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THE AIMS AND TENDENCIES IN PHYSICS TEACHING.

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In the discussion that has recently taken place concerning the teaching of elementary physics, two apparently contradictory conceptions of the value of the work have come into prominence. On the one hand, it seems to be the very general opinion of high school principals and of others in control of preparatory schools that the work in physics is highly unsatisfactory—that the amount gained by the student from his study of this subject is by no means commensurate with the time and effort expended. For example, a man, who has been for a number of years the principal of one of the largest high schools in the West, writes that his observations on the subject of physics teaching have forced him to the unwilling conclusion that physics is the most detested subject in the whole curriculum. Another principal of similar experience tells us that we surely have lost much of the spirit that the subject used to have when it was called "Natural Philosophy"—the spirit that compels us to spring from the bath and cry "Eureka!" Members of the College Entrance Board have also freely expressed the conviction that physics is one of two subjects which are in a highly unsatisfactory state to that body. Many other such opinions of men thoroughly qualified to judge have recently found expression, so that the opinion is widespread that somehow the teaching of physics is not as efficient as it might be.

On the other hand, there are many who claim that we have been developing the present system with great care and thought for a

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number of years, and that, as a result of this work, physics is now taught more efficiently than ever before. There can certainly be no gainsaying the fact that we have developed our laboratories and our apparatus in a wonderful way in the past twelve or fifteen years, largely under the influence of the Harvard Requirements and the Report of the Committee of Ten. There can also be no doubt that this development has brought with it a great deal that is of tremendous value and great importance, not only to physics teaching, but also to that of the other sciences.

Moreover, in support of this second conception, attention is called to the fact that there cannot be found a set of teachers who are more loyal and devoted to their occupation, or who work harder than do these very physics teachers. This fact cannot be denied by anyone who has seen how these teachers are organizing into associations, and who has noted the zeal with which they are constantly on the alert for some new idea that will help them to make a success of their work.

If asked to which of the opinions just mentioned I subscribe, I do not hesitate to answer "To both." For the weight of evidence is in both cases so great, that it is impossible to deny that both conceptions are true, each as far as it goes. There can be no doubt that we have developed the teaching of physics—technical physics, I almost said—to a marvelous degree of perfection. In fact, it seems at times as if we had been so busy perfecting our apparatus and methods of teaching physics, that we have for the time being entirely lost the art of teaching boys and girls. We seem to forget at times that youngsters of the high school age are interested primarily in life, in growth, in activities, and, as President Hall puts it, in the "go" of things. They are not interested then, as they may be later, in principles that have been so abstracted, not only from phenomena as they know them, but also from all human relationship, that they are stated as infallible, and are at times even called axioms.

The conclusion that seems justified, then, is not that the physics teaching is not efficiently done; but rather that it is too well done; not that it has not been developed well along the lines it has laid out for itself; but that it has been carried too far in the direction of perfecting its technical side at the expense of, or with a total disregard for its strictly human bearings. The problem thus seems to be not so much one of inventing a new set of experiments, nor yet one of perfecting our apparatus and making it more elaborate and accurate but simply one of method of presentation. Can the subject of physics be so presented as to have its human bearings evident, both explicitly and implicitly? If so, how may this be done? These are the questions to which I hope to give a partial answer this evening.

Perhaps the simplest and most evident method of relating the subject to the lives of the students is to base every argument and discussion on the experiences of the boys and girls rather than on the laboratory experiments. The current method of presentation begins by stating the general conclusion, and ends by showing how this general conclusion enables us to "explain" some of the well known daily observations. Great results may be obtained by so simple a device as that of inverting this order. Begin by raising questions about common experiences; show that some general statement like the law under discussion might assist us in relating a number of different experiences; lead up to the law, being careful that all the concepts involved in it are grasped with some degree of clearness; and then, and not until then, introduce the laboratory experiment in verification, to as high a degree of accuracy as desired, of the conclusion drawn.

Much interest can be added in this method of presentation by tales from the history of science—for the history shows clearly that this is the way in which science has developed. The study of heat did not begin with a statement of a general theory of heat, followed by statements of various laws for particular phenomena, with practical applications bringing up the rear in justification of the laws. The science of heat grew out of a practical necessity of the society of the 16th century. As you know, mining was at that time becoming very expensive, because the surface deposits of coal and ore had been exhausted and it was necessary to go deeper. This was a difficult task in those days, because of the impossibility of keeping the mines free from water at the greater depth. Treadmills were developed, until they sometimes had as many as five hundred horses in a single mill. Yet they could not keep ahead of the water. This need of society at that time led eventually to the invention of the steam engine, and to the theoretical study of thermodynamics.

In optics, in the same way, in response to a human need, spectacles preceded telescopes and the theoretical study of lenses; and even in mechanics, derricks, hoists and various "engines of war" nay, even triremes and other boats were made before

Archimedes told men what the law of the lever was and how it was that objects could float on water. Although it is clear that the so-called "historical order" cannot be followed too slavishly in devising an order of topics, we can, nevertheless, learn from history this all-important fact, that science owes its origin to certain human needs, which in turn grew out of the circumstances of social life and were expressions of desires of the human heart. If then, physics is not taught until the high school age, might it not be better presented as a response to desires for further comprehension and mastery of the practical things and phenomena about one? And is it not more in accord with the method of science to begin with the experiences and the phenomena and to lead up to the general conclusion, rather than to do—as is generally done—throw the general result at them first, and then adduce the experiences in verification?

But I dare say that many of you have been using the ideas just expressed in your work for many years, so that they are not at all new to you. Is there no other way in which the human element may be introduced into science teaching? Another way appears at once, if we can bring ourselves to realize what science really is, and what its service to humanity has actually been. In order to do this, we shall have to discard some of the ideas on which we have been brought up from our cradles. We must recognize that our modern science is not in any way a further development of Greek and Roman so-called science. Our science is fundamentally different from that of the Greeks, and is the great and distinctive contribution of the Teutonic races to our modern civilization.

Many causes have been assigned for the failure of the Greeks to develop a science that was in any way commensurate with their achievements in other subjects like art, literature, and philosophy. The most far-reaching explanation of this seems to follow from that interpretation of the Greek character and of their contributions to modern life which sees as their chief characteristics a deep feeling for absolute perfection, combined with a free creative power of artistic abandon. These were the characteristics that enabled them to execute sculptures that have never been excelled, and to create a literature and a philosophy that stand yet among the greatest productions of men. But these very characteristics which made the Greeks preëminent in other subjects, seem to have been the source of their failure in science. Since they could not tolerate anything that was not a perfect, artistically symmetrical, ideal and absolute whole, their scientific conceptions must needs also have partaken of this characteristic. Hence, no descriptions of phenomena that did not immediately "explain" everything completely could be considered by them. An approximately correct solution in matters of science was as intolerable to a classic Greek as a dogmatic, cock-sure scientist is to us today.

And this, perhaps, brings out as forcibly as is possible the ideas which seem to be of such fundamental importance to science teachers today. We must see clearly that science neither gives nor can give final answers to our queries; nor can she ever lead to complete, perfect, or absolute conclusions. The "laws" obtained by her aid are in every case the interpretation that has been put by some man on the phenomena about him. Scientific laws are not binding on nature, in the sense in which legal enactments are supposed to be binding on the individuals of a community. They are, let me repeat, but the interpretations that some human man or men have put on the phenomena about them. These laws are thus the product of two factors—nature's action on men, and men's reaction on or interpretation of nature. Hence the laws of physics are really certain men's opinions about the phenomena of nature, and they should be so taught to youngsters. These latter then perceive that scientific laws are of human origin, and they realize that human power may some day be able to alter the laws—not by reordaining the ways of nature, but by showing how a better or a broader interpretation may be put on her operations.

In opposition to this point of view it has been urged that young people need—nay, must have perfectly definite and concrete statements to deal with during their high school age. If, for example, we tell them that Newton's laws of motion are but Newton's interpretation of the phenomena of motion, and that they may be altered some time, the youngsters fail to grasp anything clearly and with definiteness. It is not, however, necessary to make the statement of these laws any more vague and indefinite in one case than in the other; and yet it makes a vast difference in the child's attitude toward science whether you tell him that these laws must be looked on as physical axioms (Sic!), or whether you tell him that they are but human interpretations of the phenomena of motion. In both cases he learns the laws as definite concrete things; but in one case they come before him as Divine fiats, to be learned by heart, willy-nilly; in the other case, they are seen to be of human origin, and so are felt to be related somehow to men and to partake of the frailties of men.

The difference in the effects of these two methods of presentation is even more marked if the laws are stated at the end of the discussion rather than at the beginning. If we begin by asking the students many questions about what they have noticed in their experiences in putting things into motion, and if we have brought them to see that some such interpretation as that of Newton is both called for and justified, and if we have, perhaps, even led them to draw the conclusions by themselves first, then the laws, stated as Newton's interpretation, will appeal to them; and they will begin to appreciate the greatness of Newton in being able to formulate such far-reaching conclusions.

We may now comprehend the meaning and the importance of this Teutonic conception of science. For if scientific laws are human interpretations of phenomena, they must of necessity be but close approximations. The Greek would not acknowledge this and he refused to work with such, to him, uncertain materials. But the German not only acknowledges that the laws are approximations, but he also is content to use these approximations until better ones are found. Herein lies the power of the Teutonic science: for unless we are willing to consider every scientific conclusion as an approximation, no growth of science is possible. Hence the Greek science did not grow. But if we do look on all scientific laws as but close approximations—as expressions of the relations that probably would exist if matters were arranged according to somebody's ideal—and if we also remember that different people may have different ideals, we build a science that has endless power of growth. This is what the Germanic races have done: this is what every scion of Teutonic blood should both appreciate and learn to do.

The effects on the students of teaching from this point of view are both immediate and gratifying. Their young minds are at once freed from the incubus of the axiomatic, dogmatic, and finality atmosphere of the usual elementary text; and there is opened before their imaginations boundless territory for exploration and investigation. They soon come to believe that they too have some chance of doing something for themselves in science, or of inventing something that may be of great value in the world. Because of the introduction of these ideas into elementary college work, I have repeatedly observed the change of heart that has come over students who have come to college with their imaginations prostrated from an overdose of finality in the preparatory work in physics. Such prostrations are invariably cured, so that both imagination and enthusiasm return, by contact with the real, vital, life-giving spirit of Teutonic science, as revealed in the works of her greatest masters like Galileo, Huyghens, Newton, Faraday, Tyndall, Helmholtz, and the rest.

One of the greatest difficulties in the way of our teaching science in the manner just described is the habit of teaching dogmatically which we have formed from having been taught that way. This habit is the more confirmed because some subjects must be taught in this way. Thus in studies in grammar, for example, the dative of such a noun is so-and-so; this fact must be learned with accuracy in a certain way; there is no chance for human interpretation or imagination to operate. In fact, the operation of the imagination in such cases usually works disaster at examination time. When science was introduced into the schools, it was naturally taught in the same manner as the older subjects, Latin, Greek, and Mathematics were taught, namely, dogmatically and deductively. But it is now time for us to realize that science is our process of interpreting natural phenomena, and that new interpretations are always possible—nay, more, without them we make no progress in the knowledge and power gained through science. Hence if young people are to become adepts in science, they must be taught how to interpret for themselves. They should develop the habit of making sound interpretations of phenomena—a habit which can be acquired only by scientific study of the right sort.

There are many other principles which should be considered in the development of a proper system of science teaching. I have attempted to call attention this evening to the two which seem to be especially important because of our frequent violation of them in the methods of instruction now current. These two are: 1. That science should originate in the individual as it did in civilization in response to a pressing necessity of social life, this necessity having in turn arisen because of some inner motive for the satisfaction of some human need. 2. Modern science consists essentially of the method of obtaining conclusions by approximation, and the conclusions or laws thus obtained are human interpretations of natural phenomena. This method was invented and developed by Teutonic men, and hence all conclusions reached by its aid are human productions, subject to change at any and every time. If these two ideas are constantly applied in our work, science will no longer be lacking in human interest; for it will be found to have been able to satisfy the human needs which called it into being, and will be found also to be as much a work of human, free, creative imaginative art as is the Iliad, the Venus of Milo, the Madonna of Raffael, or a Wagner opera.

CHEMICAL THEORY IN THE HIGH SCHOOL COURSE.

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[CONTINUED FROM THE NOVEMBER NUMBER.]

I see no reason why the law of Boyle and also that of Charles may not be omitted altogether from the elementary course in chemistry. There are very few experiments where we use them in calculations and results almost as good can be obtained without them. When pupils are required to apply these laws to experiments, the added complexity will often cause them to lose sight of the point of the experiment. This objection may not hold so well in those schools where chemistry is taken after physics. Unless this be the case both may well be postponed. Should one wish to perform an experiment involving calculations based upon these laws, their formula could be used without any attempted explanation of their action. Bradbury in his recent textbook adopts this method, these laws being placed in the appendix, where they can be referred to when necessary.

The natural place for the periodic law is the last of the course when the properties and relations of the most important elements are well understood. The pupil now sees that they have been arranged according to law. He sees that the periodic law is the best classification which can be made, and the similarity of the elements studied together is proof of the truth of the law. It now presents many wonderful features to the student, especially in its relationship to the discovery of new substances. It adds an interest to the work which has been covered when he sees the system with which all of the elements fit into one another, and forms an agreeable conclusion to the work which he has done.

We can not well give a year of chemistry without something