalogue of principles, but rather as history, biography, and the evolution of changing ideas. The topics for study are phenomena rather than laws, and principles are presented only for the purpose of explaining some definite problems in life.
8. Since all this applies equally to all general or first courses, whether given in high schools or colleges, it follows that college admission tests are the same as high-school graduation tests.[1]

[1] See also further discussion of this platform in four papers already published as follows:

1. "The Enrichment of the High School Course in Physics," Proceedings Eastern Association Physics Teachers, Boston, November 5, 1904.

2. "Modern Trend of Physics and Chemistry Teaching," *Educational Review*, March, 1906.

3. "The Intensive Method in Chemistry," *School Science*, Vol. VI, p. 585.

4. "Science for Culture," *School Review*, Vol. XV, p. 123.

After full discussion the Science Conference unanimously passed the following preamble and resolution:

Whereas: The present methods of teaching physics in secondary schools do not yield as satisfactory results as we desire to get; and,

Whereas: We believe this to be due to the fact that far too great emphasis is now placed on accurate quantitative work; and,

Whereas: This overemphasis of the importance of quantitative work is due to the fact that some colleges take the position that physics is by nature a quantitative science, that it is the only such subject in the high-school curriculum, and that it must therefore be so taught, irrespective of the needs and abilities of the pupils; and,

Whereas: We believe that physics for high schools should consist of a study of the processes and principles of phenomena of the daily life of the student; therefore be it

Resolved: That we, members of the Science Conference of the Wisconsin State Teachers' Association, in convention assembled, do hereby agree to change the methods of teaching physics by abandoning as far as may be found desirable the exact quantitative work, and by substituting therefor a more living treatment of the subject based on the daily experiences of the pupils.

The following resolutions were passed by the Central Association of Science and Mathematics Teachers at its meeting in Chicago, November 28, 1908:

Resolved: That we believe in the recognition and inclusion within our courses of the practical and applied aspects that make possible an appreciable significance and belief in the worthwhileness in practical life of the various subjects studied; and

Resolved: That we believe that the formulation of secondary school courses should be made entirely from the point of view of the needs of the majority of secondary school pupils, and further that any course that is best for the majority of the secondary school pupils is best for college entrance.

VII

THE TEACHING OF PHYSICAL SCIENCE

GIVEN a class all the members of which are the same age, all having taken the same previous studies, all having the same standing, and all good in mathematics, they will still be found to be widely different in their capacity to understand physics. The difference among them lies not in their mental caliber, but in the experiences they may have had, or rather in the attention they may have paid to their experiences. There are high-school pupils who have had no conscious experience that would lead them to think that they could secure a mechanical advantage by taking hold of the long arm of a lever. Such pupils often go through the usual quantitative experiments in the laboratory as though they were exercises in pure mathematics. The experiments seem to add nothing to the pupils' physical sense. They are no more likely to feel that they could move a log better by taking hold of the end than by seizing it in the middle; they see no reason why a heavy object may be rolled up a gradual incline more easily than up a steep one, or, for that matter, why it would not be better to lift it without an inclined plane. They have no instinct, when walking by the side of a railroad track, which would lead them to prefer the inside rather than the outside of a curve when a train is coming. They see no reason why a river should gouge the outer rather than the inner bank on its winding course. They see no reason why a propeller wheel should cause an airship to move. It is not to them self-evident that if rapidly moving air knocks a building over the air must have weight. If when looking obliquely upon the surface of a quiet lake they see a bright star reflected therein, they do not know by experience where to look for the star itself. These are not rare cases. A majority of the students who come to the study of physics feel that a large portion of the common everyday material phenomena is "uncanny." The first purpose of a beginning course in physics, whether in grammar school, high school, or college, should be to make nature and her ways seem *natural.* It matters little whether we call it nature-study, phenomenology, or physics (all of which terms are in reality synonymous as applied to elementary work); we must lay the foundation for an understanding of our subject by furnishing a basis of experience, comparing observation with observation, lighting one fact with another. This does not necessarily mean laboratory work, although that may be made a most fruitful aid.

It would seem self-evident that the first thing one must do is to find out the exact mental equipment of his students — to find out what the foundation is before he begins to build upon it. But the schools are full of persons just out of college, teaching not the pupils, but their own self-respecting course in physics. These straightway reach the conclusion that few students are fit to take physics.

The writer believes that there is nothing in the nature of physics nor in the nature of either grammar-school or high-school pupils which precludes their studying physics; on the other hand, it would seem evident that the subject is peculiarly well suited to fit them for life. This view seems to be generally accepted by the public and most children seem to have the desire for a knowledge of things physical so strongly implanted in them that they will study the subject after a fashion in spite of the delinquencies of the schools. No distaste for the physics of the schoolmaster has in the slightest degree affected their love for the physics of everyday life.

The first requisite of a high-school teacher of physical science is that he should have that grasp of his subject and that understanding of pupils that would enable him to teach his subject with equal facility to any and all persons from twelve to eighteen years of age.

Apparently not more than 5 or 6 per cent of all the high schools in the United States have a sufficient number of teachers so that one may give his whole attention to physical science, including physics and chemistry, and not more than 2 or 3 per cent have teachers who may specialize between physics and chemistry. This does not appear to be a misfortune. A rather careful and extended investigation of the matter has brought me to the conclusion that the best teachers of any science are those who are fairly well trained in all, rather than those who have had training in one science only. The high-school teacher of physical science needs at least a general college course of one year's duration in each of the following: physics, chemistry, and biology. It is desirable that he have a second year's course in each of the first two. But it is of the utmost importance that these courses be given him by a model teacher and that he be associated with those who are looking forward to teaching rather than to research. He should have also a course in the history of physical science and in the teaching of the same. He should gain a knowledge of the modern trend of teaching in his field by a study of the papers read at educational meetings and discussions published in educational journals during the past fifteen years. He should read the prefaces of a dozen or more of the high-school text-books in physical science. These have been written for the most part by the most successful teachers of the time, selected by rather astute publishing houses who keep a close watch upon the field and generally know what is most likely to meet the demand. Each author in his preface has attempted to state what are his ideals. To read these prefaces and to scan through the texts is one of the best ways to discover what are the aims and tendencies of the teaching of physical science for any period. And a clear understanding of the trend of the immediate past will enable one to predict what will be the practice of the near future.

The intending teacher should be familiar with the various syllabuses put forth in his subjects and the examination questions upon his subjects which have been given high-school graduates for the past few years. These will indicate the scope of the subject as it is in the mind of some of those who are in a position to direct the teaching of physics. Visits to schools, inspection of equipment, and talks with teachers are a necessary part of the education of the intending teacher. The reports of city and state superintendents often contain very instructive matter for intending teachers.

During the college course most young men suffer a complete intellectual revolution. Senior conservatism takes the place of freshman enthusiasm, but it is still counterfeit. Their excesses are quite as great, but they are of a negative kind. Finding that much which they had affirmed is untenable, they now deny everything. Being unable longer to believe all things, they disbelieve all things. If they have chosen science as their major study, they affect to discount all other subjects of study. They sometimes show contempt for poetry, art, music, literature, philosophy, religion, women, and people in general outside of their department. Their elders, thinking that all this is merely a phase of adolescence, are more or less complacent about it, but I cannot feel that they are yet suitable material for high-school teachers. There is still a capacity for worship in them, and it is directed toward science and the great scientists. Like most worshipers, they conceive their gods to be like themselves, and it is a very great and wholesome eye-opener to them to learn that Faraday, Maxwell, and a host of other masters of science have been devoted to religion, that Davy, Maxwell, and many others living and dead have been poets, artists, musicians, philosophers, husbands, fathers, and even men of the world. It is a distinct shock to the youthful specialist of to-day to learn that none of the great scientists have been specialists in early life. On the contrary, their interests often seem to have been particularly diffuse. Poetical imagination rather than mathematics seems to have been a conspicuous foundation in many of them. Huxley was a great reader of novels, and Simon Newcomb wrote one. It is well that a young man before he goes into high-school teaching should get over his cant about scientific accuracy and truthfulness, and learn that the physicists are no better and no worse than other people, no more accurate and no more reliable in their judgments when outside of their particular field. A man trained to scientific conservatism in one subject may be a wildcat in some other.

If one would really know what is the condition of things at the present time in which he is living and what is to be the condition of things in the near future, for which he should prepare to live, let him regard more than the ephemeris of to-day. He should study the trend of the recent past and thus divine both the true present and the near future. Let us see what authors of text-books and other persons who have commanded more or less attention have to say about vitalizing the teaching of physics by the use of practical applications and interpretations of the phenomena of everyday life; about the use of the inductive method; about the infusion of mathematics into physics; about quantitative work; about lectures; about simplification of the subject and of the apparatus.

In 1857, in the preface of his *Natural Philosophy*, Wells wrote:

> "The principles of physical science are so intimately connected with the arts and occupations of everyday life, with our very existence and continuance as sentient beings, that public opinion at the present time imperatively demands that the course of instruction in this subject shall be as full, thorough, and complete as opportunity and time will permit. The author has endeavored to render the work eminently practical, the illustrations and examples have been derived, in most cases, from familiar and common objects."

Of the fifty or more high-school texts which have been written during the past fifty years, there is scarcely one that has not reiterated this sentiment in its preface. When, however, we come to look into the body of the text we are invariably disappointed. Those who have written during the last fifteen years have noticeably been circumscribed in this matter. Wells under the head of "Strength of Materials" gives an interesting and illuminating account covering eight pages. Hollow bones of animals, hollow stalks of grains, and hollow columns in buildings are discussed among other interesting things. Within the last fifteen or twenty years, however, the exigencies of college preparation have substituted for all this a laboratory exercise in which each pupil attempts to find the number of grams required to break a piece of small wire. We certainly need common-sense instruction about strength of material. Many a man has stripped the screw thread from some fine piece of apparatus before he learned that brass was a softer metal than steel and could not be safely handled with a monkey wrench. To many persons all metals are hard and strong and able to stand any abuse, until they have learned to the contrary by some unnecessarily bitter experience. Certainly whatever we may profess in the prefaces of our text-books, we are actually doing less in our schools to-day than we did fifty years ago to make sciences minister to the needs of our common life. The fact that it requires a pull of a certain number of grams to break a piece of No. 24 brass wire is of no concern to any of us — not even to the bridge builder. It would seem that laboratory teachers, like kindergarten folks, have been at much pains to invent "busy work."

Previous to 1870 there was much in the way of "philosophical apparatus" in the schools, and in the hands of many a skillful demonstrator and true teacher it served admirably to make knowledge real. As early as 1837 the city of Boston furnished each of its grammar schools with a set of physical apparatus costing $275 for each set. A similar set was to be found in most of the academies of the country about that time, and there are a large number of persons now living who are both capable and willing to testify that they received more that was worth while from the instruction given with the aid of that apparatus than our high schools of to-day are giving under the college entrance requirements.

Between 1870 and 1880, much was said about the value of individual laboratory work and the use of the inductive method. In 1872 Eliot and Storer in the preface to their *Elementary Manual of Chemistry* wrote:

"The authors' object is to facilitate the teaching of chemistry by the experimental and inductive method, to develop and discipline the observing faculties."

Storer and Lindsley somewhat later said:

"The student acquaints himself with facts and principles through attentive use of his own perceptive faculties."

From 1873 to 1878, Steele wrote in his prefaces to books on chemistry and physics:

"Unusual importance is given to that practical part of chemical knowledge which concerns our everyday life." "A closer relation between school room, kitchen, farm, and shop." "The author has used simple language and practical illustrations (and the student) is at once led out into real life. From the multitude of principles, only those have been selected which are essential to the information of every well-read person." "Aim to lead young persons to become lovers and interpreters of nature." "Simple experiments within the reach of every pupil at home." "The text-book only introduces the student to a subject which he should seek every opportunity to pursue." "As far as possible every question and principle should be submitted to nature for a direct answer by means of an experiment."

And in no other books have I found the text fulfilling so completely the promise of the preface, as in his.

In 1881, Avery's *Chemistry* said: "As far as possible the experiments are to be performed by the pupil rather than for him." In 1882, Gage's *Physics* had stamped upon the cover "Read nature in the language of experiment." The preface quotes from Superintendent Seaver of Boston:

"The mind gains a real and adequate knowledge of things only in the presence of the things themselves."

Gage remarks that chemistry has been taught by the laboratory method for twenty years, and urges the introduction of laboratory work in physics. In the English High School in Boston, he had with $300 furnished a laboratory which answered the requirements of a large school. He proposes fifteen as the size of a laboratory class and five experiments in an hour — twelve minutes to an experiment including the writing of the notes upon the same. Gage stood for greatly simplified apparatus.

"Laboratory practice and didactic study should go hand in hand, and divide the time with one another about equally." "So far as practicable, experiments precede the statements of definitions and laws, and the latter are not given until the pupil is prepared, by previous observation and discussion, to frame them for himself."

Trowbridge, head of the Department of Physics at Harvard, in his high-school text-book in 1884 said:

"The writer believes that the necessary amount of geometry and trigonometry (for the study of physics) can be taught at about one sitting."

"It is necessary for the student of science to obtain a certain balance of judgment, and to cultivate a certain scientific instinct."

"Physics should not be made a means of teaching mathematics. I have, therefore, substituted experimental problems for the mathematical problems which are usually given in treatises on natural philosophy, in the hope of cultivating the scientific instinct."

"The natural progress of our study of any subject is from the qualitative, or the comparatively rough evidence of our senses, to the quantitative."

"The author recommends that from one to two lectures be given during the week. In these lectures the experiment should be performed which the students afterward perform themselves in the laboratory."

Hall and Bergen, 1891:

Previous to 1886 candidates for entrance to the freshman class at Harvard had been examined on text-book work only. In this year a laboratory requirement was added.

"An attempt was made to bring together such experiments as would have the most frequent and important application in ordinary life."

Hall and Bergen, revised and enlarged edition, 1897:

"The instruction should direct especial attention to the illustrations and applications of physical laws to be found in everyday life."

"The pupils' laboratory work should give practice in the observation and explanation of physical phenomena."

Hall suggests simple apparatus. He proposes about $1000 to equip a laboratory with apparatus for twelve workers and for teachers' demonstrations.

Carhart and Chute, 1892:

"The laboratory method has come in during the past decade."

They describe very clearly how the inductive method or the attempt at it results in failure.

"A few years ago it seemed necessary to urge upon teachers the adoption of laboratory methods to illustrate the text-book; in not a few instances it would now seem almost necessary to urge the use of a text-book to render intelligible the chaotic work of the laboratory."

"The pupil should be kept in his class-work well ahead of the subjects forming the basis of his laboratory experiments."

Avery, 1895:

"The class-room work must be kept ahead of the laboratory work; *i.e.*, the pupil must come to the laboratory with some knowledge of the principles involved in the work that he is required to perform."

He does not appear to think that high-school pupils can work by the inductive method.

Cooley, 1897:

"The student should study the text-book before entering the laboratory."

The order recommended is:

"(1) Oral instruction — involving illustrative experiments. (2) The study of a text-book. (3) Laboratory work to practice experimental methods of reaching or testing truth."

Crew, 1899:

"Physics, in too many of our schools, ranks as a most difficult subject. But dealing, as it does, with the familiar phenomena of daily life, and requiring, as it does, only a small fraction of the algebraic knowledge which the average student has already acquired, the author is inclined to believe that the difficulty lies chiefly in the presentation."

"An elementary presentation of physics should begin by resuming what might be called the experience of the average lad of sixteen years. The number of physical facts which a boy of this age has accumulated is astounding. Seldom, indeed, does the instructor appeal to him in vain for a verification of an elementary fact. The demand therefore is not so much for new facts, or for sheer facts of any kind, as for an orderly arrangement and an ability to use these facts."

Hortvet, 1899:

"It is found in practice that the purely inductive method fails at points where it is expected to do the greatest amount of good."

Torrey, *Chemistry*, 1899:

"Chemistry has suffered from the irrepressible wave of laboratory madness which has swept over the whole educational world."

"Nothing too severe can be said against the mechanical and demoralizing system of note-books with 'operation,' 'observation,' and 'inference' headings. They are wholesale breeders of dishonest and superficial work."

Thwing, 1900:

"Laboratory work should follow the study of text."

Henderson and Woodhull, 1900:

"Physics should be so taught as to be a desirable and even essential subject for every pupil in the secondary schools."

"The relations of physics on all sides to human life and human interests have been emphasized."

"The laboratory deals with inductions and verifications, and its chief purpose is to make knowledge *real*."

"Both laboratory and classroom work are essential to a correct knowledge of elementary physics, and they should correlate."

"Portraits and brief sketches of men who, by their researches, have contributed much to our knowledge of physics have been introduced."

Slate, 1902:

"My experience proves beyond reasonable doubt that elementary instruction in physics suffers where contact with phenomena and with experimental methods is confined to a small group of quantitative experiments; the possibilities of the class (lecture?) experiment have not been fully exploited."

"Instead of feeding them with crumbs from the specialists' table, physics for the school must be treated in relation to the average boy and girl, approaching the threshold of active life."

Holden, *The Sciences*, 1902:

"Main object, to help the child to understand the material world about him. Why should not natural phenomena be comprehended by the child?"

"It is not possible to explain every detail of a locomotive, but it is perfectly practicable to explain its general principles."

"The plan is to waken the imagination; to convey useful knowledge; excite a living and lasting interest in the world that lies about us."

"Familiar phenomena are referred to their fundamental causes."

Andrews and Howland, 1903:

"We have sought to make prominent the practical bearings of physics. To those students at least whose schooling ends with the high school, physics should be a connecting link between their study and their work. Except in special cases it bears more on the daily affairs of life than any other subject."

Bits of history are introduced to show the close relation between the science of physics and human life.

"The student should constantly keep in mind that the data of physics are much easier to remember if they are interpreted in terms of past experiences, everyday events, and that such interpretations are far more valuable than the mere acquisition of data."

Mann and Twiss, 1905:

"The aim has been to show the student that knowledge of physics enables him to answer many of the questions over which he has puzzled long in vain."

"Beginning arguments with inventions, or general observations of phenomena, may not be the logical order, but it is more nearly the order in which Nature herself teaches, and the result of the argument does not lose in definiteness, clearness, or accuracy, provided the laboratory is continually held up as the final court of appeal where all doubtful questions are settled."

"Each chapter is a continuous argument toward some principle or principles, and the entire book is an argument toward the conclusions stated in the last chapter,"

which are in part:

"It must be clear to every one who has read this book carefully that nature is not a vast chaos of chance happenings, but a well ordered and governed whole. When we study thoughtfully the phenomena about us, we must realize that there are some simple and universal principles which are manifest in them all. The universe in which we live is a marvelously organized and governed unit and we are compelled to recognize that it could not have organized itself solely by the interaction of blind matter and undirected motion."

"The attempt is made (1) to interest the student in observing carefully and accurately first the familiar things about him and then the things in the laboratory; (2) to interest him in detecting analogies and similarities among the things observed; (3) to train him in keeping his mind free from bias and in drawing conclusions tentatively; (4) to make him see the value of verifying the conclusions and accepting the result whether it confirms or denies his inference."

"We have tried deliberately to give the student the impression that science leads to no absolute results — that, at best, it is merely a question of close approximation; of doing the best we can, and accepting the result tentatively, until we can do better. This attitude places the teacher also in the position of a learner and prohibits him from making use of didactic or dogmatic statements; for these are the bane of science as well as of other things. Science instruction that does not develop mental integrity, freedom of the personal judgment, and tolerance, fails in a vital spot."

"References are given to books in which the biographies of the great men of science may be read, and the student is urged to read them and report. The arguments used by some of the great thinkers have been briefly sketched, and the methods devised by them for reaching conclusions have been given. The attempt has been made to present them as they live in the ideas which they have handed down to us; to picture their mental processes and attitudes, and to show how one thing leads to another as the subject develops in the discoverer's mind."

Coleman, 1906:

"The subject matter has been selected with reference primarily to its value as a part of a general education, and includes an unusual amount of information based upon the facts of our daily experience, introduced as illustrations and applications of physical principles."

"Physics deals largely with familiar natural phenomena and is therefore of special interest and profit as a part of a general education." "A very important part of the material is acquired through the experiences of our daily life."

Milliken and Gale, 1906:

"The book attempts to give a simple and immediate presentation, in language which the student already understands, of the hows and whys of the physical world in which he lives."

"In the description and illustration of physical appliances the course has been made unusually complete because that is what the student is most eager to learn but cannot obtain from books because their language is too technical for him."

The portraits of sixteen of the great makers of physics have been inserted "for the sake of adding human and historic interest."

William Allanach, *Elementary Lessons in Magnetism and Electricity*, London, 1906:

"The author believes that the tendency in some recent books of striving for apparently accurate results so as to appeal to the student, is much to be deprecated, resulting as it frequently does in 'fancy' experiments which give a spurious semblance of accuracy. A little careful and honest thinking is worth much of it."

Hoadley, 1908:

"Especial effort has been made to lay proper emphasis upon the application of physics in everyday life."

"Simple apparatus. Most of the experiments are for demonstration to the class, performed by teacher or chosen pupils."

"With a superabundance of excellent material within the scope of elementary physics, there would seem to be no valid reason for spending the first days in the laboratory on manipulation and measurement with vernier and micrometer calipers, the diagonal scale, the spherometer, etc., as is sometimes done with no physics in sight."

"The more simply and directly a physical problem is presented to the pupil the better, that his thoughts and attention may not be diverted from the real point at issue. This principle is especially applicable in the early part of the laboratory course, where it is most frequently and more seriously violated by the use of micrometric instruments, the Jolly balance, etc., in the work on density and specific gravity, even before the pupil has had practice in the simpler methods of measuring and weighing. It would seem as if the express purpose of such work were at the outset to throw as many obstacles in the way of progress in physics as the ingenuity of teachers and instrument makers could devise."

"Perhaps the most striking illustration of what should not be done in this respect is afforded by the familiar quantitative experiments on the breaking strength of wires and on elasticity of stretching, bending, and twisting. These experiments lead absolutely to nothing in most high-school courses. The laws with which they deal are, for the most part, not considered in elementary text-books."

"The qualitative experimental study of phenomena rightly deserves a large place in an elementary physics course. Economy of time and equipment, convenience, and the advantage of the superior skill of the teacher, are considerations in favor of presenting much of this material in the form of class-room experiments; but in a great many instances the laboratory experiment, affording, as it does, immediate sense perception of the phenomena in their simplest aspects and at close range, is greatly superior to any experiment viewed at a distance, and a laboratory course which fails to take this into account is necessarily one-sided and incomplete."

"Experiments should be regarded as a limited inquiry into the facts at first hand, not as sources of adequate data for generalization by the pupil, nor as 'verifications' of the laws and principles stated in the text. The pupil's experiment is not a proof of the law, but an aid to the right understanding of it."

"What the pupil really does is to perform an experiment which within a fair degree of accuracy, illustrates or exemplifies the law; and he does this in order that he may the better understand it, not because the law is in need of 'verification.'"

"To encourage the pupil to draw hasty and unwarranted conclusions from insufficient data is a vicious practice."

Adams, 1908:

"Physics deals with phenomena in which every child is interested; it treats of subjects with which all men and women have more or less to do in practical life."

Crew and Jones, 1909:

"Appeal to the everyday experience not only of boys but also of girls — show them physics as a science of daily life — assist the pupil in explaining the material phenomena of the world about him."

It is interesting to turn back and see what views were expressed on the teaching of physics nearly a century ago.

Elements of Physics by Dr. Neil Arnott, London, was written the same year that Faraday inaugurated his celebrated lectures to children at the Royal Institution (1826–27). The introduction contains the following:

"Mathematics are at present generally made the beginning of the study, and the reason assigned is that scarcely any object in physics can be described without referring to quantity or proportion, and therefore, without using mathematical terms. Now this is true; but it is equally true that the mathematical knowledge, acquired by every individual in the common experience of childhood and early youth, is sufficient to enable students to understand all the great laws of nature."

"Most persons find attention to pure or abstract mathematics as irksome as the study of mere vocabulary of a language. This explains why so small a proportion of students, if taught in the common way, become good mathematicians, and why, where pure mathematics are made the avenue to Natural Philosophy, this also is so much neglected. It is remarkable how much the really simple and attractive science of comparing quantities has been rendered terrible to the great mass of mankind."

"The mode of proceeding is just as if a man, to whom permission were given to enter and possess a magnificent garden, on condition of his procuring a key to open the gate and measures of all kinds to estimate the riches contained within, should waste his whole life on the road in polishing one key, or in procuring several of different materials and workmanship, and in preparing a multiplicity of unnecessary measures."

"That the importance of physics has not been marked by the place which it has held in common systems of education, is owing chiefly (1) to the misconception that a knowledge of technical mathematics was a necessary preliminary, and (2) to an opinion that the degree of acquaintance with physics which all persons acquire by common experience, is sufficient for common purposes."

"To a man who understands the simple truths of physics very many phenomena, which to the uninformed appear prodigies, are only beautiful illustrations of his fundamental knowledge — and this he carries about with him, not as an oppressive weight, but as a charm supporting the weight of other knowledge, and enabling him to add to his valuable store every new fact of consequence which may offer itself."

"It has been a common prejudice that persons thus instructed in general laws had their attention too much divided, and could know nothing perfectly. The very reverse, however, is true; for general knowledge renders all particular knowledge more clear and precise."

"No treatise on Natural Philosophy can save, to a person desiring full information on the subject, the necessity of attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external senses, leave on the memory much stronger, and more correct impressions, than where the conceptions are produced merely by verbal description, however vivid. And no man has ever been remarkable for his knowledge of physics who has not had *practical familiarity* with the objects."

Among the typical lessons to be found on page 134, I have reproduced, as worthy of imitation to-day, Arnott's method of presenting Newton's third law.

Of the numerous books on Natural Philosophy, intended for school use, written before Arnott's, several are of great interest, but the only one to be mentioned here is that by Ferguson written about seventy-five years before Arnott's book — about 1750. This book passed through many editions. In 1805, it was revised by David Brewster of Edinburgh, who will be recalled as the biographer of Sir Isaac Newton. The next year it was revised and brought out in America by Robert Patterson, Professor of Natural Philosophy at the University of Pennsylvania.

Brewster says:

"The chief object of Mr. Ferguson's labors was to give a familiar view of physical science and to render it accessible to those who are not accustomed to mathematical investigation."

"Mr. Ferguson may be regarded as the first elementary writer on natural philosophy, and to his labors we must attribute that general diffusion of scientific knowledge among the practical mechanics of this country, which has, in a great measure, banished those antiquated prejudices and erroneous maxims of construction that perpetually mislead the unlettered artist."

"No book upon the same subject has been so generally read, and so widely circulated, among all ranks of the community. We perceive it in the workshop of every mechanic. We find it transferred into the different encyclopædias which this country has produced, and we may easily trace it in those popular systems of philosophy (natural philosophy, *i.e.*, physics) which have lately appeared."

Mr. Ferguson, although wholly a self-educated man (having had only about three months of schooling), was elected a member of the Royal Society of London. His lectures were frequently attended by the King, who pensioned him in his later years.

"He possessed a clear judgment and was capable of thinking and writing on philosophical subjects with great accuracy and precision. He had a peculiar talent for simplifying what was complex, for rendering intelligible, what was abstract, and for bringing down to the lowest capacities what was naturally above them."

It is interesting to note that Ferguson devotes sixty-two pages to machines in those days when there were exceedingly few machines, and his treatment of the principles of machines is surpassingly clear; whereas in our age of machinery when every boy and girl needs to know much about the principles of machines and their practical applications in daily life, this subject is certainly most meagerly treated in text-books and altogether the most poorly taught portion of the whole subject of physics.

Ferguson devotes forty pages to pumps, and although he was writing before oxygen was discovered and before the steam engine was invented, he gives a most fascinating account of a "fire-engine," as he calls it, which, however, we should call a steam pump, or more specifically the atmospheric steam engine.

Among the typical lessons to be found on pages 128–131 I have thought it would be not only interesting, but even suggestive of a good method of teaching a subject to-day, to reproduce Ferguson's treatment of *The Spring of the Air*.

Pestalozzi died in the year that Arnott wrote his *Natural Philosophy*, and about that same time the *Lessons on Objects* written by Elizabeth Mayo was beginning to attract the attention of educators in London.

These *Object Lessons* ran through fourteen editions in London during the next thirty years, and finally the book was revised and brought out in this country by Dr. Sheldon of Oswego, who had as his collaborator Professor Hermann Krusi, also teaching at Oswego, but who was born in the school of Pestalozzi, where his father taught for twenty years.

Physics teaching in the high schools, before the colleges took a hand in the matter in 1886, was powerfully influenced by this movement to teach from the object rather than from the book and to take into consideration the nature and requirements of the pupil when making a choice of matter and method of instruction.

> "In 1837 the School Committee of Boston ordered a few articles of philosophical apparatus to be furnished for each of the grammar schools of that city."

The above appears in the preface of *A School Compendium of Natural and Experimental Philosophy,* written by Richard Green Parker, Principal of Johnson Grammar School. The book was written to go with the Boston set of apparatus. It contains engravings of the apparatus and a description of experiments to be performed with it. This Boston set consisted of nearly one hundred pieces and cost $275. The book went through twenty-two editions in the first twelve years and was still being revised as late as 1854 at least.

Very respectable equipment for the teaching of physics was to be found in academies and high schools all over the country soon after this and there were numerous firms (even more numerous than now) in Boston, New York, and Philadelphia, whose business it was to manufacture and sell apparatus for the schools.

This apparatus was used for demonstration purposes by the teachers who were usually the principals of the schools, and for the most part good teachers. They applied a large amount of common sense to the teaching of physics and with a large personal influence they impressed the pupils with the dignity and importance of the subject. There are many now living who are in position to speak of the effect of this instruction and compare it with that which now obtains. I am gathering such testimony and shall be glad to hear from any who may read this.

That the subject was very widely taught might be inferred from the great demand for text-books, which appeared almost as frequently fifty years ago as now and passed through in some cases an astonishing number of editions. The aim of the instruction in physics fifty years ago was generally stated to be the interpretation of the natural phenomena of life. It must be confessed that the writers of text-books in those days about as often as in these days failed to carry out this idea in the body of their texts. But I am of the opinion that the teachers of those days, more often than the teachers of to-day, carried that purpose into effect, the chief reasons being (1) a large proportion of them had received training directly from nature's school. A goodly number of them had college training, to be sure, but so far as it had touched them on the side of science it had led them to nature rather than away from it. (2) They were unhampered in their teaching by any prescription from a higher institution made in the supposed interests of something or somebody else than the pupils themselves.

In 1838, Olmsted's *Natural Philosophy for Schools and Academies* stated the purpose to give an "exhibition of the principles of Natural Philosophy with very copious applications of them to the arts and to the phenomena of nature."

In 1847, Dr. John W. Draper, Professor at New York University, wrote his *Natural Philosophy for Schools.* He preferred to begin with air and water rather than mechanics because the latter "is a more difficult and more forbidding subject." He says:

"The main object of a teacher should be to communicate a clear and general view of the great features of his science, and to do this in an agreeable and short manner. It is too often forgotten that the beginner knows nothing; and the first thing to be done is to awaken in him an interest in the study, and to present to him a view of the scientific relations of those natural objects with which he is most familiar. When his curiosity is aroused, he will readily go through things that are abstract and forbidding, which, had they been presented at first, would have discouraged or perhaps disgusted him."

"There are two different methods in which Natural Philosophy is now taught: (1) as an experimental science; (2) as a branch of mathematics. I believe that the proper course is to teach physical science experimentally first."

"Why is it that the most acute mathematicians and metaphysicians the world has ever produced for two thousand years made so little advance in knowledge, and why have the last two centuries produced such a wonderful revolution in human affairs? It is from the lesson first taught by Bacon, that so liable to fallacy are the operations of the intellect, experiment must always be the great engine of human discovery, and, therefore, of human advancement."

Hooker, *Natural Philosophy for Schools*, 1863:

"Daniel Webster, in his autobiography, speaks thus of his entering upon the study of law:

" 'I was put to study in the old way — that is, the hardest book first — and lost much time. I read Coke on Littleton through without understanding a quarter of it. Happening to take up Espinasse's "Law of *Nisi Prius*," I found I could understand it; and arguing that the object of reading was to understand what was written, I laid down the venerable Coke *et alios similes reverendos*, and kept company for a time with Mr. Espinasse and others, the most plain, easy, and intelligible writers. Why disgust and discourage a boy by telling him that he must break into his profession through such a wall as this?'"

"Here is most graphically depicted a defect which is now, as it was then, very prominent in all departments of education."

"In the books which are used in teaching natural science, it is especially prominent. Even in the elementary books, formal propositions and technical terms render the study uninviting, and to a great extent unintelligible."

"In the whole course of education, the natural sciences should be made prominent from the beginning to the end, not only because they are of practical value, but also because they are as useful in their way for mental discipline as the study of mathematics and of language."

"They can be taught to some extent to the youngest pupils, if they be presented in the right manner. And the busy inquiries which they make after the reasons of the facts, and their appreciation of them if stated simply and without technical terms, show the appropriateness of such teaching. Children are really very good philosophers in their way. They have great activity not only of their perception but of their reasoning faculties also, to which due range should be given in education. Not a year should pass during the whole course when the pupil shall not be engaged in studying some one of the physical sciences to some extent."

"The teaching of the natural sciences in our colleges is generally a failure, and it always will be so as long as the present plan is continued. In order to have it successful there must be the same *gradation in teaching them that we have in teaching language and the mathematics*."

Rolfe and Gillet, 1868:

"There is, as there ought to be, a rapidly increasing demand on the part of the public that the study of natural philosophy shall be introduced into our Grammar and District Schools."

"The authors believe that the subject is both such as every one ought to know about, and such as can be profitably treated in a sufficiently elementary form for the use of these schools."

"The authors believe that in teaching the sciences the aim should be, not so much to present facts and the bare statement of principles, as to train the mind to see how from the simple facts of observation we arrive at the principles of science."

"First establish the facts by experiment and then draw out the principle."

"Use simplest experiments and simplest apparatus."

"Each lesson is to be explained and illustrated with the class before being given out to be studied."

There were many other writers of books of Natural Philosophy for the schools, but enough has been quoted to show the trend. In this connection it will be to the point to quote something from John Tyndall's lecture delivered in 1854 at the Royal Institution of Great Britain on "Physics as a Branch of Education for All."

"The needs and tendencies of human nature express themselves through the early yearnings of the child. He desires to know the character and the causes of the phenomena presented to him; and I claim for the study of Physics the recognition that it answers to an impulse implanted by nature in the human constitution, and he who would oppose such study must be prepared to exhibit the credentials which authorize him to contravene Nature's manifest design."

"Most of the questions asked by children concern natural phenomena, facts of everyday life. Now the fact is beyond the boy's control, and so certainly is the desire to know its cause. The sole question then is, Is this desire to be gratified or not? Who created the fact? Who implanted the desire? Certainly not man — and will any man undertake to place himself between the mind and the fact, and proclaim a divorce between them?"

"Every physician knows that something more than mere mechanical motion is comprehended under the idea of healthful exercise. What, for example, could be substituted for the jubilant shout of the playground? You may have more systematic motions. You may devise means for the more perfect traction of each particular muscle, but you cannot create the joy and gladness of the game, and where these are absent, the charm and the health of the exercise are gone. The case is similar with mental education."

"In the study of Physics, induction and deduction are perpetually married to each other."

The following is from Thorndike's *Principles of Teaching* (page 157):

"The verification of conclusions is the keynote of correct inductive thinking in the world at large, and should be more prominent in the school. The common practice of children is to accept as true whatever the teacher does not oppose. This is not so bad as it may seem, for 'to be accepted by the expert' is a sort of verification well known and not despised by science, and to the scholar the teacher stands '*in loco experti*' . . . and recourse to other authorities than the teacher provides useful experience of the bulk of expert knowledge which is stored up in dictionaries, encyclopedias, maps, books, and the like."

McMurry in his *Special Methods in Science*, after stating what have been the various aims in science teaching (such as: teaching observation; understanding and mastering the physical conditions of life-utility; mental discipline; classification — system and law), proposes as a suitable aim, *insight into nature, a sympathetic appreciation with a view to a growing adjustment to* the physical and social environment. He adds:

"The intrusive and masterful way in which natural science has been coming into our houses, factories, and industries of all sorts, compels us to pay considerable attention to the applications of science to life."

The idea which has been most consistently and uniformly expressed in all the prefaces of text-books already quoted is *vitalize the teaching of physics, teach its applications to life.* From examination of the texts themselves it appears to be in the minds of all of the authors that the method should be, first, teach the principles, and second, mention applications, as we teach rules of grammar and illustrate by giving sentences from literature. At any rate, so far as any attempt to actually teach the applications of physical principles to life is made, this is the method used and this is precisely why the teaching of physics is languishing. The number of so-called principles has been doubled and even quadrupled since the days of Ferguson and Arnott, and the colleges at present specify by syllabus a long list of those which the candidate must be able to demonstrate like propositions in geometry. The method of teaching physics — no matter how much laboratory work it may include — does not differ essentially from the method of teaching geometry. Only the case is worse for physics than for geometry. For in geometry, there is a mutual dependence of one proposition upon another, but in physics, in spite of the efforts of one or two authors to the contrary, there never has been, and I presume there never can be, an organized whole to physics which will appeal to the mind of a high-school pupil. The fundamental idea which may be assumed to run through it all will always be found too subtle and too profound for his comprehension. To him Boyle's law is never related to anything else in physics; and if on college entrance examination he does not state the law of Charles for that of Boyle, it is a sheer piece of good luck; for that matter, if he does not make up an entirely new law by stating parts of each, it is only his good fortune. And why should he remember the vast number of strange and unrelated facts or principles — unrelated to each other and unrelated to any experience in his life? Even the laboratory illustrations given him, ostensibly for the purpose of throwing light on the principles, are like an attempt to define one unknown word by another equally unfamiliar.

Black and Davis hold that one has always to keep in mind the capacities and limitations, the interests and inclinations, of young people. They say that in preparing their book they tried to select only those topics which are of vital interest to the young. Everybody, they assert, needs to know something about the working of the machinery which is found in modern homes.

Their plan is to begin each topic with some concrete illustration, familiar to young people, proceed to a deduction of the general principle, and then show how to make use of this principle by discussing other practical applications of it.

The study of physics, they believe, does not begin and end in the classroom, but is intimately connected with industrial and domestic life.

In order to stimulate in students thought and imagination about what they see, and to get them into the habit of asking intelligent questions of mechanics, artisans, and engineers whom they meet, the authors have added at the end of the chapters questions which require some knowledge gained in this way from outside life.

Now to illustrate each principle by referring it to some one of life's experiences would be a great step in advance, but to turn the method of procedure around and develop only such principles as grow out of and interpret life's experiences would be not only ideal but, in the nature of the case, the only method which can be successful.

One cannot help thinking that if the high-school teachers of the country had been as free to work out their method of instruction as the elementary-school teachers have been during the last twenty years, they would have learned to apply to physics the modern, yet abundantly tried and eminently successful, method of teaching language to small children.

This matter is so well stated by McMurry in his *Special Methods in Science* that I cannot do better than to quote him. It will be noticed that McMurry is here speaking of the teaching of science in the elementary school — what some call nature-study; but I am wholly in agreement with Professor Bailey that nature-study is not a new subject but a new mode of teaching, which is just as applicable to the high school and the college as to elementary schools.

"A child does not want the alphabet (that is, the simple principles) of science any more than he wants the names of the letters of the alphabet when learning to read."

"What he needs is to observe more closely and to put things together for better interpretation."

"There is another great advantage in teaching science where we find it in these centers of life's activity, and not in some isolated scientific form in laboratories or text-books."

"The child who draws his knowledge of science directly from life, under normal conditions, will not have much difficulty in finding it again in life and applying it to life. It is not difficult to so isolate the study of physics and chemistry from the usual conditions of life that the student in after years will have more difficulty in rediscovering his knowledge than he had in first acquiring it. But the child who learns from the start to trace facts to their native lair will recognize them again under similar surroundings. In the usual study of the natural sciences, each science centers its materials around its leading principle, but from the home as a center radiate problems into all the sciences. Ventilation is based on physics and physiology; cooking on chemistry and several other sciences. House sanitation draws from most of the sciences. Heating and lighting carry us into several fields of applied science. In later years he may devote himself to a study and ordering of one or more of the separate sciences, but their chief merit after all will be the service they are able to render to these original centers of human interest. If we should take each of the natural sciences as a controlling center of study, we should have a complicated and difficult, if not impossible, course of study. Elementary science more perhaps than any other study is home-abiding and begets respect and admiration for common things."

"As a rule teachers are over-hasty in urging children toward generalizations. They wish them to leap from one or two facts or examples to important conclusions of classifications."

"Teachers and adults are prone to give emphasis to general laws far beyond what children need."

"The applications of science to life have so transformed our surroundings that we live in a very different world from that of fifty years ago. To live properly in this new world is to understand it, to fit into it and to make the best use of it. Since the changes are due chiefly to scientific inventions and improvements, progress in education calls for a direct and more partial acquaintance with sciences by common people."

"The problem of object and experiment teaching is the most highly recommended and the least successfully practiced phase of instruction. The freedom and confidence with which teachers, high and low, recommend observational and experimental science, and the modesty and scarcity of those who succeed in such teaching is an illustration of the wide breach between enthusiastic theory and successful practice."

Dr. James E. Russell in the December, 1909, issue of the *Educational Review* says:

"Bookish work when properly understood is above criticism. In so far as the aim of learning is to acquire knowledge there is no good reason for spending an hour in manipulation when the fact may be as well taught without it in a minute."

I am very sure that a large portion of the hours now spent in the laboratory might with profit all around be contracted to an equal number of minutes spent with books, but better than that they might be much expanded and profitably expended in getting together, comparing, and explaining the experiences which pupils have or may have under proper guidance.

Let there be, however, vastly more — ten times as much — reading on the subject as now. Let there still be a laboratory for personal contact with things and for large measurements — pounds and feet — such as ordinary people use.

The quantitative treatment of the subject belongs quite as much to the lecture as to the laboratory. The process of vitalizing physics gets small assistance from the conventional laboratory work — indeed, the demonstration of physical principles is not much forwarded by the laboratory measurements. It is not only possible, but usual, that students lose the rationale of the whole subject under consideration by laboratory work which has lost none of its distractions in the recent attempts to make it rigorous.

I am sure that Draper was right when he said that the subjects with which to begin the teaching of physics are water and air. A considerable portion of that which usually precedes this subject should be omitted from a high-school course and much of the rest should be brought in incidentally and scattered among the other subjects. What remains might form a later chapter.

Suppose with a class in a city school we begin the work by taking up the problem — the very large problem — of supplying suitable water to people who dwell in a crowded community. New York, for example, needs more water than falls in the whole Croton watershed of 300 square miles. We must go as far as the Catskills to get a supply that is sufficiently abundant and sufficiently pure. The newspapers have set forth the facts and have said much about the engineering feats of this undertaking. The physics teacher must enable the future citizens to gain some idea of them. For example, the aqueduct must be carried under the Hudson, and in order to find a firm bottom it must go down 1100 feet below the water level of the river. Now the weight of that water is about 15 pounds per square inch for each 34 feet of depth, or about 45 pounds per square inch for each 100 feet of depth and therefore about 500 pounds per square inch at a depth of 1100 feet. The method of determining the ratio of pressure to depth should be quickly shown by a lecture experiment and it will naturally be often referred to afterward so as to be well understood and not easily forgotten.

I once lived in a house where although the water pressure was great the pipes were so small that not more than one faucet could be used successfully at one time. If some one was drawing water in the laundry-tubs, it was useless to try to get water to flow from the faucet at the bath-tub. Show this fall in pressure along a water pipe as an increasing number of faucets are opened, by putting a pressure gauge on one of the faucets and noting its behavior as each succeeding faucet is opened. Quite incidentally, compare this with the fall in potential along an electric circuit as additional lamps are turned on, and later refer to this again when teaching electricity. This continual cross reference and repetition is of the utmost importance. We do not learn things once for all.

Now this fall in pressure introduces our most difficult problem in the distribution of city water. Although our aqueduct will be a larger tube than the subway tunnel, and our city water mains are four or five feet in diameter, it will be very difficult to get the water to flow through them fast enough to meet the demand, and so pumps must be used to assist the flow. Our reservoir at High Bridge is about 150 feet above our basement at Teachers College. We go down into the basement and read the pressure gauge and find it only 30 pounds per square inch when it would be 67 pounds if we were the only persons to draw water from the mains. So great is the draught of water from the mains that the fall of pressure (fall of potential) is 37 (67–30) pounds per square inch in coming a little more than two miles. This fall in pressure has greatly increased as the city has grown up around us.

Within the building also the pressure on certain faucets has fallen from 8 pounds to 2 pounds per square inch because of the increase in the number of students and the consequent increase in the use of water.

It is quite similar with the electric conductors. The lamps of a certain lecture room once had 110 volts of electric pressure, whereas now they frequently have not more than 105 volts.

The time was when water would flow of its own accord at my lecture table on the fourth floor, but now it would seldom reach the second floor if it was not helped by a pump. The question of whether water presses equally in all directions will not be raised by the pupils at this point and had better not be injected too soon, but let attention be called to it incidentally a little later, not by the usual formal demonstration, but as a fact which has been demonstrated every time we have read the pressure gauge.

The physics teacher should teach hygiene quite as much as the biology teacher does, and he should teach chemistry whenever he gets a chance, whether he is nominally the chemistry teacher or not. The water filters demand his attention on all of these counts: What they mean to health; How they save the steam boilers; How they obviate plumbing difficulties; What alum is needed for; etc.

The physics teacher should teach about all sorts of mechanisms; as, for example, water meters, pressure gauges, etc. Buoyancy and Archimedes' principle will be suggested somewhere about this time, and should have many lecture-room demonstrations and many individual laboratory experiments to make the matter a real experience. Specific gravity is not worthy of all the attention that is now given to it. It had better not be brought into this chapter at all, and in any case it should not be treated in the minute way which is usual. This exceedingly simple matter is generally obscured by being mixed up with buoyancy and paraffined blocks and lead sinkers and whatnot, which have no natural connection with it. Many days are spent in working on experiments and on arithmetical problems apparently devised as "busy work" to "hold down" the students lest they play.

I was conversing recently with an intelligent builder about how much a certain wagonload of Georgia pine weighed, and he settled the matter by sawing off a block one foot long from a timber which was four inches square at the end, and weighing it. He found that the block weighed five pounds, and from this he quickly calculated the weight of his load. I remarked that he had incidentally found the specific gravity of the wood to be about three-quarters, and he said, "Well I should never have suspected that. When I studied physics we made that a very complex matter which I never understood."

I suggested to him that the fact that a cubic foot of water weighs 62.5 pounds and that spruce timber is usually about half as heavy, while granite and most other kinds of rock are about 2.5 as heavy as water, would be very useful to remember. For instance, this enables us to quickly calculate that a granite paving block 12 × 6 × 4 inches must weigh about 26 pounds, and that 200 of them would make a heavy load for a team of horses on a good road.

Some reader has by this time queried whether our intention is to amuse and entertain the pupils and to relax their work. My purpose is to get more work and more intelligent work than we find now in our school laboratories. If the work is of absorbing and compelling interest, so much the better. I like to see high-school pupils work. They like to work. Three-quarters of all the pupils who enter the high schools of this country drop out during the course because they are tired of loafing and want to go to work. Give them something worth while to do and they will remain in school to work.

In order that we may examine the action of pumps, traps, "back-air" pipes, pressure tanks, hydraulic elevators, injectors, gas meters, etc., etc., we need to get an appreciation that air has weight and exerts pressure much as water does, also that it expands indefinitely if pressure is removed from it. One hundred and fifty years ago people were just as curious about the atmosphere and its properties as we are now about radio-activity. Public lectures upon the subject were crowded. It took a long time for people to appreciate the fact that they were living in the midst of an atmosphere which had weight, occupied space to the exclusion of other matter, and in general behaved very much like water. Teachers to-day forget that their pupils require a long time to arrive at a working knowledge of these facts. They need many closely related experiences to render the knowledge real. A single experiment, a brief statement, is not enough. To show by a lecture experiment that air has weight and to tell the pupils that a cubic foot of the air that surrounds them weighs about an ounce and a quarter is well worth while, but the real truth of the matter will not be appreciated until the subject has been attacked many times and on many sides. The pupils need some physics readers or perhaps leaflets. Let me attempt to write here a sample chapter in the hope that many others will be persuaded to take up this sort of authorship until the material for teaching physics becomes as rich as that for teaching history and English now is.

The Air

Looking from the window of my lecture room I see powerful elm trees rocking in the wind. Certainly to bend them so far would require the power of many horses. How could anything by pushing against them move them so greatly unless it had a considerable weight? By roughly estimating the number of cubic feet I calculate that the air in this lecture room weighs two tons; and with my anemometer I find that the wind is blowing forty miles an hour at present, and even while I am saying this a large limb has just been torn from the trunk of one of the trees. What might one expect if, say, the two tons of air which is in this lecture room should move at the rate of forty miles an hour and strike against anything? If I roll these two rubber balls, which look alike to you, upon the floor and each comes in contact with the leg of a chair, you will readily infer from what you see that one is a hollow ball while the other is solid, for one is deflected from its course without moving the chair while the other carries the chair with it some distance. So when you see a freight car moving down the track to couple with another, you infer whether it is loaded or empty by the way it moves and by the power of its blow when it comes in contact with the other car. That is, our experience has taught us to feel that the damage which a moving body can do by collision depends very much upon its weight. This is why one might be willing to catch a light ball thrown at him when he would avoid a heavy one. But catching a ball suggests another consideration. One is willing to catch a ball thrown slowly when he would avoid one thrown swiftly, and we instinctively conclude something about the velocity of the wind by the work it will do. Hence I found its velocity by means of this little windmill with a cyclometer attached, called an anemometer. When we speak of the wind's blowing hard we are apt to think only of its velocity, and I suppose it would be natural to say that a forty-mile wind was blowing twice as hard as a twenty-mile wind. The fact is, however, that a forty-mile wind will push four times as hard against things as a twenty-mile wind does. Some definite figures will add to the interest of this study. When smoke ascends straight we say there is no wind. When the flags are just stretched out the wind is blowing ten or twelve miles an hour. It is not difficult to estimate a twenty-mile breeze by noting the movement of the smaller branches of trees, and a thirty-mile wind by noting the movement of the larger branches of the trees, and a forty-mile storm wind by the swaying of the whole trunks of trees. If one compares his estimates with the testimony of the anemometer for a time he will soon become quite adept. A ten-mile breeze will give half a pound per square foot of wind pressure for sailing. A twenty-mile breeze will furnish 2 pounds per square foot. A thirty-mile wind will give 4.5 pounds and a forty-mile gale will furnish 8 pounds. When you estimate the number of square feet in your sail and think of the number of pieces of lead ballast you are carrying it readily appears a dangerous wind for small boats. When the College was first built we had six window-panes which were too large for their thickness to withstand the wind pressure and one after another they smashed in until finally we saved the last of them by putting a sash across the middle. Our leaded glass windows are all of them more or less concaved by the wind pressure. The wind lifts buildings from their foundations, uproots trees, piles up great snow banks and great sand dunes, raises mighty waves with their tons of water *because air has weight.*

I should like to have you go with me and see a flywheel in our engine room. The rim of this wheel is moving at the rate of sixty miles per hour. Its surface is so smooth that you can let it rub against your hand without injury, in spite of its high velocity. Standing near it, as you now are, you feel a wind that makes you hold on to your hat. The air is very still in all the rest of the engine room. Now stand one side while I pour some water upon this wheel, and you note that the wall of the room is now getting spattered with that water. One reason why the surface of that wheel keeps so bright and clean is that the wheel itself throws off from its surface every bit of dirt which might come in contact with it. It is in like manner throwing off the air in constant streams. Does not this make one realize that air is a fluid like water, having weight — although invisible? There must also be friction between it and the wheel. I'll pour upon this wheel a steady stream of water and let you notice it leaving the wheel on the line of a tangent. The so-called "centrifugal force" causes things to fly away on a tangent rather than on a line leading directly from the center. If you try to use a sling you will need to know this fact. Or to state it still more in accordance with our natural experience, when the water gets in motion it tends to move in a straight line rather than around a curve. This flywheel suggests our ventilating fans, which we must look at while they are standing still. One of these wheels reminds one of a water wheel. One might imagine such a wheel well inclosed and revolving rapidly backward, throwing water from a lower reservoir up the "waterfall" back into the mill-pond. See Figure 1. If the wheel were perfectly smooth at its rim some considerable amount of water would be thrown up the flume by reason of the friction. But it must be perfectly evident that the flanges across the rim of the wheel serve still better to keep the stream of water from slipping backward. The result is that the stream of water tends to keep more nearly the velocity of the wheel — just as a chain belt working over a cog wheel does less slipping back than a leather belt.

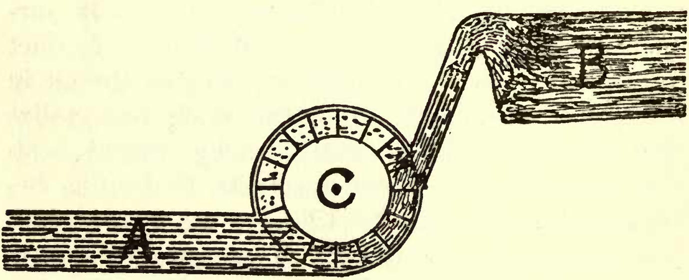

FIG. 1

Figure 1 represents fairly the construction of the first one of our ventilating fans which we come to on our trip about the building. A represents the intake of outdoor air, and B the ducts which distribute the air to the rooms of the building. Of course we shall return to this often when studying the heating, the filtering, and the humidifying of this air. The other ventilating fans about the building differ from each other in minor points, but chiefly they differ from this in that they take in the air at C instead of at A. The inlet ducts bring the air to the center of the wheels along the line of their axles. The wheels are of skeleton construction and the air is thrown out at B as before, simply because it has weight and tends to fly off on a tangent. It requires eighty horse-power to run the ventilating fans which push the air through the Horace Mann School building. This means that air has weight and offers resistance to motion. It costs about $50 a day just to push the air along, which fact seems appalling when looked at in that way, but that is only five cents a day for each pupil; and when we consider that 14,406 persons in New York State died of consumption in the year 1907 — that is, they died for want of fresh air — we must be willing to spend five cents a day for fresh air for each pupil in school.

Figure 1 also explains the construction of a "rotary" pump, a form of pump very much in use now not only for moving water but air, as particularly in the case of vacuum cleaners, one of which we will examine next. The hose is attached at A for "suction" or at B for blowing.

It must be evident that the stream of air is driven on by the *weight* of the air behind rather than by any such unthinkable thing as a *pull* or "suction." What the wheel, or pump, does is to push the air from before it and the weight of the atmosphere moves the air in from behind to keep the space full. We are at the bottom of an ocean of air, and we may best appreciate this condition by imagining ourselves at the bottom of an ocean of water, because it appeals to our senses more directly. If we did live at the bottom of an ocean of water 34 feet deep, the water would press upon us with the same weight that our atmosphere now presses. By means of this pressure gauge I will show you that the pressure of our atmosphere is 15 pounds per square inch. Of course the air is pressing upon all sides of the wheel of the vacuum cleaner and when the wheel moves it drives a stream of air exactly as it would water if submerged in that. We shall return to the vacuum cleaner again to study several features about it. But let us now recall an experience you may have had while riding in an automobile or an open trolley car. Let us suppose a quiet day, when the smoke rises straight upward (not, by the way, because it is without weight but because the air is heavier than it and pushes it up). Let us imagine, I say, a quiet day when there is no wind, and we will start our automobile at the rate of ten miles per hour. We are now pushing our way through this quiet air and we feel a resistance of half a pound per square foot. The effect is the same as it would be if we stood still in a ten-mile breeze. A small flag which we carry stands out in the same manner as it would in such a breeze. Now let us increase our speed to twenty miles per hour and hold our flag with two hands across our line of motion. We are now pushing against the air with a force of two pounds per square foot. At forty miles an hour we push eight pounds per square foot and at sixty miles per hour we push eighteen pounds per square foot, which splits our flag. If we could make it one hundred miles per hour we should feel the pressure of fifty pounds per square foot exactly as many persons have experienced it in a hurricane. This experience, upon reflection, makes one feel that air has weight and occupies space which it does not yield to other bodies without resistance.

A windmill operates because air has weight and pushes against it. If the windmill is 25 feet in diameter a fifteen-mile per hour breeze develops one horse-power. The propeller wheel of an aëroplane drives the plane forward because in its motion it pushes against the air, which offers the necessary resistance, even as water offers the necessary resistance to the propeller of a steamboat. The aëroplane lifts itself and its machinery and its passengers because its planes meet with the necessary resistance from the air as they cut it at an angle. The rising of a balloon must be looked upon as direct evidence that air has weight. The dirigible balloons which went up near the College a few months ago each contained about 7500 cubic feet of hydrogen. This pushed 7500 cubic feet of air out of its place. A cubic foot of air weighs 1.28 ounces, and it is about fourteen times as heavy as hydrogen. Hence the 7500 cubic feet of air displaced weighs about 544 pounds more than the hydrogen and therefore pushes the hydrogen up with that much force. Hence the bag of the balloon, the car, the engine, the man, and his baggage, all together equaled in weight not far from 500 pounds. Think how the fact that air is matter is illustrated by the inflated football, the pneumatic tires of automobiles, air mattresses and cushions, air cushions in door checks, air brakes, air guns, caissons, diving bells, machinery of all sorts moved by compressed air acting like steam. But lastly think of liquid air, which is merely ordinary air reduced by cold and by pressure to about $\frac{1}{800}$ part of its normal volume and which weighs a little more than water.

The following is a portion of a lecture by James Ferguson, F.R.S., on the "Spring of the Air" delivered some one hundred and fifty years ago. It is presented here as a good example of how the subject should be taught to-day — namely, by presenting the same phenomenon in many different ways.

To Show the Elasticity or Spring of the Air

14. Tie up a very small quantity of air in a bladder, and put it under a receiver; then exhaust the air out of the receiver; and the small quantity which is confined in the bladder (having nothing to act against it) will so expand itself by the force of its spring, as to fill the bladder as full as it could be blown of common air. But upon letting the air into the receiver again, it will overpower the air in the bladder, and press its sides almost close together.

15. If the bladder so tied up be put into a wooden box, and have 20 or 30 pound-weight of lead upon it in the box, and the box be covered with a close receiver; upon exhausting the air out of the receiver, that air which is confined in the bladder will so expand itself as to raise up all the lead by the force of its spring.

16. Take the glass ball mentioned in the fifth experiment, which was left full of water, all but a small bubble of air at top, and having set it with its neck downward into the empty phial *a a*, and covered it with a close receiver, exhaust the air out of the receiver, and the small bubble of air in the top of the ball will expand itself, so as to force all the water out of the ball into the phial.

17. Screw the pipe A B into the pump-plate, place the tall receiver G H upon the plate *c d*, as in the twelfth experiment, and exhaust the air out of the receiver; then turn the cock *e* to keep out the air, unscrew the pipe from the pump, and screw it into the mouth of the copper vessel C G (Fig. 15), the vessel having first been about half filled with water. Then open the cock *e* (Fig. 11), and the spring of the air which is confined in the copper vessel will force the water up through the pipe A B in a jet into the exhausted receiver, as strongly as it did by its pressure on the surface of the water in a bason, in the twelfth experiment.

18. If a fowl, a cat, rat, mouse, or bird, be put under a receiver, and the air be exhausted, the animal will be at first oppressed as with a great weight, then grow convulsed, and at last expire in all the agonies of a most bitter and cruel death. But as this experiment is too shocking to every spectator who has the least degree of humanity, we substitute a machine called the lungs-glass in place of the animal.

19. If a butterfly be suspended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhausted, though the animal will not die, and will continue to flutter its wings, it cannot remove itself from the place where it hangs in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.

20. Pour some quicksilver into the small bottle A, and screw the brass collar *r* of the tube B G into the brass neck *b* of the bottle, and the lower end of the tube will be immersed into the quicksilver, so that the air above the quicksilver in the bottle will be confined there, because it cannot get out about the joinings, nor can it be drawn out through the quicksilver into the tube. This tube is also open at top, and is to be covered with

the receiver G and large tube E F, which tube is fixed by brass collars to the receiver, and is closed at the top. This preparation being made, exhaust the air both out of the receiver and its tube; and the air will, by the same means, be exhausted out of the inner tube B C, through its open top at C; and as the receiver and tubes are exhausting, the air that is confined in the glass bottle A will so press by its spring upon the surface of the quicksilver, as to force it up in the inner tube as high as it was raised in the ninth experiment by the pressure of the atmosphere; which demonstrates that the spring of the air is equivalent to its weight.

21. Screw the end C of the pipe C D into the hole of the pump-plate, and turn all the three cocks *d*, G, and H, so as to open the communications between all the three pipes E, F, D C, and the hollow trunk A D. Then, cover the plates *g* and *h* with wet leathers, which have holes in their middle where the pipes open into the plates; and place the close receiver I upon the plate *g*; this done, shut the pipe F by turning the cock H, and exhaust the air out of the receiver I. Then, turn the cock *d* to shut out the air, unscrew the machine from the pump, and having screwed it to the wooden foot L put the receiver K upon the plate *h*; this receiver will continue loose on the plate as long as it keeps full of air; which it will do until the cock H be turned to open the communication between the pipes F and E, through the trunk A B; and then the air in the receiver K, having nothing to act against its spring, will run from K into I, until it be so divided between these receivers, as to be of equal density in both; and then they will be held down with equal forces to their plates by the pressure of the atmosphere; though each receiver will then be kept down but with one-half of the pressure upon it, that the receiver I had, when it was exhausted of air; because it has now one-half of the common air in it which filled the receiver K when it was set upon the plate; and therefore a force equal to half the force of the spring of common air, will act within the receivers against the whole pressure of the common air upon their outsides. This is called transferring the air out of one vessel into another.

22. Put a cork in the square phial A and fix it in with wax or cement; put the phial upon the pump-plate with the wire cage

B over it, and cover the cage with a close receiver. Then, exhaust the air out of the receiver, and the air that is corked up in the phial will break the phial by the force of its spring, because there is no air left on the outside of the phial to act against the air within it.

23. Put a shrivelled apple under a close receiver, and exhaust the air; then the spring of the air within the apple will plump it out so as to cause all the wrinkles to disappear; but upon letting the air into the receiver again, to press upon the apple, it will instantly return to its former decayed and shrivelled state.

24. Take a fresh egg, and cut off a little of the shell and film from its smallest end, then put the egg under a receiver, and pump out the air; upon this, all the contents in the egg will be forced out into the receiver, by the expansion of a small bubble of air contained in the greater end, between the shell and film.

25. Put some warm beer into a glass, and having set it on the pump, cover it with a close receiver, and then exhaust the air. While this is doing, and thereby the pressure more and more taken off from the beer in the glass, the air therein will expand itself, rising up in innumerable bubbles to the surface of the beer; and from thence it will be taken away with the other air in the receiver. When the receiver is nearly exhausted, the air in the beer, which could not disentangle itself quick enough to get off with the rest, will now expand itself so as to cause the beer to have all the appearance of boiling; and the greatest part of it will go over the glass.

Put some warm water into a glass, and put a bit of dry wainscot or other wood into the water. Then, cover the glass with a close receiver, and exhaust the air; upon this, the air in the wood having liberty to expand itself, will come out plentifully, and make all the water to bubble about the wood, especially about the ends, because the pores lie lengthwise. A cubic inch of dry wainscot has so much air in it, that it will continue bubbling for near half an hour together.

Compare this rich treatment of an interesting and important subject with the present practice of confining the instruction upon it to a single laboratory exercise to prove that $P \times V$ is a constant, leaving the pupil without any idea that Boyle's law is a matter of daily experience. Verily W. S. Franklin is quite right when he says:

"My experience is, most emphatically, that a student may measure a thing and know nothing at all about it and I believe that the present high-school courses in elementary physics in which quantitative laboratory work is so strongly emphasized are altogether bad. . . . I believe that physical sciences should be taught in the secondary schools with reference primarily to their practical applications. . . . I cannot endure a so-called knowledge of elementary science which does not relate to some actual physical condition or thing . . . either you must create an actual world of the unusual phenomena of nature by purchasing an elaborate and expensive equipment of scientific apparatus or, you must make use of the boy's everyday world of actual conditions and things."

Physics, as it is taught to-day, furnishes abundant material for an answer to Dr. Butler's question, "Is the present-day student brought understandingly and with ample introductory explanation into a new subject, or is he hurled into it and left to flounder helplessly until, not comprehending, he turns from it in disgust?" (*Educational Review*, Vol. 38, p. 519.)

Since Ferguson's time the world has made mighty advances in utilizing the "Spring of the Air," but in the matter of instructing the youth on that point we have gone backward. Why do we not show them the "pressure tank" connected with the hydraulic elevator which is perhaps in the school building? The last time we looked at ours, the pressure gauge stood at 90 pounds and the water gauge enabled us to estimate that the volume of the air had been reduced to about one-sixth of its normal volume. While we watched it the pressure rose and fell and the volume changed inversely — exact measurements upon this law are out of place in high school. So are all gas measurements with corrections for pressure and temperature changes. To show the relationship in round numbers is quite sufficient. A high-school pupil ought indeed to be taught the folly of one's saying that his bicycle tire burst because it was set in the sun. He ought to know that it would require a rise in temperature of nearly 500 degrees F. to double its volume if the pressure remained constant. He ought to know that a balloon did not "fall into the river because the chilly air of the river contracted its gas"; but to verify, with the usual ado, the accuracy of the laws of Boyle and Charles is out of place in the high school, not because the exercise is too difficult but because it crowds out things of much more importance. The high-school pupil should know that gas is measured for commercial purposes without reference to these corrections, and he ought to be able to estimate how insignificant the corrections would be in his gas bills, if they were made.

A similar illustration of how principles of physics may be well taught by calling attention to a large number of familiar experiences is to be found in Dr. Neil Arnott's book on *Natural Philosophy* written eighty years ago as follows:

Action and Reaction

If a man in one boat pull at the rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes, and resistances, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

A magnet and a piece of iron attract each other equally, whatever disproportion there is between the masses. If either be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same counterpoise will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and meet; but the little one would perform a greater part of the journey, in proportion to its littleness.

A man in a boat pulling a rope attached to a large ship, seems only to move the boat; but he really moves the ship a little, for a thousand men in a thousand boats, pulling simultaneously in the same way, would make the ship meet them halfway.

A pound of lead and the earth attract each other with equal force; but that force makes the lead approach sixteen feet in a second towards the earth, while the contrary motion of the earth is of course as much less than this as the earth is weightier than one pound, and is therefore unnoticed. Strictly, however, it is true, that even a feather falling lifts the earth towards it, and that a man jumping kicks the earth away.

A spring, unbending between two equal bodies, throws them off with equal velocity; if between bodies of different magnitudes, the velocity is greater in the smaller body, and in exact proportion to the smallness.

On firing a cannon, the gun recoils with as much motion or momentum in it as the ball has; but the momentum in the gun being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece will hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow guns, retards her motion; by firing from the stern she quickens it.

A ship firing a broadside, heels or inclines to the other side.

A vessel of water suspended by a cord hangs perpendicularly; but if a hole be opened on one side, so as to allow the water to jet out there, the vessel will be pushed to the other side by the reaction of the jet, and will so remain while it flows. If the hole be oblique, the vessel will turn round constantly.

A vessel of water placed upon a floating piece of plank, and allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steam-boat may be driven by making the engine pump or squirt water from the stern, instead of, as usual, moving paddle wheels. There is a loss of power, however, in this mode of applying it, as will be explained under the head of "Hydraulics."

A man floating in a small boat, and blowing strongly with a bellows toward the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

A sky-rocket ascends, because, after it is lighted, the lower part is always producing a large quantity of aeriform fluid, which, in expanding, presses not only on the air below, but also on the rocket above, and thus lifts it. The ascent is aided also by the recoil of the rocket from the part of its substance, which is constantly being shot downwards.

He was a foolish man who thought he had found the means of commanding always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern. The bellows and sails acted against each other, and there was no motion; indeed, in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man using an oar, or a steam-engine turning paddle wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force by the re-action of the water.

And a bird flying is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick, may be considered as compressing a spring between the earth and the end of his stick, which spring is therefore pushing up as much as he pushes down; and if, at the time, he were balanced in the scale of a weighing beam, he would find that he weighed just as much less as if he were pressing with his stick.

Thus an invalid, on a spring plank or chair, who causes his body to rise and fall through a great range, by a trifling downward pressure of his hand on a staff or on a table, and thus obtains the advantage of almost passive exercise, is really lifting himself while he presses downward.

When a child cries, on knocking his head against a table or a pane of glass, it is common to tell him, and it is true, that he has given as hard blows as he has received; although his philosophy, attending chiefly to results, probably blames the table for his head hurt, and his head for the glass broken.

The difference of momentum acquired in a fall of one foot or of several, is well known; the corresponding intensities of reaction are unpleasantly experienced by a man who, in sitting down, is quietly received into a chair, or who unexpectedly reaches the floor where he supposed a chair to be.

What motion the wind has given to a ship, it has itself lost, that is to say, the ship has re-acted on the moving air; as is seen when one vessel is becalmed under the lee of another.

When a billiard ball strikes directly another ball of equal size, it stops, and the second ball proceeds with the whole velocity which the first had — the action which imparts the new motion here being equal to the re-action which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and is as follows: The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed together with half the original velocity; but, as they are elastic, the touching parts at the moment supposed, are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion in the other.

If a billiard ball be propelled against the nearest one of a row of balls equal to itself, it comes to rest as in the last case described, while the farthest ball of the row darts off with its velocity, the intermediate balls having each received and transmitted the motion in a twinkling, without appearing themselves to move.

This method of treatment may be illustrated further by the following "projects," one on *Controlling Fires* and the other on *Eggs*.

Controlling Fires

During all the life of man upon the earth, down to even the last century, fires have been little understood. They have inspired awe and terror and have been objects of superstitious veneration.

It is to be noted that men know facts a long time before they acquire the habit of acting according to that knowledge. Do all people know that air makes the fire burn? How shall we interpret the following incident, which is typical of hundreds of others occurring daily?

"While preparing her husband's dinner on a gas-range in the kitchen of their home, Mrs. —— placed the sleeve of her dress too near the gas flame and was soon a mass of flames. As her husband reached the kitchen door he saw his wife run out into the hall screaming wildly. She ran down the stairway, shedding flaming fragments of her dress as she went. The husband did not overtake her until she had reached the hallway of the first floor, and was trying to open the door to go into the street. He rolled her on the floor, and stripped the remnants of the burning dress from her body. In the meantime the pieces of burning cloth had ignited the stair carpet between the second and third floors, and the hall began to fill with smoke. The other tenants were aroused, and while one went to summon an ambulance another turned in an alarm of fire. At the hospital Mrs. —— is said to be in a serious condition."

A most common headline in the daily news is *Burned in the Sight of Many*. Two recent accounts tell of women stepping upon matches upon the sidewalk, and while their clothes were in flame, not one of the onlookers knew what to do except to call a fire-engine or a policeman.

Little children whose clothes have caught fire are seized in the arms of distracted mothers who run about with them doing nothing but fanning the flames.

We continue to build costly structures of kindling wood on which as a matter of course we pay excessive rates of insurance, oblivious of the fact that a considerable number of these buildings become annually the funeral pyres of multitudes. Our annual loss by fire in the United States, including cost of fire departments and cost of insurance, exceeds two hundred million dollars, and is equal to that of all other countries combined.

The art of controlling fires requires that one should know how to build them, to regulate them, and to extinguish them at will. A fireman in a large building may save or waste many times his wages according as he understands the control of fires. It is a case where beyond all doubt the most expensive men are the cheapest.

The management of gas and gasoline engines requires first of all a knowledge of combustion. If each person had a practical knowledge of combustion, such as any person beyond the primary-school age may acquire, nine-tenths of the destructive fires would not occur, and half the fuel, now wasted by the ignorant stoking of stoves and furnaces, would be saved.

A course in chemistry may teach one to say "oxygen is a supporter of combustion" without adding anything to his stock of useful knowledge about combustion. He may increase his erudition by "O=16" and "Sp. gr.=1.1056" etc., without being any wiser to act in case of the house being on fire. Suppose we invert a bottle over a burning candle. The flame burns for a short time and then goes out. Lift the bottle, light the candle, and replace the bottle. The flame is immediately extinguished. Before the experiment the bottle contained air, which consists of nitrogen, etc., 80 per cent, and oxygen 20 per cent.; after the experiment it contained nitrogen, etc., 80 per cent, oxygen 15 per cent and carbon dioxide 5 per cent. The presence of the latter gas is shown by pouring a little lime-water into the bottle. Note that it turns the lime-water milk white. Air in which one-quarter of the oxygen has been replaced by carbon dioxide will extinguish a flame. It will also extinguish life. Hence a lantern is lowered into old wells to determine whether it would be safe for a man to descend into them. The air which comes from one's lungs is very nearly like that in the bottle after the above experiment. A bottleful of air from the lungs will extinguish a candle flame.

From the beginning of history to the time of the Swedish chemist Stahl, in the latter part of the seventeenth century, fire was considered an element. For about one hundred years previous to the researches of the French chemist Lavoisier, in 1878, it was believed that fuels were composed of ashes and a ghostly thing called phlogiston. Combustion according to this theory was the art of decomposing the fuels and setting free the phlogiston. We now know that fuels in burning unite with the oxygen of the air, forming new compounds. For example, when we burn in an ordinary furnace 15 tons of coal the furnace also consumes about 32 tons of oxygen from the air, and pours out into the air about 44 tons of carbon dioxide gas, leaving behind about 3 tons of ashes. These figures, although not exact, are intended to convey two ideas: (1) that combustion is a union of oxygen with fuels, and (2) that the process neither destroys nor creates matter, but merely changes combinations of matter. The oxygen is quite as much fuel as the coal is. It is very fortunate that the steamer has to carry only about one-third of the fuel it must burn, and fortunate that by far the largest part of the products of combustion dispose of themselves. Merely to shovel the coal into the furnace and the ashes out is a sufficiently large task.

In the case of the candle, and also in the case of the coal, water vapor is produced as a product of combustion along with the carbon dioxide. It may be noticed that when the bottle is first inverted over the candle a slight cloud of moisture forms upon the cool glass.

Breathe into a wide-mouthed bottle and notice first how the moisture gathers upon the sides of the glass. Afterwards add limewater to show the presence of the carbon dioxide produced.

Our foods correspond to fuels and we take in also oxygen as a food or a fuel. By a process analogous to combustion we cause oxygen to unite with these foods, producing water vapor, carbon dioxide, and heat for our bodies.

When a bottle of oxygen is placed over a burning candle, the candle of course burns brighter and longer but goes out before all the oxygen is exhausted. The contents of the bottle now acts as a fire extinguisher although it contains as much oxygen as ever. Part of the oxygen is now bound in chemical union with carbon from the candle, and the oxygen which is free does not constitute a sufficiently large portion of the whole to support combustion. The presence of carbon dioxide and water vapor may be shown as before.

As might be expected, many things burn vigorously in pure oxygen which burn but slowly or not at all in the air, since the air is greatly diluted oxygen. A thin strip of iron may be burned with great vigor in oxygen. The reddish-brown powder which will be found covering the sides of the bottle after the close of this experiment is iron rust. It weighs considerably more than the iron which was burned and the increase of weight represents the oxygen which was burned. Combustion and rusting differ only in the rapidity of the action. Combustion is rapid rusting, and rusting is slow combustion. Both are called oxidation and the products are called oxides.

The oxidation of our foods in our bodies is slow — more like rusting than combustion.

We cover iron with various things to prevent the oxygen of the air from rusting it. It is covered with tin in the tinware of the kitchen, with zinc in the case of "galvanized" iron, with nickel, with porcelain, with paint, with grease, with vaseline, etc.

Drop a match into a flask and warm the flask gently; the combustion of the match begins at its phosphorus end at a very low temperature. After the flame has gone out put the charred portion of the match into another flask and heat. It will be found to have a very much higher kindling temperature than before, but nevertheless it has a kindling temperature. Before matches were invented about one hundred years ago, people were greatly troubled to start a fire. It was so difficult to raise fuels to the kindling temperature that generally they preferred to keep a "seed of fire" over from one time to another, and would usually borrow fire from their neighbors rather than go to the trouble of starting a new one, which must be done by striking sparks with a flint and file and igniting tinder.

Explosive mixtures. Fill a 32-ounce narrow-mouthed bottle with a mixture of one part illuminating gas to five parts of air. Explode. Try other proportions and see how narrow is the limit for explosion. Note that in the case of an explosion the flame shoots through the whole mass instantly, each small portion of gas having next to it the oxygen necessary for combustion, and the burning of any part heats the neighboring parts to their kindling temperature. The kindling temperature of the mixture is about as hot as red-hot iron. Our experience teaches us that gas may leak into the air until the odor is very strong without its being possible to explode it with a flame. The fact is that if, in a mixture of gas and air, the gas constitutes much less than one-seventh or more than one-fifth of the mixture an explosion cannot take place. When the best proportions are reached the color of the flame during explosion is blue like that of a gas stove or a Bunsen burner.

In a 32-ounce narrow-mouthed bottle put four drops of gasoline; cork and let it mix with the air in the bottle and finally explode it. It will be found that a drop or two more or less will prevent the explosion. If less, nothing will happen; if more, the contents of the bottle will quietly burn at the mouth.

It is a marvel that a small two-horse-power marine engine may explode 1000 times a minute, when it is considered that for each explosion 4 drops of gasoline must be vaporized, the vapor must be thoroughly mixed with about one quart of air, the products of the previous explosion must be swept out of the cylinder, the fresh mixture must be taken in and compressed to about one-fifth of its original volume, and at the right instant an electric spark must be produced to raise a portion of the mixture to its kindling temperature. When one considers that all of this must be repeated one thousand times a minute, it is not strange that those who first proposed such a machine were considered erratic.

Try four drops of kerosene in place of the gasoline. It will not explode, simply because kerosene is not volatile at ordinary temperature and, in spite of all we hear to the contrary, *kerosene lamps do not explode.* Now place the bottle containing four drops of kerosene and air in a kettle of hot water heated to at least 150 degrees F., and at that temperature the kerosene will be found to be volatile like gasoline. After a few minutes it may be exploded. Gas stoves, Bunsen burners, and Welsbach lamps are all devices for getting as near to the explosive mixture as possible without quite reaching it. When the mixture comes within the narrow limits of from 14 per cent to 20 per cent gas, the flame "strikes back." If the proportion of gas is much above 20 per cent the flame becomes yellow and is not so hot. A larger supply of air is needed to give more perfect combustion and therefore more heat and no formation of smoke or other partially burned products.

The purpose of all draughts and dampers about stoves and furnaces is to regulate the supply of air and therefore the rate of combustion.

Teachers College is now (1910) burning 6500 tons of coal a year. The engines and radiators call for a certain number of heat units per year. A little bad management of the fires might result in sending the products of combustion up the chimney half burned and require double the consumption of coal to produce the same result. The coal bill would then of course be increased about $15,000, and this is not the whole story, but enough for our present purpose.

In fighting a fire at its start, the one thing to do is to make it smother itself as the candle did in the bottle in our first experiment. An ordinary living room does not contain oxygen enough to burn up five pounds of wood. If the doors and windows are closed perfectly tight, a fire burning in a pile of dry kindlings in such a room will smolder for a time and go out precisely as the candle did in the bottle of the first experiment.

Some years ago I had the good fortune to hold in check for two hours a fire which had started upon a pile of kindlings in the basement of a school building full of pupils. The fire had a good start before it was discovered and the pile of kindlings was large. When the windows and doors were closed it smoldered down, almost checked by its own smoke, but enough air leaked into the room to keep a seed of fire, which started up into a lively blaze whenever the door was opened. There was no water except such as might be brought in pails. Having marshaled out the pupils, we gathered a good many pails of water in the room above and prepared to cut a hole through the floor with an ax, knowing that the moment the hole was cut our water must completely extinguish the fire, or it would envelop the whole building in flames very quickly. The hole was cut, the water was successfully applied and the fire was extinguished, when it was found that although a considerable portion of the kindlings had been blackened, none had been thoroughly charred.

This experience should be compared with another in which a fire was discovered in the early morning in the basement of an apartment house. The maid in the basement rushed outdoors, leaving the door open, and shouted "Fire!" Those upstairs, when they attempted to descend, found smoke in the halls, and returned to open their windows and shout "Fire!" Before the fire department could arrive the building was in flames and eight persons were burned to death.

In an iron kettle, put some gasoline and set fire to it. When the flame is burning high, lay over it the pot lid. The fire is instantly extinguished because, no matter how combustible it is, it cannot burn without the requisite oxygen. Compare this with what happened not long ago. A woman was heating a pot of fat for frying crullers, when it took fire. She heroically seized the flaming pot by its bail and rushed to the sink and turned into the burning fat a stream of water which of course went to the bottom, floated the fat, and distributed the fire all over the kitchen.

A burning kerosene lamp was upset in the midst of books and paper piled upon a library table. No one was home but children. The oldest boy ordered his younger brothers and sisters to bring him all the rugs they could lay hold of. He stationed one child to keep the library door shut, while he, holding his breath, rushed in and laid a rug over the fire and came out to get a breath of fresh air. This performance was repeated until the fire was entirely out.

A little girl was playing on the lawn near where her brothers were celebrating the Fourth of July, when a firecracker, thrown into her lap, set fire to her dress. Her mother, who was looking on from the piazza, caught her in her arms and rushed with her into the house, where the fire was finally extinguished, but not until the child had been fatally burned.

A four-year-old girl played with a match until it took fire, and in her fright she dropped it into her lap. No one was in the room with her at the time, but soon after her mother came in and found the child holding her dress gathered into a tight wad in her lap. When she induced her to release it she found a hole nearly a foot square burned out of the front of the dress, but no other damage done — not even were the little hands burned at all. She had many times been taught what to do if her clothes caught fire.

Most fire extinguishers are devices for producing carbon dioxide. With this they smother small fires by pouring into the atmosphere around them enough of the gas to reduce the proportion of oxygen below 15 per cent.

Streams of water, when thrown in sufficient quantity, as by fire engines, extinguish large fires both by cooling the fuel below its kindling temperature and by diluting the air with steam until the proportion of oxygen falls below 15 per cent.

One of the most effective ways of extinguishing a fire is to separate the burning fuel into small portions. Thus a considerable fire in a fireplace may be quickly extinguished by merely distributing apart from each other the burning embers. Their mutual heat is required to keep them above the kindling temperature. A shovelful of burning coals when taken from the furnace soon cool below their kindling temperature. The heat of the rest of the coal is necessary to keep them burning.

The fireman's ax and pick enable him to extinguish fire by separating in small pieces the burning parts of wood in floor or wainscot of buildings. When thus treated, the wood soon falls below its kindling temperature.

Eggs

Problems to be solved by the pupils, mostly by experiments at home or in the laboratory.

May we determine the age of an egg by its specific gravity? Procure an egg laid within 24 hours. Write its date upon it and place a number upon it to designate it. Attach a thread to its large end by a little sealing wax. (If you cannot think why it should be attached to the large end rather than the small end, try it attached to the small end and continue with it so until you get an answer to the question.) Find the specific gravity of the egg and weigh it each day thereafter for a month or six weeks. The egg may be kept in the laboratory or any living room all this time. See if you note any connection between the weight of the egg and the state of the weather each day. Some of our records are as follows:

Egg No. 6, Feb. 3, 1909. Wt. in air, 60.17 gms. Wt. in water, 3.35 gms. Sp. Gr. 1.059.

Feb. 4	Weight 59.94	Loss .23	clear
Feb. 5	Weight 59.74	Loss .20	clear
Feb. 6	Weight 59.58	Loss .16	rainy
Feb. 7	Weight 59.37	Loss .21	clear
Feb. 8	Weight 59.25	Loss .12	damp
Feb. 9	Weight 59.05	Loss .20	clear
Feb. 10	Weight 58.88	Loss .17	humid
Feb. 11	Weight 58.66	Loss .22	clear
Feb. 12	Weight 58.45	Loss .21	clear
Feb. 13	Weight 58.30	Loss .15	stormy
Feb. 14	Weight 58.14	Loss .16	stormy
Feb. 15	Weight 57.97	Loss .17	stormy
Feb. 16	Weight 57.82	Loss .15	stormy
Feb. 17	Weight 57.59	Loss .23	clear
Feb. 18	Weight 57.39	Loss .20	clear
Feb. 19	Weight 57.22	Loss .17	clear
Feb. 20	Weight 57.08	Loss .14	damp
Feb. 21	Weight 56.93	Loss .15	damp
Feb. 22	Weight 56.78	Loss .15	damp

On Feb. 22d it floated on water. It was not dipped in water after Feb. 3d. The date when this egg was laid was not known.

On clear days it lost more than on damp days.

This egg was broken on Feb. 24th and appeared to be perfectly fresh. It was allowed to dry naturally for two days and then was rubbed up to a powder, which is still in good condition (Jan. 12, 1910).

Egg No. 1, laid Feb. 25, 1909. Wt. 58.62 gms. Wt. in water, 6.06 gms. Sp. Gr. 1.115. On April 7th it weighed 52.46 gms. and floated on water. It lost an average of .15 gm. a day and required 41 days for it to become light enough to float. It was a yellow egg and apparently rather thick shelled.

Grocers report that yellow eggs are preferred in the Boston market and white eggs are preferred in the New York market.

Egg No. 2. Wt. 53.72. Sp. Gr. 1.096. Average loss in wt. per day .17 gm. Floated in 28 days.

Egg No. 3. Wt. 44.89. Sp. Gr. 1.091. Average loss in wt. per day .1 gm. Floated in 34 days.

Egg No. 4. Wt. 62.06. Sp. Gr. 1.098. Average loss in wt. per day .15 gm. Floated in 37 days.

Eggs Nos. 1 to 4 were all laid within 24 hours of the beginning of the experiments with them.

These eggs differ so much in specific gravity (from 1.091 to 1.115) and the rate of evaporation from them is so different (from .11 to .17) that the age could not have been told at all closely by the specific gravity. This much, however, may be concluded from our experiments: all fresh eggs sink in water. Eggs which float in water are at least a month or six weeks old and have been kept in a dry room (except that infected eggs may spoil in a fortnight, generate hydrogen sulphide gas, and float). Eggs which are not infected (and few appear to be) do not spoil. They simply dry up. The air space appears at the big end and grows larger and larger.

The average egg must lose about 5 gms. before it will float, and this will require about five weeks in dry atmosphere. Eggs may be kept in moist atmosphere without losing weight, or put to soak in water and again recover weight which they may have lost.

Eggs are sometimes dipped in a diluted solution of water-glass to prevent evaporation and also to prevent infection. Some persons preserve them by dipping them in boiling water for a second.

A newly laid egg not only sinks in water but lies down flat on its side. After a week or two, if it is kept in dry air, the large end will rise a little when it is put in water, on account of the development of the air space in that end. In three or four weeks it will stand on its small end at the bottom of a tumbler of water. In four to six weeks it will float on water. An egg that is recently laid will sink in a solution of one teaspoonful of salt in a tumbler of water.

Put hydrochloric acid upon a piece of eggshell. Pass the gas into limewater. Put some white of egg into alcohol. Find the temperature at which the white of an egg coagulates. Heat some white of egg in a test tube with a strip of lead paper at its mouth. Action on silver spoons. Why does a dropped egg cook quicker than an egg in the shell? How does it happen that an egg put into boiling water in a small cup to cook four minutes is soft boiled while if put into a large vessel of boiling water for the same time may be well done? Dissolve out some of the fat from the yolk of an egg by means of ether. Produce some black charcoal from the white of an egg. Weigh the white of an egg in an evaporating dish. Let it dry two days and when it is thoroughly dry weigh again to find out what proportion of it was water.

VIII

WHAT SPECIALIZATION HAS DONE FOR PHYSICS TEACHING[1]

In his presidential address before the British Association last summer Sir J. J. Thomson, speaking of overspecialization at Cambridge University, said:

"Premature specialization injures the student by depriving him of adequate literary culture. . . . It retards the progress of science by tending to isolate one science from another. The boundaries between the sciences are arbitrary, and tend to disappear as science progresses. The principles of one science often find most striking and suggestive illustrations in the phenomena of another."

It is time to inquire whether early specialization among undergraduates in American colleges is unfitting them both for research and for teaching. The theory still prevails in college that it is good to know more than one thing, otherwise there would be no minors, but minors, according to our closely differentiated scheme, are little else than divisions of the major subject. The result appears to be that we are producing graduates whose outlook is too limited to enable them to carry on a piece of original research. They become research assist-

[1] Read before sections B and L, American Association for the Advancement of Science, Boston, December 31, 1909.

ants with little prospect of ever being very successful at independent work.

L. H. Baekeland in *Science*, Vol. 25, p. 845, says:

"I challenge you to name any truly great man who was merely a specialist. . . . One-sided pursuits are apt to make us very narrow-minded. . . . Overspecialized science is apt to degenerate into a mere hobby where all conception of true proportions and harmony are lost."

The evil of early specialization is particularly apparent when we consider the cause of education — especially that within the college walls. Not only has the régime signally failed to qualify young men for teaching, but there has grown up along with it a distaste for and even a disrespect for teaching. There are about 150,000 undergraduate students who annually contract with the colleges of the land for instruction, but no one seems to want to teach them. The colleges announce a full staff of instructors — the title still remains — but it is difficult to find a college instructor, educated within the last ten or fifteen years, who makes it his chief interest to teach or who likes to acknowledge that it is his chief business. When asked what he is doing he tries to think of some little piece of research, however insignificant, and he shows impatience and evident embarrassment if obliged to say that he is engaged chiefly in teaching.

President Hadley of Yale, speaking at Johns Hopkins University, February 22, 1909, on "The Danger of Overspecialization," said:

"It is not enough to discover truth, we must make it known among the citizens of this self-governing commonwealth. The college is ceasing to have the influence which it ought to have upon the world."

From the New York *Times*, December 20, 1909:

"President Lowell, of Harvard, has expressed himself as heartily in favor of bringing the college course nearer to the practical concerns of the community. 'A university,' he says, 'to be of any great value, must grow out of the community in which it lives and must be in absolute touch with the community, doing all the good it can and doing what the community needs. Any institution which is not in absolutely close touch with the community about it is doomed to wither and die.'"

New York State, which is typical, has about 800 high schools and probably there are not a dozen teachers outside of New York City who are employed in these high schools to teach physics alone. Still, when a young man goes to college with the intention of fitting himself to teach in one of those high schools he is compelled to choose a major subject, and if it be physics, for example, his adviser will steer him through a course so highly specialized in physics and so devoid of other things that he is quite unfit to teach anything, and especially a general beginners' course. Among the courses in physics which he takes none will have reference to the experiences of life, but each will be a distinct attempt to prepare for the next technical course beyond. Even if his duty was to teach physics alone he would not know enough about chemistry and other allied sciences to teach physics properly. But what does the college course do for the 750 high schools of New York State in which one person has to teach all the sciences? Or what does it do for the

570 high schools which have only three teachers, or less, apiece, and in which some one has to teach more than all the sciences? No one, however, can visit many of these schools without reaching the conclusion that some of them have excellent physics teaching. In some cases the credit for this is due to the state normal schools, and in some schools the physics teaching appears to be good because they are not trying to fit for college.

One cannot read the papers of to-day without feeling that the community is on the point of making great changes in its educational institutions. It appears to want undergraduate students to take general courses in several sciences. It wants these courses to be far more general than any courses now are. It will doubtless insist that these courses shall be given by men who can teach, and who are willing to devote their best efforts to it. A generation or so ago the greatest men in all the colleges were great teachers. With the establishment of universities and the encouragement of research came the decadence of teaching. It is to be hoped that both research and teaching will be fostered in the future. If, however, things go on as at present, it seems probable that the revival of teaching will be brought about by separating the research function from that of teaching.

Our present scheme of science teaching was founded upon educational theories which are not now entertained. We thought that by drill we could develop certain faculties which would functionize in other fields when called upon to do so. Whatever faculties the college teacher thought his pupils ought to have, these he made it the duty of the high-school teacher to produce. We thought high-school pupils might be trained in observation, in accuracy, etc. We thought they might be equipped with a catalogue of fundamental principles and laws, the use of which might appear when they got to college. We thought it possible to teach one single science *thoroughly*, and we said much about teaching pupils to be scientific by concentration upon one thing and we spoke slightingly of the general courses. It now seems probable that a man trained to conservatism in one field is no less likely to be a wild-cat in some other field. It has been pointed out that in matters of education, and particularly in the matter of prescribing work for the high schools, the college physicists have been strangely unscientific, dealing with snap judgments when reliable data were not at hand; prescribing out of ignorance where a council of doctors would have been baffled. Who knows that the high-school pupil has reached the time of life when he can be trained in exact science without doing him violence? The community wants its young people informed about the interpretations which may be put upon the phenomena and experiences of daily life. The attempt to make pupils scientific before their time may prevent their ever becoming scientific. Intolerance of those who have the gift of imagination may lead one to try to suppress a Davy or a Maxwell.

Public dissatisfaction with the teaching of to-day is expressed by many. Let me quote a few.

L. B. Avery, of California:

"Physics is the most fundamental in its conceptions and the most practical in its applications of all the sciences. The proposition to leave any portion of those who take a complete high school course with no knowledge of it is in itself a complete acknowledgment of the educational inadequacy of the present methods."

L. H. Bailey, of Cornell:

"Distinguish between the teaching function and the research function. We are teachers. It is our business to open the minds of the young to the facts of science. . . . Nature study is a new mode of teaching, not a new subject. It is just as applicable to the college as to the common school. . . . We should be interested more in the student than in the science."

T. M. Balliet, of New York University, in *School Review*, Vol. 16, p. 217, has an exceedingly good article, but too long to quote, on "The [evil] Influence of Present Methods of Graduate Instruction on the Teaching in Secondary Schools."

W. S. Franklin, of Lehigh:

"My experience is, most emphatically, that a student may measure a thing and know nothing at all about it and I believe that the present high school courses in elementary physics in which quantitative laboratory work is so strongly emphasized, are altogether bad. . . . I believe that physical sciences should be taught in the secondary schools with reference primarily to their practical applications. . . . I cannot endure a so-called knowledge of elementary science which does not relate to some actual physical condition or thing. . . . Either you must create an actual world of the unusual phenomena of nature by purchasing an elaborate and expensive equipment of scientific apparatus, or you must make use of the boy's everyday world of actual conditions and things."

David Starr Jordan, of Leland Stanford University:

"For colleges to specify certain classes of subjects regardless of the real interest of the secondary schools and their pupils is a species of impertinence which only tradition justifies. . . . In general, the high-school graduate who has a training worth while in the conduct of life is also well fitted to enter college for further training. The average American boy quits the high school in disgust because he cannot interpret its work in terms of life."

S. V. Kellerman:

"Only by teaching honestly what the world needs, and can use, may the schools accomplish their lofty aims."

No one has stated the dissatisfaction with present practices more justly than Principal W. D. Lewis in the *Outlook*, December 11, 1909, in an article entitled "College Domination of High Schools," from which I make an extract or two.

"The high school is failing in its mission because its methods and scope of instruction are determined by college entrance examinations made by specialists whose point of view is not the welfare of the student, but the (supposed) requirements for advanced study of certain subjects. . . . Our present college-dictated high-school course is ill adapted to the real needs of the people in that it places the emphasis on the wrong subjects, and practically eliminates those that would be of the greatest practical value in the lives of the vast majority of pupils whose only opportunity for higher education is in the public high school. No less destructive of the welfare of the masses is the limitation in method of treatment of the subjects taught. . . . College teachers have written the courses, trained the teachers, set the examinations, and execrated the results."

IX

THE SIGNIFICANCE OF THE REQUIREMENTS IN PHYSICS OF THE COLLEGE ENTRANCE EXAMINATION BOARD[1]

PHYSICS is poorly taught in the colleges — quite as poorly taught in the colleges as in the high schools.

The duty of fitting the colleges for the high-school graduates is quite as urgent as that of fitting the high-school pupils for the colleges.

The colleges should prepare teachers of physics for the high schools but those who are most recently come from college are the most conspicuously unfit for teaching high-school pupils.

These conditions must be kept in mind when preparing a syllabus of work for high schools.

By years of contact with high-school problems some college graduates who are capable of adaptation have been transmuted into good teachers of physics. Such were the six high-school men chosen by the College Entrance Examination Board to prepare the present syllabus.

With the clear understanding of conditions as they exist at present, they did the wisest thing that

[1] Read before the New York Schoolmasters' Association, November 13, 1909.

could be done under the circumstances. Education must be a conservative thing. Changes must not amount to a revolution. What these men did was a step in the right direction, and a sufficiently long step to be practicable, yet it is not the end of progress toward better things, it is merely a small beginning.

It is worth while to remind ourselves that the so-called College Entrance Board is not in reality a college entrance board. It is merely an examination bureau. It has gradually succeeded in getting its certificate accepted for entrance by most of the colleges just as the regents of the state of New York have done, but unlike the regents this board could not continue to exist if its requirements on examinations did not conform pretty closely to what the colleges demand. Its real name is, The College Entrance Examination Board — with the emphasis on examination. By calling it as we do, for short, the College Entrance Board, we sometimes mislead ourselves as to its importance. It cannot be expected to be so much a leader as a follower in educational progress. The committee was well aware of the restricted functions of the board and therefore committed it to no embarrassing position.

On the other hand, this board as an exponent of the colleges makes it known that the colleges have now for the first time become ready to recognize the fact that the high schools are better able than the colleges to determine what should be expected of high-school pupils. It behooves the high schools to get ready for some constructive work and to take a step forward each year in the matter of these physics requirements.

Let us first examine the report of this committee and see what changes they have made and then consider the next changes which should be contemplated.

The greatest hindrance to good teaching is not the syllabus. That, like all codes of law, is capable of many interpretations and may by exegesis be made to justify all practices; not the examiners, for under the régime of the College Entrance Examination Board they have usually been broad-minded men, and at any rate their sole function is to frame questions — which again are capable of many interpretations — but the real block upon high-school teaching is the readers and raters of examination papers and laboratory notebooks. These men are a law unto themselves and their rules of conduct have never been published. It is certain that they have not the same outlook upon education as the board has or as its examiners have, and it is equally certain that they exert ten times as much power as either the board or the examiners in shaping the high-school work.

The most unsatisfactory part of the physics requirement (or supposed requirement) has been the laboratory work. I say, supposed requirement, for probably no one in any position to *require* has ever wished for such extremities of mathematical frivolities as many of the recent offshoots from the colleges have vainly tried to implant in high-school laboratories. As usual the disciples in trying to imitate their masters have greatly exaggerated their foibles. Unconscious that what is bad for college students is worse for high-school pupils, they have seized upon what was either evil or without significance in their own college laboratory work and wrung interminable changes upon it for high-school pupils.

The real laboratory requirements, however, as executed by the readers have been a great handicap to good teaching. The reader's interpretation of what an orthodox laboratory notebook should be has never been authorized and never published. From the record of success and failures of their candidates the high-school teachers have inferred that the readers insisted upon the notebooks containing much of that which I should regard as not physics at all. The high-school teachers have likewise found that small credit would be given to that which this committee declares is the very aim of laboratory work, namely, "to supplement the pupil's fund of concrete knowledge and to furnish forceful illustrations of fundamental principles and their practical applications. To perform exercises such as yield results capable of ready interpretation and free from the disguise of unintelligible units. . . . Unnecessary mathematical difficulties being avoided and care being exercised to prevent the student's losing sight of the concrete facts, in the multiplication of symbols."

Most of the unjust rating of candidates for admission to college has been the result of the absurd attempt of human minds not widely trained to estimate the value of the laboratory work of a total stranger by glancing over in four minutes the notes which required a year in the writing. No demand has been more insistent than that this abuse be stopped. A majority of that committee of high-school men went into the meeting fully determined that it must be stopped.

The first and most important reform which they have brought about is that the College Entrance Examination Board will no longer undertake the marking or examination of laboratory notebooks. The high-school teacher is to certificate the laboratory work wholly according to his best judgment. It is no longer indicated to him by the syllabus what shall be the nature of the laboratory work.

It will doubtless need to be that which will best help the pupils to pass the topical examinations, but I estimate that fully one-half of the time now given to laboratory work in many of the best schools does nothing toward helping the students to pass the examination questions and does nothing toward giving them a clearer understanding of physical principles. Since half of the time given to the study of physics in these schools is devoted to the laboratory the way is now open for them to save one-quarter of their efforts for work that is worth while. If the committee had done nothing else than to abolish the rating of laboratory notebooks by readers, we could easily have been satisfied for one year. For now there is no reason why a capable teacher may not make all of his laboratory teaching fruitful. Before, much of it had to be barren by specific requirement.

In the number of topics which appear in the syllabus the committee left a larger prescription than the high-school teacher can do well — but it probably did all the pruning that it was safe to do this time. The most efficient teachers are the ones who will see the largest possibilities in each topic for instruction and will therefore feel the greatest burden. Many complaints from such persons are coming in, and now that the high-school teachers have their hand in they will doubtless bring about a reduction in the number of topics when the syllabus is next revised. The committee probably had in mind that the field was too broad to cover thoroughly when they made their second recommendation, which reads as follows:

"We urge upon those who prepare the examination questions that these be so planned that students who have received fair preparation on the work as here outlined may reasonably be expected to pass."

This sounds very different from the boast which has been made that after casting out one-third of each class during the four years of the high-school course we serve the cause still further by knocking out half of those who try for admission to college. This committee of high-school men speaks with some of the missionary spirit appropriate to those who in the service of the people are trying to extend the benefits of education.

It is not expected, I presume, that I should discuss with this audience the specific additions or omissions in the list of topics. You care not, I presume, whether $f = ma$ is included or excluded. Yet I must tell you that a considerable amount of such pestiferous knowledge has been removed from the syllabus.

Now a few words as to the future. I am speaking to an audience composed of principals of secondary schools and of the teachers of all the various high-school subjects. We all have, however, a common cause, and it is upon our common problems that I wish to speak. The same thing is the matter with physics teaching as with all other subjects. I saw a young college graduate teaching a high-school class in English. She had detained them six weeks on the first third of *Ivanhoe*, using the method of the higher criticism. She informed me that it was the only way to get them ready for college. Which is true. It is also true that it was the only way she knew for teaching *Ivanhoe*, and for both of these the colleges are to blame, but, worse than all, when after attending educational meetings and reading educational literature and having a few years' more contact with the high-school pupils she learns a better way of teaching *Ivanhoe*, she will be prevented by college requirements from using it, unless the high-school men reform the requirements.

I saw another college graduate teaching botany in a Western high school — a school accredited by the state university. They had for many weeks been examining plant cells with a compound microscope and filling many pages of notebooks with drawings of them. I asked if so much of this work were desirable. She said, "No, but the university inspector requires it." There was lying upon her desk a copy of Bailey's Botany, full of useful knowledge such as those high-school pupils need. I asked her if it would not be better to give them that. She said, "The university would not approve it." It perhaps should be said in justice to the universities that such approval or disapproval generally comes from a minor officer — but so long as the universities allow their minor officers to act as their spokesmen they cannot escape the charge of being either ignorant of or indifferent to the cause of secondary education. These are not peculiar cases. There is no subject which can be well taught in the high schools to-day for the simple reason that the colleges prevent it.

The case of high-school physics to-day is analogous to a situation which obtained for Latin thirty years ago. It was the practice of some teachers then to spend two or three weeks previous to the teaching of Virgil in training pupils in the rules of the grammar which applied to scanning poetry. These rules with their exceptions numbered several score. They were learned, "and stored in memory so that pupils might have them to use when they came to the business of reading Virgil." It often happened that Virgil was taught by another teacher and frequently this teacher made no mention of scanning, but of course if he did, he discovered no ability in the class to use those rules of grammar. This is precisely the case of high-school physics to-day. The high-school teacher feels obliged to teach what might be very well called the rules of physical grammar. Some teachers know that language teaching must come before grammar, but the real powers that prescribe the work for all teachers, good and bad alike, have not yet got beyond the a-b, ab method of teaching. After compelling the high-school teachers to teach by an impossible method and one long since discredited in other subjects, these college people are surprised to find that the high-school pupils do not understand physics.

This topical syllabus is a list of principles. A few teachers are urging that some practical applications be added, as if to say, "Some few sentences from good literature should be appended to interpret the rules of grammar," but for every one teacher who dares to suggest this a dozen will respond, "We have not time to teach applications, the list of principles is so long, and in any case we cannot teach applications before we teach principles." And the readers of examination papers on their part say, "We cannot rate questions on applications of principles; they are too indefinite; we must mark on the principles and particularly on the mathematical work, for that is definite." The examiners have on several occasions attempted to encourage teachers to enrich their work in physics by asking some general question about, say, the heating of buildings. Such questions cause great perplexity to the readers, and they decide by conference what specific answer will be given full credit and allow nothing for any other. As, for example, if the candidate explains specific heat in answer to the above question, it will be rated correct; but a paragraph or a page of other replies, however intelligent, will be rejected without credit.

The makers of the syllabus and of the examination questions are still further moved to eliminate applications because applications in physics must of necessity vary with locality, occupation, sex of pupils, etc., and the whole business of standardizing physics and bringing about a glorious uniformity runs counter to this.

The truth is that the so-called fundamental doctrines of physics are fundamental neither to the science of physics nor to the teaching of that science. Our doctrines in physics are no more fundamental than they are in religion. We change them oftener. Neither are these principles any more help to the *teaching* of physics than Calvinism is in the *teaching* of religion.

I hope the high-school men, pushed on by the public which is behind them, will gradually change that list of principles in physics to a list of physical phenomena or rather experiences which one may encounter in life and of which the ordinary man desires an explanation. And I predict that when high-school pupils have been taught to notice the experiences of a physical sort which their lives present to them and to classify them so that one fact throws light on another, they will come to the college instruction with a gratifying ability to grasp physical principles. But it must be their own life experiences, found outside of the conventional laboratory — and not such as may be prescribed for them by some central body, whose only anxiety is to rate and make uniform the contents of pupils' minds.

Our besetting sin in physics teaching is something which goes under the euphonious name of thoroughness. We have a block-measuring mania in some parts of the country. Pupils are required to measure the four edges representing the length of a block of wood to the tenth of a millimeter, which is $\frac{1}{254}$ part of an inch. These are to be averaged and the result taken as the true length. In like manner, the four edges representing the width and the four representing the thickness are to be treated, and then these results are to be multiplied together and the volume recorded in terms which represent less than $\frac{1}{1,000,000}$ of a cubic inch. The pupils know that the exercise lacks common sense, since the measuring sticks are crude, the edges of the blocks are battered, the faces are not perfect planes, and the human eye is incapable of reading such microscopic dimensions. If such training has any effect, it would seem rather to disqualify them for making useful measurements like the length of the schoolroom or estimating its height. Consider the years spent in drill. The elementary-school teacher devotes a very large portion of time to drill upon mathematics. The high-school teacher thinks the grammar-school training is defective and he takes up the drill upon mathematics. The college teacher believes the high-school training is defective and he attempts the same drill. In this series of onslaughts upon the students the college teacher effects the least results and the elementary-school teacher's work is the most efficient. Investigations show that drill in mathematics beyond a certain few years of it have no effect upon the pupils' abilities.

The percentage of high-school pupils studying mathematics increased during the fifteen years, 1890–1905, from 66 per cent to 88 per cent, and during the same time the percentage of those studying physics decreased from 22 per cent to 15 per cent and as though that were not bad enough we have tried to convert physics into mathematics, and we have been told that this was in the interests of thoroughness.

I predict that school pupils will some time have the privilege which we, who have got beyond the domination of our schoolmasters, enjoy of learning many things with the intention of forgetting them immediately — more than half of the subject of physics should be so treated. If we adults had to learn thoroughly and retain for somebody's examination one-tenth of that which we find it both delightful and profitable to learn each day we should be miserable.

These children know wherein we wrong them and the best of them are longing for the time when they may rise above us. Is there any reason why we should not be willing that the children should learn by the same method which we find profitable? We learn by the smattering method — first a passing introduction — a mere fleeting impression — then time for the ideas to incubate, and after a while another meeting with these ideas from perhaps a different standpoint followed by casual meetings at intervals. The method of the daily newspaper reader is producing clear thinkers.

Another privilege which every person young and old rightly prizes is that of learning something about many things which we cannot understand and ought not to be examined upon. The requirements in physics should be cut down so that there may be time to thus enrich the work in physics by lectures and outside reading. We have preached against mere memoriter work until our preaching has taken some effect in high-school teaching but we continue to give examinations which no amount of general intelligence would enable one to pass. No faculty nor body of graduate students could pass the entrance examinations — only those can pass them who have recently crammed their memories with the conventional material which appears nowhere else than in examinations. We have heard that high schools are deteriorating because their pupils do not pass entrance examinations to college, West Point Military Academy, and the like. I undertake to say that the more rational our instruction becomes the less will our pupils be able to pass the examinations as now given. Perhaps it is a commendation of the high schools that the secretary of the College Entrance Examination Board notes in his last report that a larger number of candidates than usual failed to pass the examinations.

An eminent authority says, "Really educated people are just those who have forgotten more than others." It is essential to good thinking that one should not retain in memory much unorganized and useless material. Ideas sometimes require a long period of incubation. Inner intellectual life of extraordinary wealth is often hidden because of lack of means of adequate verbal expression or perhaps lack of the special gift of passing written examinations.

It might be well for this association to appoint a commission to investigate the returns now on file with the secretary of the College Entrance Examination Board. It is idle for individual pupils or teachers to attempt the matter of appeal but it is the duty of the secondary schools to have a commission for this purpose. I believe there are just as good persons kept out of college as are admitted by these examinations. The high-school teachers know before the examinations who are qualified to enter college and they know what ones have injustice done them by the examinations. It is the duty of some one to defend the pupils and to defend the good name of the schools.

X

LEARNING FROM EXPERIENCE[1]

When one says he has reached a certain conclusion from his experience, particularly if that experience has been prolonged and varied, he usually expects us to consider him an authority. Nothing, however, is more common than for one person to dispute the conclusions drawn from another's experience and to appeal to his own experience for counter-evidence. One who has listened to farmers, mechanics, and all sorts of *practical* men, each attempting to disprove the conclusions of another by appealing to his own experience, is forced to think that in some cases experience serves little else than to entrench a person more firmly in error. Note how dubious the physician looks when his patient claims to know from experience that certain things are good or bad for him. I take it, however, that most of those whom I am addressing would rather rely upon the evidence of the practical than the theoretical man. We take a good deal of satisfaction in the fact that Galileo settles by observation and experiment many questions which had been mooted for two thousand years, after the fashion of the dialectics of Plato and Aris-

[1] Abstract of address delivered before the Eastern Association of Chemistry Teachers, Boston, May 11, 1912.

totle. And I suppose that most of us have a notion that we are teaching the future citizen the art of learning something reliable from his experience. We cannot hope that the few facts learned in school will suffice for life, and so we aim to prepare the student to gather facts from his experience throughout life, and we like to think that the difference between the schooled and the unschooled person is that the former will be able to give more reliable testimony from his experiences. This I find has been the *aim* of all books on science teaching which have been written in the last century and a half, and this is the *professed* aim of every one of us to-day — but what is our practice? During the third of a century, in which I have been engaged in teaching and observing the teaching of chemistry, there has been a constant increase in the attention given to chemical theory in high-school instruction — a greater and greater refinement of chemical definitions and doctrine and a proportional decrease in the tendency to lead pupils to derive their knowledge from the experiences of life. The introduction of individual laboratory work on the part of the pupils has even accentuated this tendency rather than counteracted it. Laboratory experiments are performed with apparatus which suggests nothing found anywhere outside the laboratory and for purposes which obtain nowhere else. Meanwhile, the refinements of chemical doctrine which are supposed to be fundamental remind one of the Church Catechism — and one of these codes has about as much relation to life's problems as the other. A great

American teacher, Professor J. P. Cooke, once said to a group of teachers, gathered at the Harvard Summer School:

"It is not only useless but injurious in the education of young minds to present any department of physical science as a body of definitions, principles, laws, or theories. Such facts only should be taught as can be verified either by experience of the pupils or by the simplest experiments."

The commissioner of education in this state (Massachusetts) has said:[1]

"All education seems to inherit a fundamental tendency toward the abstract, the relatively unreal, the bookish. The teaching of science has done something to correct this, but even here there seems to be a persistent disposition to wander out of the sunlight."

There is a rather strenuous attempt in some quarters to teach what is called *applications in chemistry.* I note how this association and the New York Chemistry Teachers' Club and other such organizations of chemistry teachers devote most of their meetings to excursions to chemical factories and the like, presumably in search of applications of chemical principles with which to enrich their teachings. I think, however, that many teachers have gone only so far as to use these applications to give concreteness to their teaching of principles — somewhat as a dictionary defines words and quotes phrases to show their application. Some teachers think that school and college are the places to teach fundamental principles only, leaving the applications to

[1] *Educational Review,* Vol. 39, p. 13.

be found by the pupil, if he needs, in after-life. And some scorn practical applications as savoring of vocation or trade. But those who test students in after-life know that the graduates from such instruction carry with them little understanding of either applications or principles. Some few teachers take the stand that the applications must be taught from the first for the sake of making the principles understandable, but with all of these classes the end in view is "grounding the student in chemical doctrine." Now I contend that a knowledge of chemical theory is of secondary importance to the vast majority of high-school pupils, but that a scientific study of their daily experiences is of the greatest importance to all students. I might further claim that if one is seeking a knowledge of chemical theory he will reach that end most surely by inverting the usual order of procedure. I hear some one saying, "You cannot teach application until you have first taught principles," and I reply, "You cannot teach principles until after you have taught applications — very many applications." The high-school course might well be little else than application with a very incidental reference to principles. It should be a sort of organization of experiences, letting one throw light upon another according to Huxley's idea that science is merely organized common sense. Twenty years ago I wrote a book on this plan, but I had at that time an exaggerated idea of the availability of the inductive method for the instruction of the young. I now believe in giving large doses of information.

We need not, I think, fear the "talking teacher." All great teachers have been conspicuous for that gift, and it is noticeable that they all have bristled with information which they had a passion for imparting to others. Their pupils learned to think in orderly fashion apparently by imitating their teacher. It is a powerful incentive to scientific thinking to have a master, whom you fully trust, lead you through the interpretation of your own experiences. Our experiences and our observations upon nature are not naturally differentiated under such headings as chemistry, physics, physiology, botany, etc. If we label them anything we may use the term general science. It is *science* if it is organized common sense. By a strange inversion of ideas the college preparatory course in chemical doctrine has been called science. It seems to me to bear a similar relation to science that grammar does to literature and modern students go far in literature before touching grammar and they never study grammar much.

Let me illustrate my meaning by outlining some topics of instruction.

In front of a certain building there is an iron fence, very rusty, showing that some chemical action has been going on. There is another near by which has been carefully attended to, scraped, and painted, in order that this chemical action should not go on. We are at great pains, most of us, to see that this action does not take place with our iron things. Many of our iron goods are covered with tin, zinc, or nickel to prevent this action. We cover them with vaseline. We oil them. We use agate iron, or enameled iron. Concrete covers iron in our modern buildings. It is so hard to protect iron from this destruction that we do not expect to find pure iron in nature. If we want a pure specimen in a museum, we keep it free from the action of the air and free from contact with moisture. We have noticed that when iron is brought out of the blacksmith's furnace it has undergone this action much more abundantly; it is coated thickly with this rust. We have noticed in our experience that it will not do to let water stand in tin basins; we find a yellow spot where the water has begun to attack the iron through the tin. A hardware storekeeper will bring out his best cutlery, carefully protected from this chemical action, probably wrapped in something that will keep it dry and protect it from the action of the air. Nails which are left exposed to the weather go through this process, and they grow larger, a crust forms upon them, and they actually increase in weight.

I do not suppose that anybody will imagine that I condemn the teaching of chemical theory in its proper place. I am not urging that you follow the pace of the pupil, or even his interests. However, your students should draw from you the explanation and theory rather than for you to be forcing it upon them in the wrong place. I am contending that you do now put the chemical theory in the wrong place and furnish too much of it. Your pupils will want to know the explanation of this action, and you should tell the story of the modern idea of oxidation in a very brief and incidental way, and it should come up in many different connections if you would have it well understood.

Iron is not the only metal that corrodes. We have no end of trouble to keep our silver and brass from tarnishing. We protect them by covering with some metal which is less likely to tarnish. Your students will ask, why do silver spoons tarnish so rapidly in hard-cooked eggs? Why does a dime that is kept in a pocket with a rubber eraser tarnish? Metals do tarnish; what are they given to uniting with? Look through a mineral cabinet and see what sort of compounds of the metal there are.

Heat seems to aid in this action, and heat carried to a much higher degree arrests the action. And so we can easily imagine the conditions of things outside of our experience. What about the conditions in the atmosphere of the sun? We know something about the chemistry of the sun, almost as much as about the chemistry of our own surroundings. We have thus far noticed two influences which induce chemical change — heat and moisture. See how we make use of the first influence in the laboratory; nearly all our work depends upon the use of the Bunsen burner. There are very few experiments that do not require heat of some sort to produce the change desired. We cannot observe cooking processes very much without noticing that *time* as well as *temperature* is an important consideration. Why are we so interested in the fireless cooker? Largely because it brings in the question of time.

I remember how, when I first became a teacher, I tried to bring out from the experiences of the country boy a series of lessons. We were burning a piece of paper and dropped it on the stove. It changed to a black substance, and a few drops of a thick liquid remained on the stove, smearing it. And I tried to make it clear by giving a multitude of other experiences. I will give you just an outline of this. I had been burning some waste paper in the furnace. When I opened the door of the furnace, drops of a thick liquid fell down from the inside of the door upon the paved cellar bottom. In that town I went to a country church which was heated by a stove, with a long pipe running the whole length of the building to a chimney. There were places where the stovepipe gapped, and oftentimes you could see drops of this liquid come out. Of course it was generally thought that it was water from outside that had come down the chimney. And then there was the smokehouse, where the same thing was going on over and over again, smearing the walls of the smokehouse. And then there were the chimney fires. Why should a pile of brick get on fire once in a while? I found that the inside walls were smeared with a liquid, and other things that came from the destructive distillation of what was being burned in the stove. Then there was the gas factory; because those were the days when they were throwing away the waste products. And when the long and interesting story of the coal-tar products came out they created tremendous interest in my class in chemistry. And then there was the candle, and that most interesting book, *The Chemical History of a Candle*, written by Faraday. He said in his introduction that in sitting down to watch that candle he saw every law of the physical universe illustrated. And then came the wonderful series of petroleum products.

Now heat breaks down chemical compounds, and it stimulates chemical action most interestingly in the springtime. What goes on in nature in the spring months? Why, there are two things: the rise in temperature and the increase in moisture. Where we have the two things together we get the tropical heat of summer, and we are not able to get along without using ice, because nature gives us the conditions which stir up all sorts of chemical change.

But there is something else that comes from our observation regarding this; it is the reverse that chemical action is all the time tending to raise the temperature. I engaged a man to bring me some manure, which I intended to use on the lawn. It was dumped down in a heap and left there for a few days. One day when I was out walking with my son, we passed the pile of manure. He stopped me and remarked that the pile was steaming as though there was a fire in it. Well, of course, I had to give him a lesson in chemistry, though he was only eight years old. But he was just as ready to hear that then as he will be in the third year of high school. Later in the season, we mowed the lawn, and raked the grass into a pile, and then we were negligent about removing it. My son, while playing on the lawn, put his foot into the pile of hay. It was very hot; the chemical action that was going on produced heat.

All along the street the plasterers are adding cold water to cold lime, making a mortar, and the whole gets steaming hot, and it is just sickening to see school children going by without seeing it. The trouble is they are tired of being snubbed for trying to learn from their experiences. What are all these regulations about disposing of painters' rags, etc.? They will produce heat and spontaneous combustion it is feared. To avoid such fires we are told that we must guard against heat and moisture.

But this thing is going on in our own bodies. Animal heat is simply due to chemical changes like the heat in the grass pile, and we succeed in keeping a very interesting balance between the cold of winter and the intense heat of summer. We go into a cold room and creep into so-called "warm" blankets, although they are not any warmer than the room itself. We simply make the blankets warm by the heat of the body. Vegetable life goes through the same process. We have, therefore, a tremendously interesting chemical action going on in all sorts of plant organisms. So we are not surprised to find the sign, "Keep in a cool, dry place," upon packages of various things.

Then there is another thing that comes to a pupil from his experiences. That is that light is also an agent in the bringing about of chemical changes; as, for instance, in photography. I took up photography before there was any such thing as the dry plate, or the kodak films, or instantaneous exposure. I remember how I would go out three hours after sunrise and make an exposure for a certain length of time, to get a picture, and then go out in the afternoon three hours before sunset, and it would be necessary to expose the film about three times as long as before in order to get the same result, when no one could discover by any observation of the eye that the day was less bright. This set a whole train of thoughts going; and it was not long after this that I heard of the wonderful flowers in Norway, and the short season for growing wheat in Siberia, which is explained by the fact that the very intense light is able to make up for the short season of high temperature. Then there were the sprouts growing upon potatoes in the cellar, and when you get them out in the sun they become green, because the chlorophyll in the plant is developed by the sun. Then there was the strange action upon our skins in the summer time that makes the skin tan; and the fading of fabrics which we exposed to the light, and of the wall paper except where pictures have hung. I recollect one summer we hung some pictures on the bare walls of a camp. Next summer we wanted to change the decorations and so took down the pictures. The spots showed very clearly where the raw spruce boards had not been exposed to the light, while the rest had grown very yellow. I remember a blue serge suit. After a few weeks' wear I had occasion to turn up the collar of the coat, and there was the original color under the collar, while the rest of the coat was entirely different. When my sister took down her hair, it showed the places where it had faded because of the action of the light upon it.

It is my belief that there is little in the whole field of science which you can teach to these young pupils except through the channels of their experiences.

XI

PRACTICAL CHEMISTRY[1]

THERE are about 1000 teachers of chemistry in the secondary schools of this state (New York), but probably less than 50 of these are teachers of chemistry *exclusively*.

For purposes of investigation we have divided the high schools of the state into three classes:

Class 1. — Schools having teachers of *physical science, biology, earth science, etc.* (Departments which are represented by the various sections A, B, C, of this Association.)

Class 2. — Schools having teachers of *science.*

Class 3. — Schools having (just) teachers.

Class 1 includes 7 per cent of the high schools of this state.

Class 2 includes 10 per cent of the high schools of this state.

Class 3 includes 83 per cent of the high schools of this state.

This association was formed in 1895 by certain members of Class 1 and has been sustained during these 17 years by members of that class. More

[1] Read before the New York State Science Teachers' Association at Syracuse, December 27, 1912.

than one-third of the members of Class 1 are in New York City. Those persons formed 15 years ago local associations such as The New York Physics Teachers' Club, The New York Chemistry Teachers' Club, The New York Biology Teachers' Club, etc. There are several other centers in the state where the same thing has happened. These study local problems and local industries for the purpose of making the instruction in the schools more practical. A good many of the schools which belong to Class 1 throughout the state have for one reason or another never been represented in this association. It therefore happens that this association with the all-inclusive name of "The New York State Science Teachers' Association" represents only two or three per cent of the schools of the state.

Our aim has been to find out how instruction in chemistry in the schools throughout the state might be made more practical — more vitally connected with life — more of an interpretation of the experiences of the pupils. We find that during the last 17 years the tendency has been to make high-school chemistry a very complex system of doctrine with little attempt to give it local application.

Class 1 above referred to, working under the immediate influence of the colleges, has been largely responsible for the present prescription in high-school chemistry for New York State.

The members of Classes 2 and 3, although constituting more than nine-tenths of the schools of the state, have had practically no voice in the matter of this prescription. Perhaps a majority of the teachers of chemistry in the state are principals of schools. They do not, as a rule, attend the meetings of this association. Their own association has met annually in Syracuse at this season for 28 years.

The most obvious distinction which one might make between Class 1 on the one hand and Classes 2 and 3 on the other is that a large number of the members of Class 1 are fresh from college and teach what they have been taught in the way they were taught it. They specialized in chemistry in college. They specialize in chemistry in high-school instruction. Their knowledge of other subjects is exiguous. Their experiences in life are too limited for them to meet high-school pupils upon their own ground. They are said to teach chemistry rather than pupils. In Classes 2 and 3 there appear to be a larger proportion of persons who understand their pupils and who know how to make chemistry mean something to them. Such have in many cases risen to principalships because of their wider knowledge of human nature. They are, in short, bigger men and women than specialists can be. They live in the smaller cities and towns and have fewer pupils to deal with. They have more direct contact with nature, with their pupils, and with their pupils' homes. They are the persons who are making chemistry or any other subject which they may teach *vital*.

Our statistics show that members of Class 1 dwell on the average in cities of 112,000 inhabitants and teach in high schools of 1200 pupils, having 37 teachers to the school, each confining his attention to one subject. Members of Class 2 dwell on the average in cities of 15,000 inhabitants and teach in high schools of 165 pupils with 7 teachers to the school, each giving instruction in a group of allied subjects. Members of Class 3 dwell on the average in towns of 6360 inhabitants and teach in schools of 70 pupils with 4 teachers to the school, each teaching pupils in groups of half a dozen with that personal contact which is the chief factor in all good instruction.

I have visited many schools. In a typical case of the 3d class I found a town of 5000, a high school of 60 pupils and 3 teachers. The chemistry was taught by the principal. He is a leader in the life of that community. He has a house, a garden, and a family. There is plenty of chemistry in his life. It gets into the school and enriches the lives of the pupils. I turn from this to a case in the 1st class, of whom there are some — a city of 100,000 inhabitants, a high school of 1000 pupils and 35 teachers. An instructor who conceived the idea while in college that chemistry was his forte. He says he *majored* in chemistry. Under the guidance of his college adviser he took everything possible in chemistry and as little as possible in other subjects. The longer he stayed in college the fewer things he knew. He is now instructor in chemistry to 35 pupils in a school of 1000. He has no garden to till. He lives in a hall bedroom and the students believe that contact with him is belittling.

1. The statistics presented above raise the question whether after all *general science*, now being so widely

introduced throughout the country, is not *more practical* than chemistry and physics.

2. The discussions now going on all over the country raise the question whether boys and girls must be segregated in order that the teaching of chemistry may be practical.

The United States Commissioner's Report gives only 6 high schools in New York State for boys alone and only 3 for girls alone, while there are 866 for both sexes. In the whole United States there are only 35 for boys alone and 27 for girls alone but 12,151 for coeducation. Nine-tenths of the high schools are too small to make segregation possible and in the large ones the complexity of the program with all its electives makes it rarely possible to separate boys and girls in classes. Girls are present in all our classes and they predominate. They constitute 55 per cent of all our high-school pupils. Who thinks that the man who holds down a chair in some business office has more contact with problems of physical science than his wife with all her modern household appliances? Perhaps this talk about segregation is an *academic discussion.*

3. The question of men teachers *vs.* women teachers for chemistry or physics.

Women constitute 62 per cent of all high-school teachers. We desire to find out whether they are in the majority as chemistry teachers, and whether they are considered quite as satisfactory as men in such positions. The average salary for a high-school teacher in this state is now $1100. It was $665 seventeen years ago when this association was born.

4. Should science be made practical in the same way that English has been of late years in the schools?

Some of us can remember when English was the weakest subject in the schools. Here are some statistics to show that it is now the strongest. I found that in one school library during a period of two months 993 readers appeared in pursuit of their work in English; 722 came for information in history, but only 40 read because of their interest in science. There were in the library 3915 volumes, but only 71 of these pertained to physical science and two-thirds of these were the numerous text-books contributed by publishers.

5. Here is a group of statistics which raise the question whether teachers are practical.

In New York State 48 per cent of high-school pupils are in the first-year class. We manage to eliminate more than one-third of these so that 26 per cent appear in the second-year class. More than one-third of these disappear, so that 16 per cent are found in the third-year class. More than one-third of these fail to reach their senior year and 10 per cent are found in the fourth-year class. A quarter of these are not allowed to graduate, and 8 per cent is the number of those who succeed. Half of these (four per cent) through "toil and trouble and tears" have prepared for college, and the colleges think they are doing the Lord's service by rejecting half of these so that 2 per cent enter. There are plenty of people who raise the question whether these are superior or inferior to those who have dropped out by the way. These figures tabulated present the following appearance:

Of high-school pupils in New York State there are 48 per cent in 1st-year class, 26 per cent in 2d-year class, 16 per cent in 3d-year class, 10 per cent in 4th-year class, 8 per cent graduate, 4 per cent prepared for college, 2 per cent admitted. These statistics do not differ materially from those shown by the United States Commissioner's Report for the high schools of the whole country.

If we were attempting to manage any other business with such a record as the above, the question would be raised whether we were practical.

XII

GENERAL SCIENCE

In 1912 the National Education Association appointed a Committee on General Science. As chairman of this committee I sent out the following circular:

All persons interested are invited to coöperate with this committee in finding out what is good material to present and what are good methods to use.

It has been suggested that we gather lists of questions which young persons ask of parents and teachers in search for information in the field of science such as: What is the sun? How does it keep hot? Why does it sometimes turn red? What gives the clouds so many different colors? What makes the street car run? How can animals breathe when under water? Why do leaves of plants turn red in autumn, etc.?

A lawyer testifies that in his profession he has found of great value the general science course which he took a generation ago consisting of the Geological Story Briefly Told and the stories of half a dozen other sciences briefly told. Many intelligent men have testified that what they need particularly is general information in the field of science. It has been suggested that teachers, parents, and grown-up persons in general send to the Committee lists of facts in science which they by years of experience have found worth while to know.

It has been suggested that lists be prepared of the incredible things persons say and do which show the need for instruction in general science and show what instruction is most needed.

Suggestions for organizing common sense, developing gumption, etc., are in order. Lists of problems are suggested in the field of natural science which require diagnosis at the hands of the ordinary person. In this age of machinery, life is becoming increasingly embarrassing to those who regard all mechanisms as uncanny. That education which its devotees are pleased to call the humanities, but which seems to leave its disciples incapable of serving humanity, is becoming daily more inadequate.

Lists of aims for this work are desired as also lists of sources of information. Lists of fundamental principles have been suggested. It has been suggested that no syllabus be prepared of work expected of all schools alike, but rather let it be urged that each teacher should adapt his work to local conditions. It has been suggested that any good work must be considered good preparation for the following years of high school and college. Facts which will be needed in the future years of any course at school are best taught when they are needed and when they are to be organized for some purpose. It is suggested that sample lessons be published in detail to guide inexperienced teachers in the best method of presenting topics in general science. Several courses in general science have been already published indicating the progress in this matter up to the present time.

All who are interested in this matter are invited to make further suggestions, to criticize those already made, and especially to make some constructive contributions which will in each case be credited to their authors in the published reports of the Committee.

The returns which came in indicated that the schools should give information from the whole field of science — not neglecting astronomy. The public needs unmistakably require a new organization of science instruction according to *projects.* The problems of life are not differentiated after the manner of specialized science. Pupils in both elementary and high schools are in a much more primitive state of mind in regard to all science than our school programs would indicate. Many are apparently blind and deaf to nature's most evident teachings. They are in the depths of superstition about common things even while surcharged with academic formulas regarding things scientific. Our secondary schools persist in articulating with that which is above them rather than with the elementary school. Few persons appear to know that they have the answers to most of their questions readily accessible in dictionaries, encyclopedias, and readable books. Apparently we have deprecated the teaching of science from books too long and too successfully. The greatest need, and likewise the greatest demand, among even highly educated persons, is for *information* rather than *training* in science. All workers and students require training in their specialty, but in other fields they want knowledge in simple form and by the most direct method.

Natural science has moved from a position of great worth as a school subject to one of minor importance. Science teachers everywhere are beginning to regard it a high duty to bring it back to its rightful place and value. Attention has been too sharply focused on teaching "subjects" as against teaching students those things that are important for them to know. The schools reached the lowest point in real science instruction when, under the stress of preparing for higher institutions, they narrowed their work to "the forty quantitative experiments." It was desultory, scrappy, unorganized, unscientific. At best the teaching was confined to vocabularies of technical words, definitions of scientific terms, statements of "fundamental principles," etc. The natural and effective order is not principles followed by applications, but the reverse. From a multitude of experiences, facts, and observations, arranged so as to illuminate one another, some few principles may be derived, if these principles can be shown to be fundamental and can be brought into immediate use. The trouble with most of the so-called "fundamental principles" is that they are never again met either in school or life, and the majority even of enlightened men get on very well without having ever heard of them, or, having heard, they have forgotten them because they did not prove to be fundamental to anything. A principle which occurs, or is likely to occur, so often that one cannot forget it, is fundamental and few others need be considered. Principles are not to be taught merely for discipline and training, nor for use only in a remote future.

The study of "projects" in science will necessitate the breaking down of boundary fences that have been erected between highly specialized sciences. *General science* should be adapted to local conditions and may not be universalized. Many projects elaborated by ingenious and skilled teachers should be published in a series of small books or pamphlets for the use of pupils. Teachers may select from these as time, place, and other circumstances require. Enough of this material may easily be prepared to occupy many years of study on the part of pupils. What is worth while to know from the fields of astronomy, botany, chemistry, geology, meteorology, physics, physiology, zoölogy, etc., may be thus acquired.

XIII

SCIENCE TEACHING BY PROJECTS[1]

THERE are those who say that nothing worthy to be called science may be taught before the last three years of the high-school course — the Senior High School. They say that real, serious science is to be found chiefly in the college, and that what is permissible in the senior high school is the learning of "fundamental principles" preparatory to college science. There are, however, others who say that children from 12 to 15 years of age come nearest of all persons to using the method of the great masters of science, and practice the most real research.

"The native and unspoiled attitude of childhood, marked by ardent curiosity, fertile imagination, and love of experimental inquiry, is near, very near, to the attitude of the scientific mind."[2]

Bacon said:

"We must become as little children in order to enter the kingdom of science."

"At present, the notion is current that childhood is almost entirely unreflective — a period of mere sensory, motor, and

[1] Abstract of addresses delivered at the Annual Conference of High School Teachers, University of Illinois, November 20, 1914, and at the annual meeting of New York State Teachers' Association, Albany, November 24, 1914.

[2] Dr. John Dewey, *How We Think.*

memory development, while adolescence suddenly brings the manifestation of thought and reason. . . . But thinking itself remains just what it has been all the time. . . . Only by making the most of the thought-factor, already active in the experience of childhood, is there any promise or warrant for the emergence of superior reflective power of adolescence or at any later period."[1]

Elsewhere Dewey says:

"It is not our function to teach children to think — they think quite as much as we do. It may be our privilege to guide their thinking."

We are told that the high-school-college-preparatory course in physics, for instance, with its 200 odd topics, is serious science, that it is highly specialized and that it is preparatory to still more serious science hereafter. My opinion is that it is a disjointed skeleton of falsely called "fundamental principles"; that it is not science and does not prepare for science; that it is not specialized at all but is a hodgepodge of stuff never met by intelligent people in real life.

Dr. Coulter in his address on what the university expects of the secondary schools said:

"The average college preparation presents to the university the most narrow and unevenly trained material that can be imagined."[2]

And those who deal with graduate students say the same thing about the college work.

Since the defects in high-school teaching are due chiefly to the fact that high-school teachers are

[1] Dr. John Dewey, *How We Think*, p. 65.

[2] *School Review*, Vol. XVII, p. 81.

college products and are close imitators of college methods we must first deal with the colleges.

"An ever-present question in an institution of the higher learning is how to interest officers of instruction in the subject of education. They are certain to be interested, each in his own particular branch of study, but too few of them are interested in education itself. The consequence is that the teaching of many very famous men is distinctly poor; sometimes it is even worse. This results in part from the breakdown of the general educational process into a variety of highly specialized activities, and in part from the carelessness of college teachers as to everything which affects a student's manners, speech, conduct, and sense of proportion, provided only he gets hold of certain facts which the teacher desires to communicate.

"One mistake into which college teachers are most likely to fall is that of confusing the logical with the psychological order in the presentation of facts. The really good teacher knows that the logical order is the result of mature reflection and close analysis of a large body of related phenomena, and he knows too that this comes late in the history of intellectual development. He knows also that the psychological order — the true order for the teacher to follow — is the one which is fixed by the intrinsic interest and practical significance of the phenomena in question. The good teacher will not try to force the logical order of facts or phenomena upon the immature student. He will present these facts or phenomena to him in their psychological order and so give him the material with which to understand, when his knowledge is sufficiently complete, the logical order and all that it means. . . .

"It should be possible for an advanced student specializing in some other field to gain a general knowledge of physical problems and processes without becoming a physicist; or a general knowledge of chemical problems and processes without becoming a chemist; or a general knowledge of zoölogical problems and processes without becoming a zoölogist; or a general knowledge of mathematical problems and processes without becoming a mathematician. The reply that knowledge has become so highly specialized that no one can be found to give such courses of instruction is the saddest confession of incompetence and educational failure that can possibly be made. It ought not to be made except under cover of darkness." [1]

The process of learning in school should not differ from that out of school.

"Adults have some occupation about which their thinking is organized. Information is not amassed and left in a heap. Inferences are made not from purely speculative motives but because they bear upon some of life's problems." [2]

Dr. McMurry states the case convincingly as follows:

"Should the student be a collector of facts at large, endeavoring to develop an interest in whatever is true, simply because it is true? Should he be unmindful of particular problems? or should his study be under the guidance of a specific purpose?"

"Much has been said in times past about art for art's sake, science for the sake of science, and knowledge for the sake of knowledge, but these are vague expressions that will excite little interest so long as the worth of a man is determined by what comes out of him, by the service he renders, rather than by what enters in." [3]

"There is nothing less profitable than scholarship for the mere sake of scholarship, nor anything more wearisome in the attainment. But the moment you have a definite aim, attention is quickened, the mother of memory, and all that you acquire groups and arranges itself in an order that is lucid, because everywhere and always it is in intelligent relation to a central object of constant and growing interest." [4]

"If students regularly occupy a portion of their study time in thinking out live questions that they hope to have answered by

[1] Annual Report, November, 1914, President Butler, Columbia University.

[2] *How We Think*, p. 41. [3] *How to Study*, pp. 16 and 198.

[4] *How to Study*, p. 37, . . . quoting Lowell.

their further study, and interesting uses that they intend to make of their knowledge, they are equipping themselves with active power both for study and for the broader work of life." [1]

"Indeed the reason why self-trained men so often surpass men who are trained by others in the effectiveness and success of their reading, is that they know what they read and study, and have definite aims and wishes in all their dealings with books." [2]

Some are accusing General Science of lacking organization of subject matter. But when rightly understood it will be found that the whole movement is an attempt to introduce first of all a very specific organization where none now exists, and secondly a very different kind of organization from that hitherto attempted. This lack of organization which makes the school below a sort of dumping ground for the school above is one of our grievances. If the teacher above wants to use the slide rule, the teacher below must teach it. If he wants to use the metric system, the teacher below must teach that. If the college professor wants to measure gas as no one else on earth does it, the high-school teacher must teach that process even though it crowds out a thousand more important matters judged from the standpoint of the pupils' needs. These pupils are going to buy and sell gas all their lives. But anything done in school to teach them to do that intelligently is decried by some as savoring of the practical.

Very little of this knowledge which the high-school pupils spend so much time to acquire, is

[1] *How to Study*, p. 39.

[2] *How to Study*, p. 33, . . . quoting Porter.

possessed by any intelligent group of persons. But for the high-school pupils it ranks as "fundamental principles" preparatory to "serious science."

"The greatest problem that the schools are facing is the lack of intimate relationship between the work of the schools and the work of the world. School work needs to be real instead of artificial. When pupils are learning something real that has an object behind and a result to come, they are energetic, when they listen to or watch or read something that is to them artificial, they are apathetic. In all of these characteristics the children in our schools closely resemble us adults."

"The most serious defect of the present course of study, is that it makes thousands of children waste tens of thousands of precious hours in the laborious acquisition of facts for which they will never have any practical use. The material which the children in the schools are daily learning is of a sort that is seldom or never met with in the business of even the most successful men engaged in commercial and professional pursuits." [1]

Eleven prominent men of Springfield, Ill. — a state senator, a lieutenant governor, a banker, a physician, a lawyer, a clergyman, a merchant, the president of a manufacturing company, a superintendent of parks, an efficiency engineer, and a newspaper editor — allowed themselves to be examined on the spelling, the geography, the arithmetic, and the history taught to the fifth, sixth, and seventh grades of the schools of that city. Not one of them could make a passing mark in any of these subjects, as taught to the little children of ten to twelve years of age. Does any one think that these men, or any other group of intelligent citizens, would succeed any

[1] See Educational Survey of the Public Schools of Springfield, Ill., by Leonard P. Ayres, Ph.D., Division of Education, Russell Sage Foundation, New York City.

better with the so-called fundamental principles of high-school science?

The movement for general science is first of all a protest against the present régime of unorganized subject matter. We propose *general* science as an antidote for that which now is too general to be called *science*, either serious or flippant. The movement for general science is, in the second place, an attempt, for purposes of instruction, to introduce a "psychological organization," as Dr. Dewey puts it;[1] or a "genetic organization," as President Hall states the case:

> "The chief among many reasons why all branches of science are so disappointing to their promoters in high school and college is, that in the exact logical, technical way they are taught, they violate the basal law of psychic growth, ignore the deep springs of natural interest and attempt to force a precocity against which the instincts of the young, so much wiser and truer and older than their consciousness, happily revolt."[2]

Organization of subject matter must be made around the knowledge of the pupil, not around that of the teacher or syllabus maker. We have to build on the instincts and experiences of the individual, otherwise we are hanging our building on a hypothetical foundation in mid-air.

The real way to learn fundamental principles is to attack those problems of which life is full for each individual, not through the preparatory fallacy called the scientific method, but by a "forked road situation." The school should prepare pupils to

[1] See, *How We Think*, Chapter V.

[2] *Adolescence*, Vol. II, Chapter XII.

walk alone by attacking real problems as Archimedes, Galileo, Davy, Faraday, Pasteur, Tyndall, and all the rest did. Most of us know, if we would think back over our experiences, that we never really learn these so-called fundamental principles until they come to us as an interpretation of some of our life's problems. Our teaching bears so little fruit because we are attempting what in the nature of the case can never succeed. We know that we are not learning things that way now, never have learned things that way, never can. We prescribe that sort of "serious science" for the defenseless, and when their unerring instincts revolt, we accuse them of being unwilling to be serious, unwilling to work, even while they are pleading to be rid of us that they may get to work. It is not merely the geniuses like Newton, Maxwell, Kelvin, and all the rest who thank the Lord when they get out from under their teachers, but this is likewise true of many of the pupils of to-day, some of whom instinctively know what science is, and are pursuing it in spite of us and outside of our tuition.

Imagine one of us in the following situation: we build a dam across a stream of water, and the pond that thus results surrounds some trees which we value. In our ignorance we may think the trees will fare better now than before, having an abundance of water and food brought to them by the river. But soon they die, and we go to the botanist, for light on this subject, and he undertakes to prescribe to us, as he does to his pupils, something like this: "You must take a series of preparatory courses in botany before I can help you with your problem. Here is a First Course in Botany for children which I prescribe." It has 158 pages, the first thirty-six of which classify leaves as net veined, parallel veined, feather veined, palmate veined, entire, serrate, crenate, dentate, repand, hastate, sagittate, lanceolate, cordate, ovate, reniform, orbicular, rotundate, acicular, deltoid, spatulate, peltate, runcinate, pedate, lyrate, pinnate, digitate, cirrus, adnate, ochreate, sessile, etc., for thirty-six pages. You are advised to have the leaves present to make the study concrete. This is classified knowledge, and hence science, serious science, preparatory serious science. As a supplementary exercise one might classify all the nails in the school yard fence.

Or imagine ourselves going to a physicist for information regarding a self-starting system for our automobile, and his prescribing Newton's laws of motion, Boyle's law, Charles' law, Lenz's law, Archimedes' principle, index of refraction, laws of falling bodies, law of reflection, law of cooling, Ohm's law, polarization in a cell, specific heat, modulus of elasticity, hysteresis, etc., up to 260 items of unclassified knowledge which the physicist is so lacking in a sense of humor as to call *serious* science.

This is the preparatory fallacy and it runs throughout all our subjects. Our method of teaching to-day by the study of "fundamental principles" is closely analogous to what was in vogue about a century ago in the field of grammar, when children were required to commit to memory rules of grammar, to learn syntactical laws of language and acquire skill in logical analysis in order that they might be prepared to read, write, and speak. The analogy goes still further. We have recently heard something of an attempt to make physics a little more concrete by the interjection here and there of a few applications of principles for the sake of elucidating these "fundamentals." It was about 1823 that the teaching of rules of grammar was made a trifle more concrete by the introduction of sentences to which the rules might be applied. For a discussion of this sort of teaching grammar see Dr. Briggs' monograph in Teachers College Record, Vol. XIV, from which it appears that science teachers to-day are in perfect accord with English teachers of a century ago in attempting to present an adult, scholarly interest to children by a logical and metaphysical treatment of their subjects.

"Tradition has perpetuated details which have lost much or all of their justification. When old reasons have faded there is a tendency to invent new ones to justify practice."

This attempt to store facts for future organization is what the Massachusetts Board of Education in Bulletin 4, 1912, calls "Education in Forgetting."

"The structure and habits of the human mind and brain are such that following the psychological laws of segmentation, unused knowledge tends to be forgotten. Much, a vast deal, of the subject-matter turned over and otherwise dealt with by the subject-study method is of such a nature that in out-of-school hours and in after-school years it remains unused. Examinations once passed and the school year ended, subjects are forgotten. . . . But project study has merits peculiarly its own. No more diligent or effective application of the inductive method in education has ever been witnessed than that proposed, and in good measure already practiced, by the project study of agriculture."

"The knowledge which is the boy's quest in project study is knowledge of which he sees the need. Being needed year by year, it will, year by year, be recalled. Used again and again, added to, modified and exactly applied, it will tend to be distinctly remembered."

"The project method of education, more, it is believed, than all others, takes into account the aptitudes, requirements, and accomplishments of individual pupils as these are revealed from hour to hour."

The Smith-Lever bill which has just passed Congress appropriates five million dollars annually to foster the *project method of study* in agriculture throughout the country.

The project method in *General Science* is more specialized than any portion of the college preparatory science, and like a dog pursuing a hare, it has a specific aim, albeit it jumps those useless boundary fences between the various fields of science. This is our justification for the use of the word *general.*

The idea of completeness — complete statements of facts and principles, is one of the greatest barriers to successful teaching. The attempt to teach all that is known about each topic results in very little being understood about any topic. What is wanted is to set the face in the right direction; teach the first steps; arrange many facts and many observations to point in a similar direction; acquire the habit of having one experience suggest another.

The method is precisely that of the masters of research who are, after all, *Masters of General Science.*

There is no difference between educating for research and educating for life. But the high schools and colleges have a strong propensity to neglect this, their chief duty. It requires continual belaboring to get the high schools to do much else than to cram facts for college use. The colleges do little else for education than to prepare professors' assistants; professors' assistants in research, professors' assistants in college teaching, professors' assistants in high-school preparation for college.

One hundred and fifty years ago the academies were founded as a protest against the idea which dominated the grammar schools of the time that education consisted in storing the facts which the higher institutions would use. These academies were called the people's colleges. The pupils were to be taught wholly according to their own needs. But forthwith the process of inbreeding began. The teachers appointed for these academies were youths recently graduated from college; in effect, professors' assistants who stored data for college use, a process as futile to the education of the few who went to college as to the many who did not. Again the same protest was renewed fifty years ago in the founding of public high schools. These were to be free from the preparatory fallacy to which the academies had fallen victims.

It remains to be seen whether the high schools, which are the people's colleges of to-day, can be saved from repeating this history. During the last twenty years we have had committees of ten, of fifteen, of seven, and of various other numbers laboring to saddle the preparatory job upon the under school. Perhaps the thing most to be feared is that the colleges may accept General Science and place it in the preparatory group. Before this happens we must introduce into the school and college the psychological organization of instruction and suppress the preparatory fallacy.

XIV

PROJECTS IN SCIENCE

A CERTAIN man became the possessor of a motor boat which filled his summer with projects for interesting study. By inquiry, by reading, and by experiment, he found that a very small amount of gasoline vaporized and mixed with each cylinder full of air constituted an explosive mixture which, when fired, furnished the power. He found that the proportions were fixed within very narrow limits; say, four drops to each quart of air. Varying the proportions to either three or five drops would result in a weaker explosion; hence the necessity of a very careful adjustment in the carburetor.

To explode this mixture an electric spark must be produced inside the cylinder at the proper instant. This spark was produced by a battery of dry cells. Rubbing together two wires leading from opposite terminals of this battery would produce a faint spark, but this spark would not explode a mixture of gasoline and air; it was not hot enough. Indeed, the coal upon the end of his cigar would not explode the gasoline and air. A coil of wire surrounding a soft iron core must be introduced into the circuit to produce a spark having sufficient heat to ignite the mixture.

As one searching through an encyclopedia for certain information often gets sidetracked upon some other search, so this man spent many days or even whole weeks passing through one project to another. The mysterious action of the coil; the tracing of the current through its complete circuit; the timing of the spark by means of a commutator; the oiling devices; the circulation of water for cooling the engine; the clutch for engaging the engine with the propeller, to go forward or backward or stop. All these and many other projects seemed to him to be real physics; nay, more and better than real physics.

A second man, possessing an automobile, pursued a dozen or two projects of study more absorbing than anything else which he had on his mind during the whole winter. With books of instruction furnished by dealers he studied carburetors, throttles, chokers, "vacuum feeds," high-tension magnetos, spark plugs, cooling devices, self-starting devices, differentials, clutches, gears, countershafts, breaks, horns, springs, "shock absorbers," tires, "non-skid" devices, mufflers, silencers, steering devices, lighting systems, lubrication, storage batteries, cycles, horse-power, generators, motors, relative merits of engines with four, six, eight, and twelve cylinders, non-freezing solutions, thermosyphons, pumps, care of varnish, speedometers, ammeters, the retarding of the spark on going up a hill, the causes of "knocking" in an automobile engine, etc.

A third man bought a small farm and began to read farmers' bulletins which he procured from the

Government Bureau at Washington. For three months he was the butt of ridicule as a "literary farmer," but nothing ever took such real possession of his mental faculties as that project of making the ten acres produce all the grass it was capable of. In the course of a few years, according to an account which he published, the neighboring farmers were eager to learn how he had succeeded in producing seven blades of grass where one had previously grown. These studies appeared to him to be real botany, nay, more than botany, real science.

A fourth man spent a few days at Mammoth Cave and came back with projects which seemed to him to be the most interesting studies in the fields of geography, geology, zoölogy, botany, physics, and chemistry. He was so enthusiastic over the results of these studies that they entered into every speech he made for the next year or so.

A fifth man spent a summer by the seaside and heard faintly on a few occasions the sounds of a bell buoy anchored four miles away. He reflected upon the problem of what conditions must obtain in order that that sound might carry so far. He questioned many men and read upon the subject until he got his mind possessed with an explanation which forms the substance of an interesting article.

These five men, all intelligent men — at least they are professors — have testified that these projects furnished them exceedingly fruitful themes for study. They will not admit that those studies lacked organization nor that they were desultory and scrappy. None of them was prepared for these studies by specializing in those fields any more than Pasteur was prepared by his formal education for the six or eight great projects which made him one of the greatest scientists and the greatest Frenchman that has lived.

Young people have plenty of projects which we may help them to study if we choose. It is not often possible to hinder their studying them if we will. They furnish the natural means for starting them on a scientific career. Why do we require young people in school to use a different method of study from that used by all of us outside of school? Why should we be averse to using methods of study in science which are considered eminently proper in other departments? Why should instruction be for specialization rather than for "magnanimity and enlightenment"? Why this mania for codifying subject matter which has cankered education during the last two decades?

If the two or three hundred "fundamental principles" in physics, for example, are fundamental, why do intelligent people having once learned them forget them without regret? Why do engineers have little use and much contempt for them? Why do those engaged in research in fields of physics ignore them? Is it tacitly for purposes of mental discipline that they are taught? Are students in schools and colleges made into scientists by learning the so-called fundamental facts, or by practicing the methods of a scientist in finding the solution of real problems?

The following project is taken from the notebook of a young man who spent a summer on a farm.

Drowning Trees — A Project

We dammed a small stream to make a skating pond and a place for cutting ice in winter. The pond which was thus formed surrounded certain trees in the valley which had often suffered for water during dry spells. Some of us thought this would be a benefit to the trees, inasmuch as they would hereafter always have an abundance of water. Furthermore, the stream would now deposit about the roots of the trees an abundance of the food which they would need. In spite of our good intentions, however, the trees soon died. Upon inquiry we learned that the trees had been drowned. They needed air at the roots quite as much as water. We were then reminded that a neighbor when he regraded the land in front of his house had built a circular retaining wall around a tree to keep the earth from being banked against the tree itself and excluding the air. Another man said that it would do quite as well to pile loose stones against the tree and throw earth over them, and let the grass grow quite up to the tree. Air would readily find its way to the roots through loose soil, as indeed it does to all trees. He said that earthworms, ground moles, and various burrowing animals loosen up the soil and let the air in. The earth is ventilated annually in preparation for the summer crops. When water in the ground freezes it expands; we say it heaves the ground up. Then when in the springtime the ice melts and the water drains out, much room is left for air to come in. Thus land which may be very hard in autumn becomes soft and spongy in spring.

Spring is the time to mend fences. One can dig post holes easily then. Spring is the time to cart off from the fields the stones which the winter frosts have brought to the surface.

Soils which are too clayey to let the water drain out of them may for lack of air sustain only a very stunted growth of vegetation. The mixing of gravel with such land, thus letting in air, will sometimes make it produce abundantly. All soils are improved by having a network of drains a few feet below the surface, so that all the water which will drain off may do so. The ideal arrangement for plants is a loose, porous soil with air filling all the spaces between the particles and only so much water present as will cling to the surface of the particles. This is called capillary moisture, to indicate that the spaces must be very small so that water will creep through the soil as kerosene does through the lamp wick.

The care of potted plants requires continual thought about maintaining the balance between air and water at the roots. If the soil is very rich and has little gravel in it and if water is always poured on from above, the soil gets packed down so hard that air may not enter. The hole in the bottom of the pot permits of under-draining, but the water soon makes channels down through the mass, and it does not spread to all the rootlets. In the hardly packed earth they may be suffering for both air and water in spite of the fact that the pot is porous and that it receives frequent watering. By this consideration soil may be too rich as well as too poor. It must have air and moisture quite as much as fertilizing material. If the soil is rightly proportioned it will suffice to pour water into the saucer. The proper amount of both air and water will creep through the soil.

Persons who set out young plants, thinking that the tender roots require very soft soil, sometimes make the mistake of not packing the dirt around them firmly enough. The result is that while they get plenty of air they have too little moisture. Moisture creeps by capillarity through very small spaces, not large ones. If the soil is properly proportioned the best way is to press it as firmly as one can around young plants when they are first being set out.

The surface of the ground should be frequently scratched over to make the spaces between the particles at the surface too large for the water to creep by capillarity quite to the surface and pass off by evaporation. This is one great reason for hoeing, harrowing, and cultivating fields. Another is to kill weeds.

Some people have asked whether earthworms rain down since they are seen in such great numbers crawling on the surface of the ground after a rain storm. The fact is that they crawl out of the ground to get air, having been drowned out. They cannot live without air as long as the trees and some other plants can. There are certain plants, however, which are able to live in earth that is perpetually flooded with water, as we see about all ponds and streams.

In winter, when there is lack of air and water at the roots, lack of heat to stimulate chemical activities, lack of green matter in leaves to respond to the actinic ray of the sun, plants put winter blankets upon their buds and on their root tips and remain dormant.

XV

THE NATURAL METHOD[1]

We sometimes hear it said that one cannot teach applications of physical principles until the principles themselves are understood. I wish to contend that only the converse of this proposition is true. That is, we cannot teach the principles of physics except through an experience with their applications. Of course these principles were first learned by mankind through their manifold applications in nature, and I venture to say that with each one of us it has been true that the principles which we did grasp in our pupil days were those for which we had been prepared by previous experience, and there were many principles taught us which we did not comprehend until later in life when we had met the experience necessary for their comprehension.

In a very real sense one studies physics from his birth to his grave irrespective of his formal education. The function of the school should be to help the pupil to interpret his experiences. When we find physics very difficult the probability is that we are trying to build without the necessary ground-

[1] Abstract of an address delivered before the Eastern Association of Physics Teachers, Boston, 1915.

work of experience. The extra-academic study of physics which each one of us pursues through our experiences during the whole of life is of vastly greater importance than the formal study of that subject in schools. One may be a master of physics without the formal study, but he can have no comprehension of the subject at all without the projects which grow out of life's experiences. The characteristic of education which has been most often noted is the tendency to teach "fundamental principles" without rooting them in experience.

The person who hangs upon the strap in a street car and has acquired the habit of reflecting upon his experience finds it natural to say when the car starts and he has to tug upon the strap to get himself started, "A body at rest tends to remain at rest." When the car stops and he pulls on the strap in the effort to bring his one hundred and fifty pounds to rest it is not difficult for him to say, "A body in motion tends to continue in motion," and when the car turns a corner he learns by his tussle with the strap that "A moving body tends to continue moving in a straight line."

Projects in physics begin with learning to walk, learning to walk on stilts, learning to skate, to swim, to swing, to teeter, to "snap the whip," to play "duck on a rock," to ride horseback, to ride a bicycle, to sail a boat, to fly kites, to curve a baseball, to play billiards, to make water wheels, to shoot, to fish, etc. These projects are invariably studied by the method of "trial and error." These are not pastimes, although they are play. They are very effective studies in physics. They furnish the means for "organizing common sense" according to Huxley's definition of science.

Let me suggest a new type of college entrance examination for physics. Have the candidate move a heavy log. If he attacks it in the middle and gives up, reject him. If he moves it by lifting at the end, admit him. Have the candidate step on and off a moving platform. If he does it gracefully, receive him. If he falls headlong, refuse him. Have the candidate discharge a sling. If he hits the mark, admit him to college. If he hits the umpire, condition him. Have the candidate tend a hot-air furnace. If he adjusts all the drafts and dampers wisely, admit him. If he shuts the "cold-air box" to keep out the cold, as many of his professors do, reject him.

This is the age of machinery, when a majority of intelligent folk would rather know about an automobile than to know much about the college type of physics.

Our so-called thoroughness is rather wooden. One hundred men know about the differential of an automobile; ninety of them know what it is for; nine of them know about its anatomy, and one, knowing what it is desired to accomplish, can design it. The first group are the owners; the second, the chauffeurs; and the last man is the chief engineer at the factory. Each has the knowledge that he needs. It is not necessary to call the first group "smatterers." Some of them are likely to be doctors of philosophy, and hence are supposed not to be victims of "soft pedagogy" or "kindergarten methods." If occasion demands additional knowledge, the natural advance is in the order stated above; namely: First, What is it for? Second, the details of its structure. Third, the invention of the device. Teachers of physics sometimes try to reverse this order, and when the inevitable failure results, their subterfuge is to charge the world with lack of thoroughness.

XVI

THE HIGH-SCHOOL SITUATION[1]

TABLE showing the number of high schools in the United States at certain periods:

Number of High Schools	Year	Number of High Schools	Year
1	1821	160	1870
2	1838	800	1880
3	1843	4158	1890
4	1847	8000	1907
40	1860	13071	1914

The above table shows the high-school situation in a nutshell. Such phenomenal growth has of necessity produced conditions which are embarrassing.

Less than one hundred years ago, there was but one high school in the whole United States — The English High School in Boston. It was seventeen years before the second one was established — that was in Philadelphia. Five years later the third one was started in Providence, and the fourth one came in Hartford in 1847 — 26 years after the first one. There were only 40 high schools in the United States in 1860, when some of us were beginning our education. When I began teaching in the high

[1] Abstract of an address delivered before the New York Chemistry Teachers' Club in 1917.

schools, there were 800, and the 1914 report of the United States Commissioner of Education gives the number as 13,714. There are, at this present date, probably 15,000. Buildings, equipment, and teaching force have not kept pace with that rapid increase in the number of schools. I say unhesitatingly that we are not as well off for rooms in which to teach, nor for equipment with which to teach, nor for teachers as we were 36 years ago. And this is but the necessary consequence of our astonishing growth.

When I began to teach, those 800 high schools were all little affairs, averaging perhaps 25 pupils each. There were not so many high-school pupils in the whole country then as there are now in some single high schools. We have several high schools in New York City now that have more pupils than all the United States had when I began to teach. The pupils now number about 1,500,000 against, say, four or five thousand in the whole country then. Think what the situation was like 36 years ago. I recall it very distinctly. One was apt to have about 6 pupils in the chemistry class. We had laboratories then as we have now, and with 6 pupils — all American born — homogeneous — there was no reason why one should not do good teaching, at least the best he was capable of. If what some one has said be true, that the instruction which each pupil receives is inversely proportional to the number of pupils in a class, there can be no good teaching in the great high schools of to-day. When we reflect upon the large number of pupils that a teacher has to handle in each recitation, the large number of recitations each day, the care of apparatus in such large quantities, the necessity of ordering apparatus and supplies a whole year ahead of time and then rarely getting what one orders, the high-school situation seems not only embarrassing but impossible. I recall that I secured during the years I taught in the high schools the privilege of buying directly from an appropriation whatever I needed, and I also had the privilege of planning the work — there was no syllabus, and no specific college requirement. It was a free hand for teaching individual pupils according to their needs.

When schools were small, a teacher was not all the while being supervised and super-supervised as at present. A teacher who knew his job was not then handicapped by the supervision of those who knew it not. This is a familiar feature of the great systems of to-day.

In those days when schools were small, politics did not enter. It was not worth while.

In those days we did not have a mongrel lot of pupils of all races not yet amalgamated. Only those got into the high schools who were fairly alike, intelligent persons, coming from intelligent families.

I do not think the tax-payer is slow in appreciating the value of the schools of to-day. One-third of his taxes goes to the schools and the high schools get about one-fifth of the school tax. We are spending on the education of each high-school pupil about five times as much yearly as we did thirty-six years ago but I believe we are giving him poorer instruction.

Another condition which may not be called embarrassing, but which I am sure we do not provide for adequately, is that the girls predominate very largely over the boys, and we generally plan for the boys and do not think of the girls. The percentage of girls in our high schools is increasing. Ten years ago 48 per cent of the pupils were boys and 52 per cent girls. To-day 44 per cent are boys and 56 per cent are girls. And when it comes to graduates, 40 per cent of the graduating classes are boys and 60 per cent are girls. The girls continue longer in the high schools and go to college in about equal numbers with the boys. When I was a college student, a college girl was a rare, not to say a unique, thing, anywhere in the country. Almost all the colleges and universities now receive women as well as men. I can at this moment think of but four institutions that exclude women from candidacy for the undergraduate degrees. There are a large number of institutions, chiefly state universities, that have more women than men. The college women seem to be likely, in the near future, to gain more prizes, such as election to Phi Beta Kappa, than the men. And if in the future, as in the recent past, men in the community continue to drift into office work and women continue to drift into the control of practical affairs, it will soon be true that women will surpass men in their knowledge of physical science.

Another item in the high-school situation which is worthy of comment is the fact that out of 13,715 high schools, 10,547 are schools with only 3 teachers each. Very few high schools — three or four hundred — have specialized teachers of any particular science. In the face of this fact we have recently undertaken to equip teachers for the schools with that dense ignorance which characterizes specialists. This is doubtless a passing phase in secondary education.

Thirty-six years ago, the value of the books in the high-school library was many times the value of the apparatus for science teaching. Now the figures are: sixteen million dollars for scientific apparatus against six million volumes in the library. The "scientific apparatus" has not much to do with the interpretation of life and should give place to "commercial stuff," but the most disgraceful thing about the present situation is that the libraries do not contain anything useful. A lot of the high schools have in their libraries no books of science that any one reads. Meanwhile the community outside of the schools is reading much that should gain admission to the school libraries as a real aid to science instruction.

Not only have the schools within the last third of a century become overcrowded with pupils, but they are greatly overcrowded with subjects, the number having increased from half a dozen to more than two dozen in typical high schools.

The greatest cause for embarrassment, however, is our changing ideas concerning the purpose for teaching any subject. Three or four decades ago, if we wanted to indicate that a man had great knowledge, we always attributed to him great powers of memory. President or professor so and so was a wonderfully bright man because he could remember the old students and call them by name whenever they came back to visit alma mater. Afterward it dawned upon us that a table waiter surpassed professors and presidents in the matter of memory. I remember one of the first shocks I got on that theory of education. Many years ago while attending a teachers' convention at Saratoga several hundred of us passed into the hotel dining room and a big, burly negro took our hats without checking them. When we came out he astonished us by handing each his own hat. And I said, "What is the use of a college education?"

XVII

THE AIMS AND METHODS OF SCIENCE TEACHING

THE aims and methods of science are best portrayed in the lives and labors of those masters of science who have lived since the time of Galileo, notably Pasteur and Faraday. These aims and methods are now so generally approved and applied by the teachers of all subjects that the "scientific" method no longer distinguishes the science work from other work in the schools. Science teaching, if it follows the examples of Pasteur, Faraday, etc., may not justly be differentiated from other subjects as materialistic or lacking in cultural or humanitarian elements.

The purpose of science teaching in all grades of schools is not chiefly to impart knowledge of subject matter but to train persons in the method of the masters, which is invariably the *project method.* This is the method used by intelligent men in achieving their ends, in school or out.

A project is characterized in the words of Professor Mann as follows:

"(1) A desire to understand the meaning and use of some fact, phenomenon, or experience. This leads to questions and problems. (2) A conviction that it is worth while and possible to secure an understanding of the thing in question. This causes one to work with an impelling interest. (3) The gathering from experience, books, and experiments of the needed information, and the application of this information to answer the question in hand."

A *project*, or *problem*, differs from and is superior to a *topic* in that (1) a project originates in some question, and not in such a logical sequence of ideas as may be found in codified subject matter. In teaching from the so-called "logical" texts one wrongly attempts to induce pupils to accept topics as their own projects. Logical organization of such material as functions in life will be the final result of a protracted study of projects. (2) The project involves the active and motivated participation of the pupil in carrying it out. It does not, therefore, like the topic lend itself to didactic, formal treatment in which the teacher does all the thinking and the pupil passively absorbs. (3) Projects furnish a basis for the selection of facts according to value or significance, topics furnish no such basis for selection. (4) The project seldom ends in a complete, final, or absolutely finished conclusion. It is, therefore, far less likely than is the topic to leave the pupil with the idea that he has heard the last word on the subject. It leaves him open-minded. The project, or problem method of teaching when well done leaves the pupil with a well-organized mass of useful information plus a method of work which will lead him to continue to acquire more. This entire discussion arises from the fact that the logical, topical method has failed to do just this.

Children and adults alike are endowed by nature with the elements of the scientific spirit. The purpose of science teaching is accomplished most successfully when the science classes merely furnish and shape an environment in which the scientific spirit may grow. Under the direction of a teacher who comprehends the workings of the mind, the project method duplicates the methods of active life and thus prepares the pupil for independent thinking.

The present need of the schools is for a large collection of sample projects, or problems, which may be used in showing teachers in a given community how to devise and utilize projects adapted to different grades of pupils in their own environment. The curriculum is the sum of such projects. It must always remain in a state of flux.

XVIII

THE IMITATION OF THE MASTERS[1]

In using the project method, one does not begin with a topic or a caption like a proposition in geometry. The project is in its nature less formal, less conscious of what conclusion is to be reached. It cannot, if genuine, proceed according to a plan of organization imposed by another. It works toward conclusions which may be far distant. It is merely the method of research adapted to the age and capacity of the individual. It works *toward* definitions and fundamental principles rather than *from* them. In short, it reverses the prevailing order of school procedure and follows the natural method of scientific workers.

Any one who has observed the innumerable attempts during the past quarter of a century to codify logically the subject matter of science for school programs, any one who has listened to the academic and endless discussions regarding the syllabus which engage the attention of teachers' conventions, must sometimes feel that high-school and college courses in science are designed to kill research, which is, after all, merely the method of intelligent life.

Our "text-books" in physics and chemistry are

[1] Abstract of an address delivered before the Conference of Schoolmen at University of Pennsylvania, April 11, 1918.

chiefly encyclopedias, or, in some cases, dictionaries. They are not, properly speaking, text-books. They should be treated as books of reference. They are not courses of study. Those who call project study a hodgepodge and oppose to it what they call a logical arrangement, or a plan of organization of subject matter, are thinking of these so-called text-books as study plans. One might as well hope to get history from an encyclopedia as science from an encyclopedic text-book. Real science instruction follows a different kind of organization from that of the encyclopedia or the dictionary. We get literature from Shakespeare, not from the dictionary. But Shakespeare is a hodgepodge from the standpoint of the lexicographer, Shakespeare is not arranged alphabetically. And the orderly projects of Pasteur are a hodgepodge from the standpoint of some of our elementary science texts.

Dictionaries, encyclopedias, and such text-books as we now have are very satisfactory books of reference. But students in schools and colleges should have books which present science as living projects. They should read as many books in science as they read in literature. No scientist has ever developed without this reading habit. He who will study the lives of the masters of science will find that they were all great readers. They were also rebellious against the formalism of the schools. And they pursued projects in science apart from teachers and schools. These projects have an organization unknown to the schools but known and approved by all of the masters of science.

I suggest books, not as a side issue, but books to be used as the teachers of English use books, a dozen or more a year for each pupil, not the same books year after year. We have hundreds to choose from.

Among the books, which students should read and report upon, are scores of biographies of the scientists, histories of the development of science and invention, original monographs of the work of scientists, such books as John Tyndall and Silvanus Thompson wrote on scientific subjects, etc., etc.

The great masters of science, Galileo, Faraday, Pasteur, Darwin, etc., illustrated in all their lives and work the project method. The intelligent man illlustrates it in all his work outside of the field of education. High-school pupils use the project method in all their self-directed work outside of school. But when the schoolmaster undertakes to direct the pursuit for knowledge, he formalizes, he systematizes, he schematizes, and invariably inverts the natural order of learning. The result is that our young people are getting their real science through various outside agencies.

About the time of our Revolutionary War there lived in the parish of Selborne, England, an excellent exponent of the project method. His name was Gilbert White. He roamed the fields and woods to see what he should see and made notes of his observations upon a great variety of subjects. His book, published under the title *Natural History of Selborne,* is still a classic.

Very perfect illustrations of the project method are to be found in the works of Galileo, Davy, Faraday, etc., but Louis Pasteur was the greatest master of the project method and nowhere is the method better presented than in *The Life of Pasteur* by his son-in-law, René Vallery-Radot, Doubleday, Page & Co.

It is easier, and perhaps more important, to tell what the project method is not, than what it is. It is not "merely an entertainment for the young who are not yet ready for serious science." There seems to be an impression that the project method is somehow connected with the *general science* movement and that the whole matter has to do with young children. It is quite as important that high-school and college students should learn the scientific method as that junior high-school pupils should do so.

It is not "a device for getting hold of deficient students and keeping them from making trouble or from leaving school." This argument has been used for the introduction into the schools of industrial education and a multitude of subjects. It was very much used to help the introduction of science into the schools a generation ago. But such considerations are too trifling for us.

Nor are we concerned with the question whether incompetent teachers can handle it. Every suggestion for improvement in the schools meets the knock-down argument that incompetent teachers may not be able to handle it.

The project method is not "some new thing." We are not engaged in promoting new philosophies for fickle Athenians. It is not something to be stereotyped and printed in a "text-book" and sold to the schools of a nation to be memorized by a million unhappy pupils. It is not "soft pedagogy," nor "a hodgepodge," nor "an unorganized mass," nor is it "desultory and scrappy," nor "a royal road to learning." It is none of those things which its pettifogging, hypercritical foes say of it, and it is not much of what its superzealous friends say of it.

If it is true, as I believe it is, that the project must always arise in some "cross-road situation," some doubt as to the next step, some question, vital and impelling because of its personal interest, then *air* is not a project. No intelligent person inquires about the air, and no free person would submit to the protracted instruction which we expect the young people to endure upon that topic. If we spend the first month teaching them what they already know about air and the second month teaching them what they can never care to know about it, we should expect that the intelligent among them would vote that "science is the most useless study in school." Nor may we help the matter by calling this sort of thing *general science*, or project study, as some misguided persons do. If, however, a pupil says, as one did to me, "I can understand the use of a propeller to a ship in water, but how a propeller may be useful to an airship is a mystery to me," we have a challenge to enter the topic of the air by way of a project. And if we satisfy the inquirer so that he will come again, the chances are that we are good teachers. But if we persistently put aside such questions as irrelevant to our scheme, we shall not long have inquirers, and it is fairly certain that we shall not be rated as good teachers.

Heat is not a project. But when the first subway opened in New York and men, expecting a cool ride to their offices on a hot summer day, found it hotter than the street, a project in heat arose which inspired diligent study on the part of many.

Combustion is not a project. But when, about a century ago, the coal mines of England were likely to be abandoned on account of the frequent explosions of fire damp, Humphry Davy had a project in combustion, kindling temperature, and whatnot, which resulted in the miner's safety lamp.

It is not necessary that project study by high-school and college students should always involve experimental work. To read a description of project study by a master scientist is often more profitable.

Projects do not often confine themselves to one topic. It is their nature to overflow these artificial boundaries. In this connection one cannot fail to think of the farm projects that are engaging the minds of some of us.

According to Pasteur, a project has more to do with the general and everyday happenings of nature than it has with academic specialization.

Pasteur, the greatest scientist France has known, and, by their own election, the greatest Frenchman, had great difficulty in gaining admission to the Academy of Science because, as he said, the members were such narrow specialists that they could not appreciate a piece of research.

They thought, because he examined crystals with polarized light, he must be a physicist. But they sought him in vain among the ranks of the physicists. Because he studied crystals, they thought he might be a mineralogist. But he was not to be found in their ranks. Because he analyzed those crystals, he should be a chemist. But he was working upon fermentation at the time and that was not the business of pure chemistry. And so the founder of the doctrine of *isomerism* was rejected. This was in 1857, when Pasteur was thirty-five years old.

In 1861 Biot, on account of researches pursued by Pasteur, nominated him for membership in the Botanical section of the Institute, saying, "I can hear the commonplace objection: he is a chemist, a physicist, not a professional botanist. But that very versatility should be in his favor." He was rejected.

In 1862, when Pasteur was forty years of age, this chemist, physicist, mineralogist, botanist, zoölogist, physiologist, and, more than all, this scientist was elected to membership in the Academy of Science only by the sheer weight of influence of two great men, his great friends, Biot and Dumas.

Pasteur, the man who put medicine upon a scientific basis, was barely elected (by one vote) to the Academy of Medicine. This was in 1873, when he was fifty-one years of age. He was at the time world famous and the holder of an honorary M.D. degree from a foreign university. At every incursion on the domain of medicine he was looked upon by specialists as a chemist who was poaching on the preserves of others. The physicians and surgeons called Pasteur a physiological chemist and said that physiology can have no connection with medicine and they considered it a waste of time to listen to a chemist. Pasteur maintained "that science was indeed one and all-embracing and that all sciences gain by mutual support." At sixty years of age "he vehemently opposed the false idea that each science should restrict itself within its own limitations."

His life had been given to the study and the teaching of such varied projects as isomerism, fermentation, spontaneous generation, the diseases of wine and beer, silkworm diseases, fowl cholera, swine fever, splenic fever, and hydrophobia. His students acquired not a taste but a passion for study. His greatest ambition in life was to serve humanity. "Nothing," said he, "is more agreeable to a man who has made science his career than to increase the number of discoveries, but his cup of joy is full when the result of his observations is put to immediate practical use."

"His great intuition, his imagination, which equaled that of any poet, often carried him to a summit whence an immense horizon lay before him."

We are now reaching the stage when many are attempting to *define* the project method. Educators are prone to separate into camps and schools over definitions, and many good ideas fail of realization in the schools because of partisan discussions.

Christ illustrated Christianity by His life and it may be doubted whether He has ever been misunderstood. But Paul wrote more than half of the New Testament to define Christianity and the church fathers have written countless volumes to expound it with the result that hundreds of warring sects have been formed and Christianity has been almost lost in a fog of dogma and debate.

The only way to appreciate the project method in the pursuit of science is to study its exemplification in the lives of its masters. It must be acquired through imitation of the masters. The greatest teacher of science in America was Louis Agassiz. One summer of association with him on the little island of Penikese, with the intimate relationship of disciple to a master, produced that galaxy of scientific men: Apgar, Brooks, Crosby, Guyot, Holder, Jordan, Minot, Morse, Packard, Putnam, Shaler, Wilder, etc.

Most great scientists have been disciples and imitators of other great scientists.

No one can teach the scientific method unless he is himself a scientist and the scientist must teach more by example than by precept.

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Printed in the United States of America.