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THE EDUCATIONAL VALUE OF THE STUDY OF QUANTITATIVE ANALYSIS[1]

How often it has been said that the most important and fundamental instinct of man is the creative instinct, and how many morals have been pointed from this conclusion! This, it may be said, is one of the principal causes for the high degree of development of science and for the advanced state of our civilization. But if this is the orthodox scheme for looking at the matter, I am going to venture a heterodoxy by saying that, quite the contrary, the most primal, fundamental instinct of man is that which prompts him to take things to pieces. If you can remember when you were at the tender age of, say, four to ten years, you will probably recall no greater delight than was given by the opportunity to tear down an old watch, a bicycle or a piece of domestic machinery, to see how it was made and what made it "go." Unfortunately it was not always easy to reverse the process, and the thing would not always go when it was put together again. We are all familiar with the ancient story of the boy who took apart the family clock and who somehow could not get it together again without having a quart or so (I mean a liter or so) of wheels and screws left over. And the small boy often "analyzes" the logic of theory and rules of his elders with the same disconcerting thoroughness, neither he nor his elders being able to piece the thing together again into anything that will "go." Many embarrassing and uncomfortable moments in the family life have resulted from this.

All of which merely gives us a chance again to state that we are, by nature and inheritance, analytical and not synthetical. We want to know of what the universe is constructed and what forces keep it operating. Our greatest minds are devoted to the search for the answers to these questions. It is only a logical consequence and a secondary outgrowth of this passion to know the how and why of things that we utilize the results of scientific search for causes and ultimate forms in the construction or "synthesis" of things having a different outward form and inner nature, and having a wider field of usefulness.

In the analytical laboratory of the college and the university we attempt to direct this useful and un-

[1] Read before the Section on Chemical Education of the American Chemical Society, at the New Haven meeting, April, 1923.

quenchable desire for a knowledge of fundamentals along the lines of orderly and systematic investigation of the composition of things. Possibly it is for this reason that the student often feels that this is the first course in his chemical training that offers any prospect of practical usefulness. He is here, at least, utilizing some of his laboratory effort in the pursuit of semi-practical questions. But as we now gain from the quickened interest taken by the student in his work, we encounter a new difficulty in our attempts to keep the scientific aspects of the subject in their proper prominent relation to the practical bearing of the figures which represent the result of the analysis.

Should the primary aim of the college course in quantitative analysis be to impart to the student the necessary equipment for doing and applying practical work in the industries or to train his mind for logical, orderly thinking, in careful manipulation of the methods of quantitative analysis and in scientific methods of general procedure? To many of us the second purpose would appear to be the more important. Without discounting the fact that the analytical methods should be such as apply, so far as possible, to practical industrial and economic problems, we yet feel that the college should give something more than the mere ability to use such methods to obtain accurate results. The steady trend of college education toward the "practical" has resulted in very strong pressure in favor of the mechanical side. At least in the engineering and agricultural colleges there is commonly a feeling among the students in chemistry that any course in quantitative analysis that is not largely made up of exercises which the individual student will use after graduation is more or less a waste of time. This is, perhaps, a natural attitude and it may even be made unobjectionable if the teacher will recognize the fact that almost any analytical work may be administered in such a way as to emphasize the scientific side of the student's training. Unfortunately, the passion for the practical goes even to the extent of demurring to the suggestion of whatever mental effort may be considered by the instructor as necessary for the proper study of principles. Speaking from a considerable experience in teaching this phase of chemical science, I express the belief that there is no part of the work that is more interesting and, at the same time, more baffling than the problem of causing the student to appreciate the value of the quantitative courses as training of the mind in methods of thought and in attitude toward scientific problems. He is constantly weighing the course in terms of its value as a tool to be used in his expected activities after graduation and he does not readily see that the tool, in this case, is general mental and analytical skill, and not simply the accumulation of a repertoire of laboratory methods. From this comes the impatience to be "getting on," the desire to cover a large field in a superficial way, and the disinclination to stop to weigh and consider. Self training and discipline in accurate thinking and manipulation are foreign to this purpose.

This spirit is sometimes allowed to dominate the planning of the course in quantitative analysis. Comparatively large amounts of time are devoted to laboratory exercises and little or no time to consultations, recitations, lectures or outside reading. The work thus degenerates into what is often aptly described as "cook-book" chemistry, the student acquiring little better than a fairly wide acquaintance with the mechanical processes of quantitative analysis. Students who have transferred from other colleges have sometimes come to me for credit in certain elementary portions of my own courses. Questioning would then bring out the fact that they had already covered more ground than I do in all my courses, but with little or nothing in the line of drill upon principles.

This is not my idea of college work. The student might better acquire his smattering of mechanical processes by serving an apprenticeship in an industrial laboratory, where he would not only become skillful in rule-of-thumb methods of certain practical applications but, at the same time, earn a certain stipend instead of spending.

Then there is another attitude that we have to consider—grown up, to a considerable extent, in these latter days of the remarkable development of so-called "chemical engineering" in the colleges. We are familiar with the fact that American industries have only within comparatively recent years begun to see the real possibilities of chemistry in their own development. This has been reflected in the evolution of curricula in our technical schools, designed to meet the need for chemists who have some knowledge of industrial engineering problems and methods. This has had an effect which is generally good but it has entailed certain results in our colleges which, I imagine, were not entirely foreseen and which are not for the best interests of American chemistry. The result that I have in mind is, first, that the great majority of our young men who are looking to the technical college for chemical training are now drifting toward chemical engineering curricula, rather than toward chemistry as one phase of liberal arts or general science training and, second, that their ambitions are directing themselves to an increasing extent toward positions of an administrative character where, as they suppose, their knowledge of chemistry and of engineering will fit them for directing great enterprises in industrial life. This is a fine and a worthy ambition—for the few who are so constituted as to make success along these lines a hopeful prospect. But a considerable proportion of our chemical engi-

neering graduates are not so constituted, as is shown by a study of the present occupations of the graduates of any good chemical engineering school. Of course a certain fraction of these would not be successful in any field of chemistry and some, indeed, would be failures in any field at all. But if we speak only of those who develop a certain talent in chemical studies, it is unfortunate that we now experience such difficulty in interesting them in the possibilities for productive endeavor, mental satisfaction and high accomplishment in what, for want of a better word, we have been calling "pure" chemistry. They feel that the best that the laboratory has to offer them is an understanding of how the chemist and his laboratory are to be utilized in solving plant problems. They have much less interest in the present need of our American industries for men who have a thorough training in chemistry and in methods of research. Quantitative analysis, to one with such an attitude of mind, is merely a place to stop for awhile to acquire a limited acquaintance with a species of animal which he will later, from behind the mahogany desk, order and browbeat and "fire." He does not realize the value of the quantitative courses as a discipliner of mind and hands and as a necessary preparation for directing the highest type of development in applied science. He is not expecting to be a "laboratory man" and if he tries out some methods of analysis and acquaints himself with the general superficial aspects of laboratory technique, any further training in this work would be mere delay in progress toward more important enterprises. Our difficulty, then, is in finding students who are willing to spend time and effort in convincing themselves, by first-hand experimentation, that chemistry is a quantitative science and that it must be studied as such and, incidentally, to accumulate an extensive knowledge of the methods and applications of analytical chemistry as a necessary basis for almost any use of chemistry, pure or applied. We can scarcely overestimate the value of this study to him who is to make any phase whatever of chemistry his major activity in life. And we may go even farther and assert that a reasonable period spent in the study of quantitative analysis can be made of great value to anyone, without regard to the nature of his major activities, as an education in the orderly methods of study and reason employed in all scientific work of every description. To one who has applied himself to this study for even a semester, especially if he has had proper help from a good teacher, the material world has a new meaning and there is a new respect for the work of men of science everywhere.

The various difficulties here discussed may be overcome if the teacher will persist in his determination to teach the subject as a part of the student's education and not as a mere manual training course. There remains another problem, the serious character of which no teacher of experience will desire to minimize. Shall the laboratory for quantitative analysis be made a place for education and mind development, or a training school for scientific crooks and expert jugglers of figures? It may be either, but I believe that it is possible for teachers of this subject to fail to appreciate to the fullest degree the difficulties involved in entirely avoiding the second alternative. The possibilities for obtaining credit by clever manipulation of figures, ostensibly the results of careful analyses, are exceptionally great in this work. Knowing this, we sometimes are inclined to surround our work with obvious preventives and penalties and to treat all our student reports with suspicion.

This is truly a mistake. If we leave out of consideration that small minority of men without conscience or character who may infest almost any class —men who will readily lie or cheat to gain "credit" or "standing" in a class, it may safely be said that the great majority of our students desire to work honestly and to gain credit and benefit from meritorious work. They make honest reports in most cases but occasionally the temptation to make minor falsifications becomes too great and a slip occurs. Probably the most common case of the kind is where the student runs his analyses in duplicate and finds that the results do not check as closely as he thinks the instructor will require. He may or may not know that some small error has occurred in one of his determinations, but he has reason to believe that neither is very far from the correct result. He reasons that he will gain nothing valuable, either in experience or in knowledge, by repeating the work and he yields readily to the temptation to alter the figures from one or both of the experiments so as to make a report that will be acceptable to the instructor.

There is, of course, the more aggravated case of cheating, where the student makes a pure guess at correct figures without any experimental work at all, or where his guess follows a carelessly performed experiment. This is a form of dishonesty which is usually not difficult to detect, if the instructor has a well-chosen and well-prepared set of samples for student analysis and if he knows accurately the composition of these samples. The student is likely to excuse to himself even this obviously dishonest method on the ground that he has already had his experience, that he will gain nothing of value by repeating the work and that by so doing he will fall behind the class and so possibly lose credit for the course. The fallacy of the first part of this hypothesis is obvious to the instructor, though not to the student.

These and other forms of petty dishonesty are pres-

ent in all (or nearly all) classes in quantitative analysis and there is nothing to be gained by closing our eyes to this fact. We have only to consider how we may minimize these practices, so destructive to all scientific ideals, in the most effective way. In this connection I should like to mention one thing which we should not do and this is to preach to the students about it. No one ever pays much attention to preaching, in church or out of it. We have, it is true, certain reports of sinners brought to repentance by the fiery eloquence of the preaching evangelist but this is mostly an appeal through the emotions and, while some few may possibly yield permanently to this appeal, unfortunately too many others relapse into former chicken-stealing habits the night after the meeting closes. No one pays any attention to preaching except to indulge in the pious hope that this or that acquaintance may profit by it. As teachers we may solemnly warn our students that if they once begin the use of beauty-shop methods for preparing reports they will never be able to do honest, accurate work after graduation (which is absolutely true) but, at the time we are saying this, each student, instead of experiencing any remorse for his own possible infraction of the rules, is feeling in his heart that several others whom he could mention would do well to take home the advice and to profit by it. I have tried this sort of procedure on occasion, and I have no reason for believing that it ever did any good whatever. The real truth is (and our reformers, preachers and teachers of every description would do well to consider this) that one's conscience can be made to approve anything whatsoever that one desires very much to do.

Falsification of analytical records is encouraged chiefly in three ways. These are:

(1) By assigning for analysis materials the composition of which is obvious to the student, so that if pressed for time or if accident has ruined a determination he is too strongly tempted to report data that were not obtained experimentally but calculated from known values. This is the case when pure salts, rather than mixtures or commercial products, are employed for student analyses.

(2) By requiring impossible accuracy in the results of students' analyses. Rather, we should carefully explain at the outset that skill is to be attained only by long and careful practice, that a kind of work that is worthy of the best efforts of men and women of college age and serious purpose can not be done with the highest degree of accuracy when one is trying for the first time and that, while we do not tolerate careless, slip-shod work, neither do we expect from a novice analytical work of a character worthy of an expert. This is a policy of simple fair play with the students.

(3) By creating an attitude of hostility on the part of the student. This applies to all teaching. We well know that even our best students are not likely to do good or honest work in any class in which the teacher is disliked or considered unfair or oppressive in his methods or requirements. Any instructor who assumes an attitude of frowning aloofness—of a taskmaster who is intent only upon getting work done—will very likely be unable to keep in his students the state of mind which is a prerequisite for work of character. On the other hand, if they understand that he desires to be sympathetically helpful, using his experience and more extensive knowledge in assisting his students to a better perception of the possibilities of good work, I am convinced that he has thereby taken a most important step in the direction of reducing the cheating nuisance to a minimum.

In conclusion, let me restate my conviction that the study of quantitative analysis, pursued under proper guidance and in correct atmosphere, may be made of the greatest possible value in the acquisition of an appreciation of chemistry as a quantitative science and of all science as the study of rigid, quantitative principles of nature. And surely it can not be doubted that if all serious minded people could catch something of this sort of appreciation, our progress toward a more orderly, and therefore a more happy, state of civilization would be very much accelerated.

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THE YIELD OF WHEAT IN ENGLAND DURING SEVEN CENTURIES

POLITICAL economists agree that the inclosure of open-field farms in the sixteenth and seventeenth centuries was one of the most important economic events of England. It is said that over a thousand books and essays have been written on this subject in an attempt to reach an understanding of the causes which led up to the medieval system of villages and of communal open farms and the principles that underlay the breaking up of the open fields into inclosed fields where individual effort was possible. Quite recently four very interesting articles have appeared on this subject.[1]

[1] V. G. Simkhovitch, "Hay and history," *Political Science Quarterly*, September, 1913; Harriet Bradley, "The enclosures in England: and economic reconstruction," Columbia Studies in History, Economics and Public Law, Vol. LXXX, No. 2, 1918: Lord Ernle, "The enclosure of open field farms," *Journal* of the Ministry of Agriculture of Great Britain, December, 1920, and January, 1921; Reginald Lennard, "The alleged exhaustion of the soil in medieval England," *The Economic Journal*, March, 1922.