SCIENCE.

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PRECISION OF OBSERVATION AS A BRANCH OF INSTRUCTION.

We sometimes find the philosopher envying the physicist because the results sought by the latter can be expressed *exactly*. In so doing, he doubtless overlooks the fact that all quantitative work has to be regarded as giving merely an approximation to the truth. Numerous and refined as are the precautions adopted, the careful experimenter must admit that his measurements contain errors whose sources are more or less hidden. Success will lie, not in ignoring this, but in recognizing it, and studiously avoiding any unwarranted claim to accuracy. His investigation may establish some law beyond a reasonable doubt. This law may be expressible in exact terms; but, so far as the direct quantitative results are concerned, he must give up, once for all, the popular notion of exactness. He must admit that the work merely shows it to be reasonable to assume the truth to lie somewhere between two limits, respectively greater and less than the one magnitude which he names. Desiring that these limits shall fall as near together as practicable, he will study the observations for internal evidence of the precision attained; but any appearance of accuracy greater than might reasonably be expected will often cause him more uneasiness than would a greater apparent error. Until the extent of the error is recognized, and found to be in harmony with experience derived from other similar observations, a cautious observer will not be confident of the result reached.

As the scientific professions are currently taught, it is possible to get a fair training (as a chemist, engineer, or electrician, for example) without properly appreciating the practical limitations to precision. He may instinctively acquire correct notions of the performances of the instruments he most frequently uses; but let a new operation, with a different instrument, be required, and he will too often develop the wildest notions as to the great accuracy attainable by the use of sufficient care. What is needed in our professional courses is systematic instruction in the general science of planning, conducting, and discussing observations, accompanied with adequate practice. This should be given as early as the student is fitted to profit by it, in order that the subsequent practical training in special branches may have a firm foundation.

The field for such instruction is ample. A good routine observer is one who, being informed of the accuracy desired at each step, is able to take just care enough to attain it, without wasting time and energy in uselessly perfecting certain parts of the work. Our professional observer must add to this the good judgment which is able to discover the relative accuracy required in different parts of a complex observation, and to decide how accurate to aim to make a single performance of the whole. In general, he will seek to avoid errors which usually occur in a single direction; but he will not always take the greatest care to avoid errors which are as liable to be negative as positive. Life is short. Time, to most, is money; and the ability to repeat an observation will often depend upon the ability to do it quickly. Moreover, in many cases, mere lapse of time allows additional errors to enter. Having avoided the larger errors, he will therefore seek to eliminate the effect of the smaller by repeatedly performing the work. Recognizing, then, the importance of reasonable speed, he will allow rough measures of certain quantities, provided the final error of the complex operation is not thereby appreciably affected. All this calls for a clear understanding of the causes of error, and an ability to reason out their effect upon the result. The knowledge of the differential calculus required is indeed elementary; but it must be a *tool* which can be applied as readily, for instance, as the knowledge of the properties of logarithms. All the principles are covered by the customary courses in physics and mathematics; but additional special practice in their employment is very desirable.

In the planning of observations, the theory of maxima and minima gives important aid; but this theory has so many other applications, that we can hardly ask of the regular course in differential calculus such attention to this one point as would insure the required facility. In the absence of such a course of instruction as is recommended in this paper, the matter is left to slow acquisition through practical experience. Knowledge is often thus bought at a high cost.

A general understanding of instruments of precision, so necessary to successful planning of observations, is also within the field of instruction proposed. Instrumental errors should be treated systematically: their preliminary adjustment to zero, their elimination from the mean of pairs of observations properly taken to that end, their determination in such manner that corrections may be duly applied, and the cost in time of variously managing them, should come to be understood through suitable practice. Here, particularly, each professional course is liable to inculcate its own narrow view.

An examination of the proceedings of the leading learned societies will convince one of the importance of good method in the discussion of results. It will also develop the fact that there exist numerous valuable, analytical, and graphical processes, which at present are not likely to be brought to the attention of the professional student.

The theory of probabilities as applied to observation would naturally be treated in the course proposed. If it were previously given to the student as a branch of pure mathematics, the attention could here be riveted upon its use, which calls for the exercise of much practical good judgment. It furnishes an important means of studying the precision attained, but just here is a great abuse. Its results, demonstrated for a very large number, are applied to very limited series of measurements. Again: its assumption of equal probability for equal positive and negative errors is allowed, in face of the fact that a preponderance of error in one direction is unavoidable. The rising generation of experimenters in every field of applied science should therefore be taught the many limitations which surround its application, and they should learn to avoid that indiscriminate use of its principles which has led to so many unfounded claims to accuracy.

We have outlined a subject the successful teaching of which requires qualifications not to be found in every scientific professor, and the successful study of which requires a concentration of the attention not likely to be given to it as a subordinate part of some other course. Already the appearance of treatises on probabilities, errors of observation, and least squares, has enabled writers on astronomy, geodesy, physics, and engineering, to devote their attention to special applications, and has saved the waste of space which would otherwise be given to the general theory. Similarly, we should avoid that distraction of the student's attention from the main subject of a professional course which results from the necessity of frequently pausing to give additional information about the subject of this article.

Although the first object of establishing a course of instruction in any branch of applied science is to put the students into possession of the best methods already reached by workers in that field, the end attained is often something more. The instructor's attention is speedily called to conspicuous omissions, and his energies are consequently bent upon supplying the defect by demonstrating and testing some theorem or method which meets the want. Thus the schools come to the aid of the professions. Are they yet doing their whole duty in regard to the science and art of observation?