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Keeping the Curriculum Up to Date

Three of the more serious challenges facing the makers of college chemistry curricula — and some changes which have been made at Caltech in an effort to meet these challenges.

by Ernest H. Swift

Three serious challenges face those who are concerned with college science courses today. The first of these challenges, and one which will demand increasing recognition, is the result of the various efforts being made to improve high school mathematics and sciences courses.

There is a general impression among the lay public that it took Sputnik I to awaken a concern for the teaching of science in our high schools. As evidence to the contrary, however, there is the ambitious project, activated a full year before Sputnik I, which had as its objective the improvement of the teaching of physics in the high schools.

This project, initially sponsored by the National Science Foundation, was centered at the Massachusetts Institute of Technology, and is still active. It has involved the cooperative effort of college and high school teachers from all sections of the country, and has cost several million dollars to date. A text and laboratory manual have been produced, supplementary monographs written, and demonstration experiments and various other teaching aids made available. The physics teachers are to be commended for taking the initiative in such a program. Some chemistry teachers are so unkind as to say that it was the quality of high-school physics courses which stimulated this initiative.

Similar, though less ambitious, programs are now in effect for improving high school courses in chemistry, mathematics, and biology. At the present time, again under the sponsorship of the National Science Foundation, two experimental high school chemistry texts are being developed. The first of these texts stresses the types of chemical bonds as a logical method for presenting chemistry to high school students; approximately 250 schools are using this text on an experimental basis this year. The second text emphasizes a more experimental approach; about 125 schools are using this text this year. It seems inevitable that increasing availability and use of these texts in the future will raise the general level of high school chemistry courses.

Also preceding Sputnik I was the National Science Foundation program of summer institutes (initiated in 1953) and academic-year refresher courses (initiated in 1956) for both high school and college science and mathematics teachers. These programs have been expanded until there were 398 summer institutes held during the summer of 1961; the cost of the program approached $23,000,000 and stipends were provided for 18,000 high school teachers. Twenty-one of these institutes were for chemistry high school teachers and ten were concerned exclusively with training teachers to use the two experimental texts mentioned. Participation in the academic-year institutes has grown from 95 in 1956-57 to over 1500 for 1961-62, and the budget has gone from $500,000 to almost $10,000,000.

Another activity, which began after Sputnik I, but which I believe has had a significant effect on high school teaching in both physics and chemistry, has

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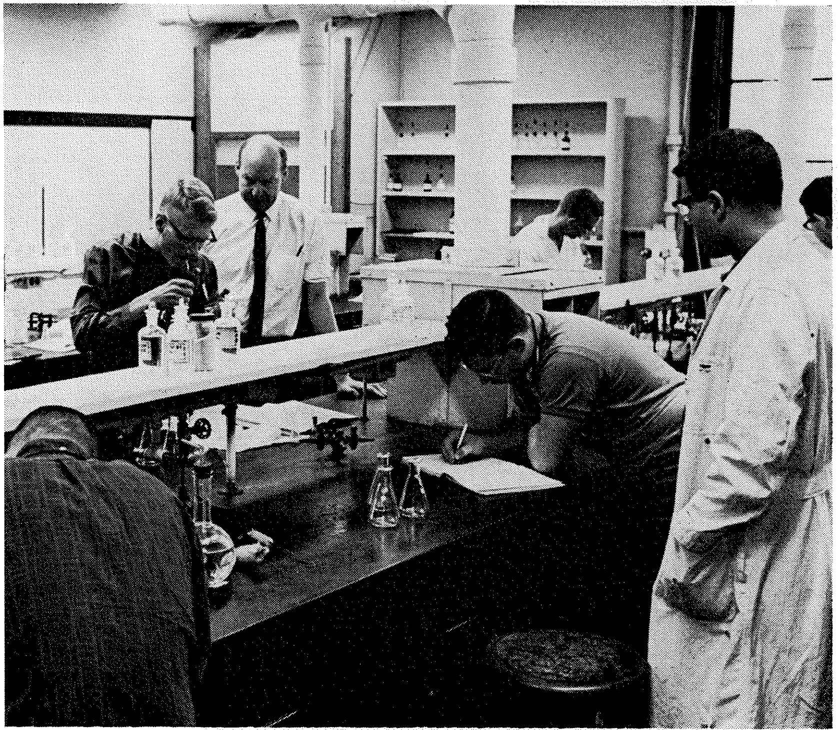
"Keeping the Curriculum Up to Date" has been adapted from a talk given by Dr. Swift, chairman of the Division of Chemistry and Chemical Engineering, at a dinner given by the western chapter of the American Institute of Chemists in Pasadena on September 20, 1961.



Freshmen chemistry students get more personal instruction these days. Here, Professor Jurg Waser and a graduate teaching assistant supervise a group of 10 students in the laboratory.

been the televised Continental Classroom series. These courses are exceedingly well done and are very popular. It would seem inevitable that high school teachers, knowing that their students were viewing these programs, would endeavor to prepare themselves for the inevitable barrage of questions from the students.

In addition, an increasing number of high schools, both public and private, are already giving a second chemistry course which qualifies their students to take the College Board Advanced Placement Examinations, with the resultant possibility of obtaining credit for the college general chemistry course.

In summary, there is definite evidence that these various efforts have already had a significant effect on the average quality of high school science courses. Thus the colleges are being increasingly challenged to recognize these trends and revise their curricula. Not to do so would be grossly unfair to high school teachers who have developed good courses and to students who have taken advantage of these courses.

The second challenge to college science curricula arises from what Dr. Joseph B. Platt, president of Harvey Mudd College, has called the knowledge explosion. A semanticist might prefer *publication* explosion since Dr. Platt measures this phenomenon in publication units. When both industrial and academic advancement is often dependent upon papers presented and articles published, one can question that there is a linear relation between increase in publications and increase in knowledge.

In his address to a recent Conference of Academic Deans, which was considering the effect of the expansion of knowledge on the college curriculum, Dr. Platt pointed out that John Harvard gave a library of 300 volumes to Harvard College in 1636 and that the current Harvard library has about six million volumes. These figures represent a doubling in the number of volumes every 20 years and this exponential rate of increase is representative of other university libraries. The publication rate increase for the sciences approaches a doubling every 10 years, and in the July 17, 1961, issue of *Chemical and Engineering News* the director of Chemical Abstracts Service cited data for the past 10 years showing that the chemical literature now doubles every 8.3 years.

These figures raise serious questions. Do they imply that in order to attain the same relative competence in a scientific field today 30 times as much information must be pumped into a science student as 50 years ago; or, more frightening, a thousand times as much 50 years hence? Obviously this process cannot continue indefinitely. For one thing, we have to recognize that our science curricula are likely to remain what has been termed "constant volume systems." There will be strenuous resistance to increasing the total time spent in college and an equal resistance to giving a larger proportion of the undergraduate time to science at the expense of humanistic studies. I, for one, will join the opposition to either of these proposals.

What methods remain for coping with this formidable information inflation? The improvement in high school courses represents one method which is already functioning. Another is a better organization of this expanded information. This approach implies an earlier and increased emphasis on fundamental principles and theories which the student can use to systematize the information to which he is exposed; and, of equal importance, to find or produce additional information as needed.

This approach was emphasized and pioneered almost 15 years ago by Linus Pauling in the preface to the first edition of his *General Chemistry*. He stated: "Chemistry is a very large subject, which continues to grow, as new elements are discovered or made, new compounds are synthesized, and new principles are formulated. Nevertheless, despite its growth, the science can now be presented to the student more easily and effectively than ever before. In the past the course in general chemistry has necessarily tended to be a patchwork of descriptive chemistry and certain theoretical topics. The progress made in recent decades in the development of unifying theoretical concepts has been so great, however, that the presentation of general chemistry to the students of the present generation can be made in a more simple, straightforward, and logical way than formerly."

There are some chemists who will question how far one can go in emphasizing principles and theories at the expense of experimental and factual chemistry and still be able to classify the product as a chemist. I intend to avoid debating this question. There is certainly evidence that this theoretical approach can be pushed to a degree which engenders a disregard for the experimental method and which can lead to an unrealistic, and at times woeful, misuse of theory.

A third challenge which faces the makers of curricula is the exceptional student. For present purposes an exceptional student will be defined as one with the potentialities—perhaps as yet latent—which could enable him to become a creative and productive scientist. And this country must produce creative and productive scientists in increasing numbers. Otherwise we will not keep pace with the scientific and technological advances of the future, with a consequent loss of national prestige and status and even national security.

One of the qualifications which this exceptional student must have is intelligence of a high order. But, of equal importance, he must have intellectual curiosity and imagination, scientific integrity, and exceptional motivation. The efforts which are being expended on high school science courses will bring more of these exceptional students into the colleges—students who have been motivated by good courses and inspired by good teachers. The challenge to the college is to maintain and strengthen the motivation of such students rather than to stifle their interest and curiosity with poor teaching and repetitious courses.

Independent research

One method of meeting this challenge is to arrange the college curricula so that students are given full credit for work they have done and are allowed to proceed at whatever pace they can maintain. Another method of meeting this challenge is the one which I first saw dramatically demonstrated over 40 years ago by Arthur A. Noyes at Caltech. Dr. Noyes took a personal interest in such students. He sought them out and gave them the opportunity for independent research. I purposely avoid using the term "undergraduate research;" too often this term is taken to mean a required senior thesis. I am skeptical of required research at the undergraduate level because of the belief that all students should not be required, regardless of their interests and qualifications, to go through the motions of fulfilling such a requirement. Likewise, I sympathize with instructors with large classes who are supposed to provide stimulating and scientifically productive problems for all of their students, regardless of ability and interest, and who then have to supervise the students' efforts until they produce a required thesis. There are brilliant students with predominantly theoretical interests who profit more from advanced courses; there are mediocre students who will profit more from expending the same effort in more closely supervised laboratory courses.

There is no required research in the undergraduate chemistry curriculum at Caltech. There has been a vigorous program of research in chemistry by undergraduates since the arrival of Dr. Noyes on a full-time basis in 1920. Qualified and interested students are encouraged and given the opportunity from their freshman year to undertake research under the direct supervision of members of the staff. They receive academic credit for this work and this credit can be used to satisfy elective requirements of the junior and senior years. Increasing numbers are working through the summer period and they receive academic credit for this work without payment of tuition.

I would like to cite one recent example, unusual but illustrative, of the operation of this program with an exceptional student. Two years ago Professor J. D. Roberts was approached by a freshman who stated that he had heard of Professor Roberts' use of nuclear magnetic resonance as an aid to studying the structure of organic compounds. He also explained that he had worked with electronic equipment in high school, and, although he intended to be a physicist, he would like to undertake some nuclear magnetic resonance research with Dr. Roberts. Questions showed that the student had taken the trouble to learn something about nuclear magnetic resonance, and that his academic record was very good, so he was allowed to begin work on a simple project. The student worked in his spare time for the remainder of the freshman year, worked through the following summer, then in his spare time during his sophomore year, and again during the past summer. As a result of this work three papers have been submitted for publication and another is being prepared.

Last year, as a sophomore, the student presented a report of his work before our weekly Research Conference. The level of his report can be judged by the fact that one of our staff members subsequently asked if the speaker was a visiting lecturer being considered for an appointment.

I am aware that this is an unusual case and that there are undergraduates who become disillusioned and discouraged by lack of success with a research problem. It is also true that directing the research of undergraduates is likely to be a time-consuming effort. I can only cite the willingness of our staff to give their time to directing the research of undergraduates as an indication of their estimate of its value.

Revising the chemistry curriculum

In 1956 a revision of the undergraduate chemistry curriculum at Caltech was put into effect in an attempt to meet these challenges more effectively. Honesty requires a confession that this revision was motivated by the observation that since World War II

In Caltech's freshman chemistry course each student is provided with a notched-beam chainomatic analytical balance.

there had been a continuous decrease in both the number and quality of the students electing to major in chemistry or chemical engineering. This election of a major is not made until the end of the freshman year, which at the Institute is uniform for all students. Even more disquieting was the observation that students entering the Institute with an expressed interest in chemistry were electing other fields at the end of the freshman year.

These observations indicated that the laboratory work of the freshman general chemistry course was failing to meet the first two of the challenges mentioned. First, although substantially all of our students had had high school chemistry courses, the laboratory work was failing to take advantage of this previous training. Most of the experiments were largely repetitious of ones they had already done or seen demonstrated. Some so-called quantitative experiments had been introduced, but as one student observed "we were supposed to measure some constant which had been measured fifty years ago fifty times more accurately so we just dry labbed." That is, they were not being challenged.

Secondly, many of the experiments were still unduly influenced by the period when chemistry was a predominantly descriptive science, and they conformed to a pattern which has been characteristic of chemistry curricula. They followed the historical and chronological development of chemistry and required the assimilation of a large mass of descriptive material without developing the principles which would systematize this material. That is, the laboratory work was not following the approach now used in modern general chemistry texts.

As a result of these considerations a committee composed of Professors Carl Niemann, John D. Roberts, and myself was asked to consider a revision of the work of the freshman year and, if it seemed appropriate, of the entire chemistry and chemical engineering curricula. After much discussion within the committee and with other staff members, the recommendation was made that an experimental curriculum be initiated in which the conventional laboratory work of the first two quarters of the freshman year was to be replaced by work essentially equivalent to that which was then being given in the sophomore course in basic quantitative analysis. At first this recommendation will appear questionable, since the freshman chemistry course is general in nature, and is taken by all freshmen, and since quantitative analysis is usually considered to be a specialized professional course. The recommendation was based on several observations and conclusions, however.

First, there was convincing evidence that the freshman laboratory work had not adequately recognized that science and engineering were becoming progressively more quantitative in both theory and practice. For this reason there seemed strong justification for including in the freshman chemistry course experiments which would develop the ability of a student to plan, execute, and critically interpret quantitative measurements of various types. Also, because of the increasing emphasis on theoretical material in modern general chemistry texts, it seemed almost imperative that students should develop an appreciation and respect for the experimental method and a realization that it is the basis of scientific progress.

It was further hoped that subsequent laboratory courses, regardless of their fields, would be modified to take full advantage of this early proficiency in quantitative techniques.

Second, the committee believed that by proper selection of these quantitative experiments the general principles underlying the various types of chemical reactions could be more clearly illustrated than by the multiplicity of descriptive and qualitative experiments conventionally used.

The recommendation of the committee also involved the assumption that it would not be much more difficult to teach freshman students quantitative techniques than it had been to teach these techniques to sophomores; there would even be some advantage because of the absence of dubious habits acquired from the use of pseudo-quantitative instruments and techniques in the freshman year. Subsequent experience demonstrated the validity of this assumption.

Also, it was believed that present-day freshman students, at least those who had taken a high school course in chemistry and had enrolled in a science and engineering course, were sufficiently mature and motivated to be interested and challenged by quantitative work done on a professional level.

Finally, this recommendation was based on the assumption—perhaps gamble would be a better word—that quantitative analytical experiments could be so taught that they would be more effective than the descriptive experiments previously used in arousing the interest and maintaining the motivation of the general students entering the Institute with an interest in chemistry.

The reaction to this assumption has ranged from raised eyebrows to profanity—both used to express the belief that no course in the curriculum has driven more students from chemistry than quantitative analysis. Too often this has been true, because the teachers and the texts of quantitative analysis have still taught the course as it was taught 50 years ago. At that time there was economic justification for training the student by repetitive drill with typical gravimetric and volumetric procedures to be able to go out after four years and start his career doing routine work in an analytical or control laboratory. This is not true today. In fact, it is believed that the success of such a course, especially for those students not having a strong interest in chemistry, will in large measure depend on how effectively both students and staff are convinced that training analysts is not the primary objective of the work.

The laboratory course

Initially there was justifiable criticism that too large a proportion of the work in this laboratory course was conventional gravimetric and volumetric procedures. Subsequently, under the direction of Professor Jurg Waser, there has been continuous experimentation to obtain diversification of measurements. As of last year, in addition to conventional gravimetric and volumetric methods, there were gas volumetric methods; there were coulometric and electrolytic methods involving measurements of electrical potential, current, resistance, and total quantity of electricity passing in a given time; and there were colorimetric methods involving measurements of light intensity.

As a result of shifting the quantitative analysis from the second year into the first, there has been a general shifting downwards of the chemistry courses. The basic organic course, both class and laboratory, was moved from the junior to the sophomore year. The basic physical chemistry course remains in the junior year; in place of the organic laboratory of that year there is now a one-quarter course in advanced quantitative analysis, and two quarters of physical chemistry laboratory which was formerly given in the senior year.

Because of these shifts, a student now completes his basic courses by the end of his junior year. Consequently the senior year is completely free, except for required humanities work, for a student to take research or graduate-level courses in special fields. As an alternative, serious consideration is being given to advising unusually mature and capable students to enroll in graduate school after completing their junior year.

To what extent has this curriculum been successful? An objective quantitative evaluation is difficult. The results have been most apparent in the first year where there has been a dramatic improvement in the application and apparent interest of the students in laboratory work. We believe that this has resulted in part from elimination of any repetition of high school work and from the challenge involved in using professional instruments to their full capacity. For example, freshmen learn to weigh on notched-beam, chainomatic balances.

Perhaps the most objective evidence of the relative effectiveness of the revised freshman course is the fact that after the first year there was an increase of approximately 60 percent in the number of students electing to major in chemistry or chemical engineering. This increase has been maintained in spite of the current glamor of mathematics and physics. Also, this revised freshman work has enabled greater emphasis to be placed on research by exceptional students. The proficiency in quantitative measurements and the understanding of principles now obtained in the freshman year not only enables but stimulates students to undertake research work earlier than they did before. In addition, the acceleration of the basic courses has left more time available for research or advanced courses in the last two years.

Indefinitely experimental

I wish to emphasize that the curriculum I have described is still considered to be experimental, although it is now in its fifth year. I hope that this attitude continues indefinitely. Also, even though this curriculum has been reasonably successful at the California Institute, one cannot conclude that it would be equally effective at other schools. Recently I was invited to participate in a project to establish "the ideal chemistry curriculum." Such a concept frightened me, since if it were generally accepted, further experimentation would be inhibited. I believe that the ideal curriculum for a given school is determined by the interests and capabilities of the staff and of the students of that school at that particular time. One of the most promising current developments in connection with the undergraduate chemistry curriculum is the widespread willingness to re-examine the objectives, content, and sequence of the various courses and to apply the experimental method to this re-examination.

The establishment of this revised chemistry curriculum at Caltech has been a cooperative undertaking in both planning and execution by the members of the Division of Chemistry and Chemical Engineering. The time and effort they have contributed has been responsible for whatever degree of success has resulted. To those concerned, it is obvious that continuous expenditure of both time and effort will be required if this or any other curriculum is to meet the challenges of our rapidly changing modern world.