

good teachers are not easily made. It is harder to train a teacher to conduct laboratory work efficiently than to train one to teach mathematics or a language. In science the laboratory presents a new problem, and serious errors have occurred and are occurring. Yet, in spite of this, great progress is being made, and there is little doubt that in the end scientific training will fully justify itself in the schools and colleges.

In closing let me again specifically state that I do not consider myself competent to speak of science training in the secondary schools; all that I have been saying applies, so far as my own definite knowledge goes, only to the colleges.

A RETROSPECT AND A VISION.*

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One can always see a thing in truer proportion by viewing it from a distance. In the last three years since I gave up teaching physics, my confidence in the validity of some of the principles to which I had clung for years has gradually weakened and the number of things which I think that I would do differently, if I were to teach the subject again, has gradually increased. I have no intention of making a sweeping criticism of present conditions and I do not presume to be qualified to judge your work. I propose merely to speak of the misgivings which have come to me about my own teaching and of an occasional vision of something far better which has appeared within range in moments of optimism. I hope that my experience may touch yours closely enough to make my confessions and my suggestions of interest. I shall be particularly interested to know how far you men who are teaching physics regularly will agree with my notions.

As a schoolboy, I had the Harvard course in physics soon after it was devised, and in all the years of my teaching of the subject, I have had college preparatory pupils. It is not surprising, therefore, that the forty experiments should have filled a large place in my conception of the proper course for high school pupils. I was always rather more fortunate than the average teacher of physics, in regard to time allotment, and was,

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therefore, not greatly impressed by the complaints of some of my friends in the profession of the difficulty of meeting the requirements.

I have always enjoyed exact measurement. The careful determination of physical constants and the consideration of percentage of error have always appealed to me. The quantitative experiments naturally seemed especially worth while, and I used to value highly some of the experiments which recent practice has tended to disparage. I stood for much individual laboratory work, for the mathematical statement of physical laws, and for the solution of problems based on any relation which would lend itself to mathematical statement, as an essential test of the understanding of the relation.

The dictum of the Committee of Ten that the same course should be taken by all pupils I accepted on authority. It seemed reasonable enough at the time that what is good preparation for life is good preparation for college. The college preparatory course in physics seemed adequate as a basis for such preparation.

I welcomed the tendency to make the class-room work touch life and used illustrations especially from engineering practice freely. Time permitted one or two excursions to industrial plants, telephone exchanges and the like, though not as many as I should have liked to make. I approved of the suggestion that some use be made of the history of physics but never found time to carry it out in practice.

The boys, as a rule, and a few of the girls were thoroughly interested in the work and did it well. In most classes the majority of the girls had no very strong interest and some found it next to impossible to get any real grasp of the subject as presented, although most of them succeeded by painful effort in remembering enough to pass the examinations, both at school and at college.

As I think of my experience with these classes, I am convinced that the work as given was excellent training *for some of the pupils* but that others gained comparatively little of permanent value. Many of the pupils did catch an enthusiasm for exactness of work. For them such work was a real training which gave permanent results in their attitude toward experiment and measurement.

For some pupils, too, the mathematical treatment of the subject is a delight. I am not in sympathy with the recent attempt

to cut out practically all mathematics from the subject. One of the most important conceptions to be given the student is, in my opinion, that of the existence of order, law, exactness of relation, in the universe. The student ought to be given some sense of this exactness of relationship, and some notion of the tremendous part which a knowledge of mathematics has played and is playing to-day in the development and application of science. Now, to deny the student with some taste for mathematics this view in the form in which he can grasp it most clearly and with the greatest enjoyment is, to say the least, neglecting an opportunity. For some of my pupils, then, the mathematical treatment and the quantitative experiment were of distinctly more value, so it seems to me, than a qualitative treatment would have been. For other pupils, however, and especially for most of the girls, a course in which less exclusive emphasis was laid on the quantitative aspect would, I now think, have been more effective.

This raises the question of the validity of the view that there is one best course for high school pupils—a course which is made up of material which everybody should know and whose methods furnish training calculated to produce certain qualities in the pupils. As I reflect upon the question, I am inclined to think that reliance upon such a course is vain, and that to produce permanent results, we must adapt the course to the capacities, tastes, experience, and so far as possible, future plans of the pupils. We urge the value of individual laboratory work in cultivating habits of observation, and skill in manipulation, and we insist on mathematical solutions as training in logical thought. Experience shows, however, that this work does not necessarily produce anything of the kind. We have all had pupils, I imagine, whose laboratory experiments were a thing entirely apart from the rest of life, and whose habits of observation were not affected in the least by their experience in performing the experiments required. I have had not a few pupils in mathematics who could be taught the necessary operations and types of problems to enable them to pass the examinations but of whom I was morally certain that, once the examinations were over, the mathematical knowledge would evaporate with great rapidity, leaving no increased power of logical thought, as far as anyone could see. On the other hand, we all have pupils whose progress is unquestioned and in all whose work we can see the effects of lessons which have struck deep. The point

is that the cultivation of powers in a pupil is not *assured* by the type of work which he goes through. If he catches the spirit of exact measurement, if it appeals to him as something admirable, and so affects his own standards of work, the end is attained. If he performs the experiments, seeking the degree of accuracy which the teacher prescribes, conscious of the difficulty of attaining this result, but not impressed by its intrinsic value, the mere performance of the experiment is not likely to change his future performance. Indeed, it may result in a positive distaste for such painstaking work. It is of the greatest importance that the pupil's study of physics strike home, influence his standards and his attitude toward things. The same treatment will not affect all pupils in the same way, and the single course, especially if, as is often the case, the work outlined is so great as to require the teacher to hurry from one topic to another, is not, I believe, an efficient instrument for the purpose stated.

This leads me to a word about the college entrance requirements. I recognize the very great benefit which the requirements in physics have brought to science teaching in the schools of the country. They have raised the standards in equipment, in the training of teachers, and in the quality of teaching, and have had a powerful influence affecting the introduction of science into the high school course. I think, however, that the requirements have already served their purpose in these particulars and that at present their influence is a restraining and narrowing one.

Nobody will admit that his sole purpose is to fit his pupils to pass college examinations. I always protested that that purpose was strictly secondary. Nevertheless, I am aware that the necessity of covering certain ground, for which there was none too much time, kept the examinations very near the level of consciousness for the pupils and myself. I was obliged to leave out matter that seemed valuable, and I was seldom able to follow out a topic beyond the restricted field of the text-book. A remark of one of my mathematics class illustrates the frame of mind which the examination requirements produce. While studying the principle of similarity, I explained the construction and purpose of the pantograph, devoted a lesson or two to a consideration of the principle of the instrument, and suggested that one of the boys construct one. At the second lesson, one of the pupils came to me and asked how much longer we were going to spend on the pantograph. I asked if he did not find

it interesting. "Yes." Valuable? "Yes, but it isn't required for college, is it?"

So long as teachers are required to give so large a part of their attention to covering ground, they are not in a position to improve the course much, and they have little encouragement to reflect upon the ultimate value of their work. A "loosening up" of the requirements which would permit a teacher, who has established a reputation for thoroughness, to vary his course considerably, shift the emphasis from one topic to another, or from one type of work to another would result, I am sure, in better preparation for college work, as well as greater progress toward his own ideals.

I know the difficulties of the certificate system and I do not propose to start a discussion on the subject of college entrance requirements. I merely wish to express my view that, whatever value the requirements may have in raising and maintaining standards in the schools, they do stand in the way of progress toward an understanding of the real purpose of science teaching and the means of attaining it. As the examinations are likely to hamper us for some time to come, the opportunity for progressive work lies with those who are not concerned exclusively with college preparation. The non-college courses have, as a rule, been modeled on the college preparatory plan, but I have no doubt that there will be an increasing tendency on the part of non-preparatory schools to plan their courses in accordance with their own needs.

My *vision* relates to the effect of the study of physics upon the pupil's attitude of mind. I can imagine a teacher inspiring his class to the extent of causing *them* to have visions. Indeed, that takes little imagination, for we all know a few such teachers; but there are times when I see how I could do something of that sort myself. At least I feel sure that I could come nearer to it than I used to do. If the study of science by high school students is to have its highest value, it must affect their emotions. Boys and girls of this age are capable of intense enthusiasm. It ought to be possible to arouse in them an enthusiastic appreciation of natural law, a sense of awe and admiration for the perfection of order and of relation in the universe, as well as an intense interest in man's effort to understand, to unravel the mysteries, to know. I think it is safe to say that very few pupils carry away anything of this sentiment from their study

of physics. On the contrary, many have acquired a deep dislike of the whole subject, a dislike which is strong enough to have its influence on younger pupils and to cause them to approach the work with something almost of fear. The average pupil thinks of physics as a certain text-book, experiments in specific gravity and boiling point, problems, etc. He has no greater love of nature, no conceptions of the vastness and perfection of the universe.

To attain the desired attitude on the part of the pupils is quite a different matter from seeing the vision, and I can only hint at possible ways of working toward it—ways which I think I should try if I had the chance. In the first place, it would be necessary to change the emphasis given to different topics and some of the topics commonly studied would have to go. The teacher would have to take time to make thoroughly clear the topics on which he relied to influence his pupils most, without feeling that by so doing he was getting behind his schedule. He should treat carefully some of the great laws of nature, like Conservation of Energy, or the Law of Gravitation, using plenty of illustration and trying to give a conception of the magnitude and the perfection of order in the universe as expressed in these laws. When the laws are used as convenient expressions upon which to base problems, they arouse little enthusiasm. I venture to say that they can be so treated as to be a real inspiration, and, with the right emphasis and due care in presentation, numerical examples can be used to make the conception more definite and striking, even to the non-mathematical mind.

Historical material could be used to good advantage. Enough time should be taken to give some aspect of reality to the scientists of past centuries. A little study of the knowledge which men of the Middle Ages possessed would serve to disabuse pupils' minds of the impression that all scientific discoveries have been made within a few years. Then a rapid survey of the search for truth continuing from century to century, and of the sacrifice and even martyrdom which were suffered for truth's sake, should help to give an appreciation of the inheritance which we enjoy and a keen interest in present efforts to extend the frontiers of knowledge.

Besides the sense of reverence for the universal harmony, a pupil ought to leave the physics course with an interest in the physical phenomena and the applications of physical principles with which he comes in contact day by day, and with the ability

to use his knowledge of physics. To arouse this interest and to make it most effective, there is again need of differentiation. The things with which the pupil is familiar or with which he is most likely to deal after leaving school ought to furnish the illustrations for class work. The books have been adding much material which is of interest to the *boy*, but it is not surprising that alternators and gas engines have not the same attraction for the *girl*. It would be advisable, I think, to point out to girls as far as possible the applications of physics relating to the home. For example, in connection with specific gravity, the use of hydrometers for determining adulteration of milk, might well be substituted for the measurement of the specific gravity of a copper sulphate solution. In discussing machines, the egg beater, ice cream freezer, or sewing machine might well take the place of or supplement the usual illustrations. The water supply, plumbing, and heating systems are especially valuable topics to take up with girls. A rather more extended study of the principles of sound illustrated in musical instruments and of color suggest themselves to me as features of a course for girls.

In conclusion, I would repeat the points which I have emphasized—

(1) That physics should be presented so as to arouse enthusiasm, not simply as a disciplinary exercise.

(2) That differentiation is necessary in order to make the subject most effective, the work being adapted to the needs, tastes and experience of the pupils.

Enthusiasm is the chief product to be sought and the effort to produce it should be uppermost in the teacher's mind. The means employed is far less important and the teacher should be ready and free to vary subject matter and method to attain his end.

You will bear in mind that I have been confessing my own shortcomings and expressing my hope for better results than I have ever attained. I am aware that some of you are doing the very things which I would like to do. The obstacles which hampered me are, however, still in the path of many teachers, and taking the general view of physics teaching in the country to-day, I believe that no apology need be made for urging the need of a clearer understanding of real values to be gained by a study of science, and a more searching examination of actual results.