

SCIENCE

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THE SCIENTIFIC TEACHING OF SCIENCE

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SCIENCE, with its introduction of the laboratory, was expected to revolutionize teaching. But the ever-recurring distrust of the new has given us a curious combination in our scientific departments of the modern laboratory, the medieval lecture, and a degenerate form of the Socratic quiz. And the student feels them about as far apart in content as in origin. While the head of the department is lecturing to him on chlorine, the second man in the department is directing him in the manufacture of sulfur dioxide, and some assistant, once a week, is extracting from his brain all it contains of hydrogen sulfide. An unsavory mess it is!

If we could accept as the purpose of education the development—perhaps it is more accurate to say the restoration—of the right mental attitude in the student, we could bring order out of this chaos. For we should then see that the dogmatic handing on of facts through lecture and text-book inculcates the wrong attitude of mind in the student. A student will much more rapidly develop the right mental attitude by discovering facts for himself, even though they were known before, than by memorizing a multitude of facts discovered by other people. Men prate a good deal these days about the conservation and development of our natural resources, and are curiously neglectful of our greatest resource, humanity's power of creative thinking. The little child is, of course, the scientist, par excellence, curious, experimental, creative. Our education must retain and build on the curiosity and experimental eagerness of the child, and develop his power of creative thought. We can never know what the new generation has to contribute to us till we give it greater opportunity to express itself. We think when we have let a student choose his

major subject we have given him all the freedom it is safe to give him.

It is curious how far we are from the idea that a university exists primarily to develop this power of creative thought in its students. If our teaching is to develop this power, we must change the focus of our work. Heretofore we have had vaguely in mind as our focus a text-book or an instructor. But instead of a tyrannical text-book or the instructor's somewhat egotistical presentation of ideas in his lectures, instead even of his charming and stimulating personality, we must choose as the focus for our teaching the student and his problems. Every student has all sorts of problems more or less consciously in mind when he comes to a university. The laboratory books and instructors should exist as aids in the solution of those. Before he has gone far in his investigations, if laboratory, library and instructor are adequate, they will have led him out toward several other departments of the university, and a continuously increasing number of other problems will be tempting him on.

The lecture, the quiz, the laboratory manual, the text-book must be tools for the student rather than guides. The logical order underlying the text-book and lecture is that of a person with many years experience in a subject. The student approaches the subject in quite a different way, touching it at only a few, possibly unrelated, points. The logic of another, more experienced mind lacks significance for him. He needs to evolve his own orderly arrangement of the subject. That is all he can, as yet, comprehend. The laboratory manual, with its arbitrarily selected experiments, is similarly objectionable; it starts not with the student's problems, but with imposed problems. No lecture, or text-book, or laboratory manual exactly fits any one's needs. The quiz as at present conducted, instead of being used even as Socrates used it to lead up to some definite idea, or instead of its being, as it ought to be, a frank give and take between coworkers, has become merely insulting.

In place of these must be substituted the laboratory, reference books, private consulta-

tion with the instructor, group discussions, and an occasional supplementary lecture. This means merely that the university exists for the student, be he called student or instructor, twenty years old or seventy, modest scientist or titled grandee. It means that the older student is to see that the younger student has what he needs to work with, that he can find the reference books he needs, that he has access to the more complete experience of this elder whenever his problem seems to require experience greater than he has at his own command. It means that instead of memorizing facts for possible future use, the student is already at his life business of solving problems, the business he began, by the way, in the cradle. The group discussion will, of course, be based on the problems that have arisen in the laboratory, will be reports of laboratory work, and will relate the knowledge gained there with other sciences or other aspects of the same science. And now and then, there may be a lecture by a visiting scientist on his specialty. There is, of course, gain rather than loss in the instructor's reporting from time to time his own research work, or some particular interest, or bibliographic suggestions, just as the other students do. Such reports will give the younger students greater acquaintance with the instructor's point of view than they could get, perhaps, merely through conversations. But in such reports the instructor takes his place as a fellow student, not as a superior. Laboratory, reference books, a more experienced scientist to consult, occasional exchange of ideas with groups of fellow workers, these are all our incipient scientists need.

For three years the experiment was made in a scientific department of one of our middle western universities of teaching by the method just suggested, so far as that could be done under the conditions that exist in every university at present. All the courses in the department were so conducted, the students ranging in rank from freshmen to graduates, and numbering usually about twenty to the course.

At the beginning of each course there were

conferences with the students, who had registered for the work, to find out why they were there, what contact they had already had with problems in this subject, what points they expected the course to clear up for them. They were asked to prepare a rough outline of the subject, limited though their knowledge was, and from this outline their laboratory work was begun, so that they began with the points of contact previously made with the subject, and were already at work organizing what slight knowledge they had.

Each student's laboratory work was made at all times the center of his activity; it was starting point and unifying element. The questions that arose in the student's mind during his laboratory work were the basis of laboratory conversations and class-room discussions. Most of the conferences on work took place in the laboratory, when problems arose. The class room was used in part for the discussion of problems that could not well be worked out in the laboratory because of lack of time or equipment. This discussion of more general problems and of investigations carried on by other scientists, though usually introduced by the instructor, was brought in when suggested by the laboratory work of the students. Each student presented, also, during this class hour, the results of his own research studies. And though many problems were individual in origin, some of them were, of course, related, and lent themselves well to group discussion. It is true the students were less interested in the discussion of each other's investigations than in their own; still, a problem that a fellow student feels vividly is more interesting than one imposed by an instructor. Nearly all work was done independently of both his fellows and the instructor, in so far as the student was able, unaided, to solve his own difficulties.

Most of the systemization of work was done in laboratory conversations between instructor and student. Such correlation was urged throughout the course. Attempt was made to order data as they accumulated. At the end of the course, this systemization was rounded

out in a second outline of the subject the students prepared.

The students almost invariably floundered at first. They had grown so dependent on directions that for a time they could only with difficulty initiate work of their own. Gradually they came to understand what was expected and they became clearer as to what they themselves wanted. And as the course continued the method seemed to them increasingly desirable and successful.

There were difficulties and hindrances in applying the method, of course. Almost all of them came from having to fit it into the regular university system. It couldn't be adopted wholeheartedly because of the regular schedule; and when work was prescribed in all other courses and enforced by examinations, there was a tendency, naturally, to slight a more flexible course.

And it is difficult to persuade a student one is really interested in his opinions when all through his home and school life independent thinking has been discouraged as inconvenient. But probably it is better to save him at the eleventh hour than let his power to think be dammed forever. It certainly seems absurd to dictate all details of work to the undergraduate and expect the graduate student suddenly to manifest originality, initiative and creative power. The method of the little child and the graduate student should not be interrupted by the years of directed mental effort our present school system imposes, should not because it is inefficient, and so fatiguing as to be almost disastrous. It is equally important that the beginnings of a science be taught by the scientific method as that graduate work be so carried on. For the early years in any science should be given largely to discovery and original research, as are the early years of childhood. Thinking and first-hand contact would better come early, else they may never come.

The difficulty of handling many students in this way is more fancied than real. One can not, of course, believe it possible to know and develop individually as many students as one

can lecture at. But if lecturer, laboratory assistants, quiz aides combined and divided the entire group in any department, students would develop more power than under the present method. They might not come in contact with as many facts, but they would retain more of those they did become acquainted with, and their power of thought would be much greater. We have probably swung to an extreme anyway in paying large salaries to a few lecturing departmental heads; we should have a better faculty and consequently a more creative generation of scientists developing if we spread our resources more equably over the entire teaching force.

A few other objections to the method one always expects to encounter in any discussion of it: that students are purposeless and lazy; they must have their work planned for them and be held or driven to it. They are children. Yet an unspoiled child is purposeful. And even if a freshman is somewhat dulled by his previous training, that seems scarcely a good reason for going on with the dulling process.

One hears, too, that the years of preparation are so short and the facts of knowledge so many it is the business of the instructor to organize material into simple form, easy to memorize, and give it to the students in lectures or text-books. Of course if a university chooses to do this inferior sort of work, training accurate automata instead of turning out thinkers, that is, presumably, its privilege. One wishes, though, there were some place students who didn't choose to become automata could go. So little of life is lived at the conscious level, and it is primarily from that part of life that progress is obtained, it seems a pity to shorten a man's real living and limit his contribution by discouraging living at that higher level.

Another objection that is subconscious rather than expressed is that the method requires rather more self restraint and mental flexibility than most instructors feel equal to.

Whether or not it seems worth while to excavate beneath the crust of indifference

formed in self-defense during the preparatory years of prescribed work will depend on the value one places on creative thinking. Perhaps it does not seem to every one our greatest natural resource; but such an one is probably not himself very creative.

It is frequently contended that under such a method of teaching a student will lack system and an orderly grasp on the whole subject. The amount of systemization of knowledge will undoubtedly vary among free students; some orderly arrangement of material there must be. But the creative mind is less intent on classifying data than in gathering more, and in projecting new theories. It cares less to make of itself a card index of the literature on any subject than to "push forward the boundaries of knowledge."

The real rock on which the method is likely to founder, however, is the executive mania for definite classification of mentality. We must rule out variations from the medium. We must know in just what stage of development each student's mind is—or rather, at just what point in the assignment of the year's work he is. However could we give degrees? We can not be bothered with all this individualized education. We don't want thinkers anyway; we want followers.

None of these difficulties and hindrances greatly matter, once we are convinced of the need for developing creative thinkers in our scientific courses.

But it will require grace to step down from the lime light of the lecture platform, to cure ourselves of this contagion of text-book writing. We elders are so sure that out of our greater experience we can save our students effort and time. It is a clogging efficiency we seek. The greatest contribution we can make to a developing mind is to "stand out of its sunlight." And in the long run, that is the most efficient method; for individual initiative produces most in the least time, and produces it with a minimum of effort and friction. The problem we ourselves find is a fascination; the problem some one else sets us is a task. And our memory in the latter case is treacherously unreliable, while the knowledge

we worry out for ourselves is seldom forgotten.

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LEVULOSE SIRUP

THE present—and, we are told, very likely the permanent—shortage of crystallized sugar is stimulating very markedly the interest in other sugars. The consumption of glucose or corn sirup is increasing steadily; the making of sorghum sirup bids fair to return to the prominent place it once held; our friends the bees are being exploited more and more; and a great many breweries, instead of retiring as requested, are now malting grain as usual, but instead of fermenting it are converting it into maltose sirup. Of the above four sugar products, sorghum and honey are the only ones which compete with cane sugar in sweetness; maltose is much less sweet, and glucose is very much less sweet, than sucrose. Now, it is sweetness that we demand; we do not eat sugars and sirups primarily for their calories, but because they sweeten other, less palatable, and cheaper, food products. Therefore, glucose and maltose have very natural limitations on their extensive utilization, if sweeter materials can be found. Of the two sweeter products, honey will probably of necessity always remain a luxury; and sorghum sirup has a flavor that precludes its unlimited use for all purposes, although it should be said that this flavor can be almost entirely removed, with practically only the sweetness remaining, and that there is a possibility of an enormously increased utilization of sorghum in this way. Is there not, however, a sugar which is sweeter than any of the above, which is not now of commercial importance, but which possibly could be obtained in large enough quantities and at a low enough cost to become important?

Levulose, fructose, or fruit sugar, is the sweetest known sugar. Exact data as to the relative sweetness of the various sugars are not available, but it is often stated that levulose is 30 to 50 per cent. sweeter than sucrose. A levulose sirup, then, would be a distinct

asset in the present commerce in sweet products. Levulose occurs in practically all fruits, is abundant in honey, and is found in appreciable amounts in sorghum sirup. Its most conspicuous occurrence in plants, however, is in the form of inulin in the tubers of the Jerusalem artichoke and in the bulbs of the dahlia. Inulin is a polysaccharide somewhat resembling starch, but whereas starch yields glucose on hydrolysis with acid, as in the manufacture of corn sirup, inulin yields levulose.

The inulin is present to the extent of 12 to 14 per cent. of the fresh tuber. As is well known, the artichoke gives very large yields, from 700 to 1,000 bushels per acre being normal. If one assume 40,000 pounds per acre, and a 10 per cent. recovery of inulin from the tubers, there would thus be 4,000 pounds of sugar per acre. A 50-bushel crop of corn yields about 2,000 pounds of starch; an acre of good sorghum yields about 1,600 pounds of sugar; an acre of sugar beets, 3,000 pounds; an acre of sugar cane 3,000 to 4,500 pounds.

Thus it is seen that the possible yield of sugar from artichokes compares very favorably with that of our other sugar crops; and the writer believes, on the basis of the above facts, that levulose sirup from artichoke tubers is one of the most promising sugar possibilities that we have. The levulose would probably have to be in sirup form, since it crystallizes with difficulty. The above figures are estimates based on known yields and analyses of artichokes. The unknown factor in the proposition at present is the technology of manufacture. Practically nothing is known about the isolation of the inulin and its hydrolysis to levulose on a commercial scale. But what is known concerning the chemistry of these substances gives us every reason to believe that the problem connected with the manufacture of levulose sirup could be solved, as were those in the manufacture of the other sugar products. Likewise the question of the cost of production is unknown. Since, however, the resultant product would be so much sweeter than any of the present sugars, it would be worth considerably more, and a greater cost of manufacture, if such should