REPORT RESUMES

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SELECTED PAPERS FROM REGIONAL CONFERENCES 1966-67.

BY- MARQUARDT, D.N.

ADVISORY COUNCIL ON COLL. CHEMISTRY

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REPORTED ARE 15 SELECTED PAPERS ON VARIOUS TOPICS OF CURRENT INTEREST WHICH WERE PRESENTED AT THE VARIOUS REGIONAL CONFERENCES DURING 1966 AND 1967. THE VARIOUS CONFERENCES HAVE AS THEIR MAJOR CONCERNS (1) RECENT TRENDS IN GENERAL CHEMISTRY, (2) CHEMISTRY FOR GENERAL EDUCATION, (3) TEACHING UNDERGRADUATE ORGANIC LABORATORIES, (4) THE INTEGRATED LABORATORY, (5) THE GENERAL CHEMISTRY LABORATORY, (6) CONTEMPORARY DEVELOPMENT IN TEACHING GENERAL CHEMISTRY, AND (7) NEW APPROACHES TO LABORATORY INSTRUCTION. PAPERS ON THE FOLLOWING TOPICS ARE INCLUDED IN THIS PUBLICATION--(1) TEACHING CHEMICAL BONDING, (2) THE GENERAL CHEMISTRY COURSE, (3) INSTRUCTIONAL TECHNIQUES, (4) INTRODUCTORY LABORATORY, (5) CORE CURRICULUM LABORATORY PROGRAMS, (6) THE GENERAL CHEMISTRY LABORATORY, (7) THE INTEGRATED LABORATORY, (8) STRUCTURED CHEMICAL EXPERIENCES, (9) DEMONSTRATION EXPERIMENTS, (10) COMPUTER SIMULATION OF LABORATORY INSTRUCTION, (11) ANALYTICAL INTRODUCTION TO ORGANIC CHEMISTRY, (12) LABORATORY SAFETY, (13) TEACHING NON-SCIENCE MAJORS, AND (14) CHEMISTRY FOR TWO-YEAR COLLEGES. (DH)

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1966-67

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Reports From REGIONAL CONFERENCES Sponsored By The ADVISORY COUNCIL ON COLLEGE CHEMISTRY

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University of Omaha

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Department of Chemistry, Stanford University, Stanford, California 94305

The Advisory Council on College Chemistry, an independent group of chemists, has as its goal the improvement of undergraduate chemistry curricula and instruction. The Council collects and disseminates information through the activities of standing committees on Freshman Chemistry, Curriculum and Advanced Courses, Teaching Aids, Teacher Development, Science for Non-Science Majors, Two-Year College, and Resource Papers. Additional *ad hoc* groups act as necessary to further assist the Council in providing leadership and stimulus for imaginative projects on the part of individual chemists.

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PREFACE

In the past year, seven Regional Conferences have been sponsored by the Advisory Council on College Chemistry. Formal presentations by principal speakers, along with question and answer periods and discussion sessions, are an important part of these conferences. These presentations are distributed as part of the conference report to each of the participants at the conference. The availability of these reports to non-participants is announced through the Newsletter.

A few of the papers on various topics of current interest are presented in this publication so that a wider audience may have an opportunity to see some of the material discussed at AC$_3$ regional conferences. (Full reports of individual conferences are still available on request).

The Regional Conference program is a continuing Advisory Council activity and selected material, such as presented here, will be collected periodically. As the attached material shows, a variety of topics can be dealt with. (Perhaps even more important than the rather formal presentations reprinted here is the involvement of the participants during and following the conference which cannot be demonstrated in a report such as this.)

We are indebted to the contributors for permission to publish their papers. They were originally intended only for rather informal presentations at Regional Conferences. They are reprinted here in their original style.

The Advisory Council-sponsored Regional Conferences stem from the invitation of an institution to host a conference. We welcome such invitations.

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* Present address: Simmons College, Boston, Mass.

Conferences Included in
"Selected Reports from AC_3 Regional Conferences"
(Nov. 1966 - Oct. 1967)

1. "Recent Trends in General Chemistry", Texas A&M University, A. F. Isbell, chairman November 18-19, 1966.

2. "Chemistry for General Education" and "Balance Between Theory and Description in General Chemistry", Florida State University (Jointly sponsored by AC_3 and the Center for Research in College Instruction of Science and Mathematics), R. Johnsen and G. Schwarz, chairmen, February 24-25, 1967.

3. "Teaching Undergraduate Organic Laboratories", Bellarmine College, John Daly, chairman, March 31 - April 1, 1967.

4. "The Integrated Laboratory", Bucknell University, Lester Kieft and B. R. Willeford, chairmen, March 31 - April 1, 1967.

5. "The General Chemistry Laboratory", Worcester Polytechnic Institute (Jointly sponsored by AC_3 and the Central Massachusetts Section of ACS), R. C. Plumb, chairman, April 27-28, 1967.

6. "Contemporary Development in Teaching General Chemistry", The University of North Carolina at Charlotte, S. L. Burson, chairman, May 12-13, 1967.

7. "New Approaches to Laboratory Instruction", Washington State University and the University of Idaho, Carl Stevens and Elmer Raunio, chairmen, October 13-14, 1967.

TEACHING CHEMICAL BONDING TO FRESHMEN

Harry B. Gray

California Institute of Technology
Pasadena, California

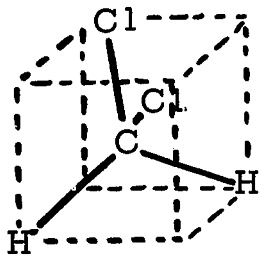
The electronic and atomic arrangements of matter make up the study of structural chemistry. The importance of this area of chemical study can hardly be overemphasized. Firm concepts of structure are needed in order to explore in a coherent and intelligent fashion the sister fields of chemical dynamics and chemical synthesis. Although teaching structural chemistry has advanced to a higher level than has that of chemical dynamics, it is still a poorly taught subject in many places. We must continue to explore new and better ways of presenting the subject to eager young students who are hearing about it in detail for the first time.

Molecular structure can be taught to freshmen at three different levels; these levels correspond to three periods in the history of the subject. The first level covers the period 1860-1920 and includes the models developed by van't Hoff, Le Bel, Kekulé, Werner, and many others. Although these "classical" ideas of molecular structure can be covered rather rapidly, it is worthwhile to present them as the beginning of the logical development of the subject. After all, chemists knew a lot about the shapes of molecules long before anyone had heard of quantum mechanics. Quantum mechanics is even more beautiful when studied after an exposure to classical structural chemistry.

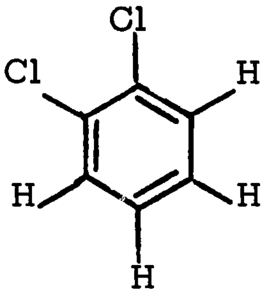
Concepts such as covalence (the number of "hooks" an atom has to attach other atoms), oxidation number, coordination number, ionic charge, and their relationship to the composition and structure of matter can be introduced during this part of the course. A particularly good example to use is the list of the numbers of isomers found for chloro compounds with the following compositions:

Composition	No. of isomers
CH_2Cl_2	1
$C_6H_4Cl_2$	3
$Pt(NH_3)_2Cl_2$	2
$[Co(NH_3)_4Cl_2]Cl$	2

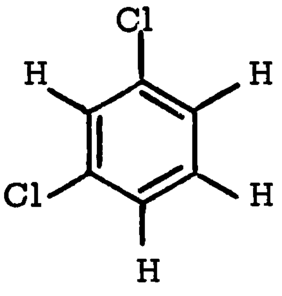
Facts such as these led early workers to suggest that carbon bonded to four groups is tetrahedral:



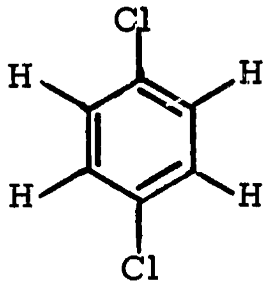
The three isomers of $C_6H_4Cl_2$ can be explained using a planar, hexagonal C_6 framework (and introduction of the early ideas of electron delocalization):



ortho

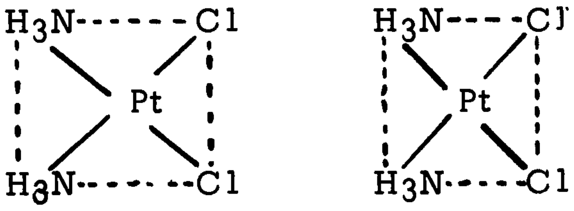


meta

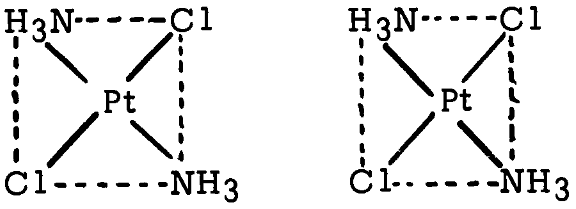


para

The two isomers of $Pt(NH_3)_2Cl_2$ show that four-coordinate Pt is <u>not</u> tetrahedral, but square planar:

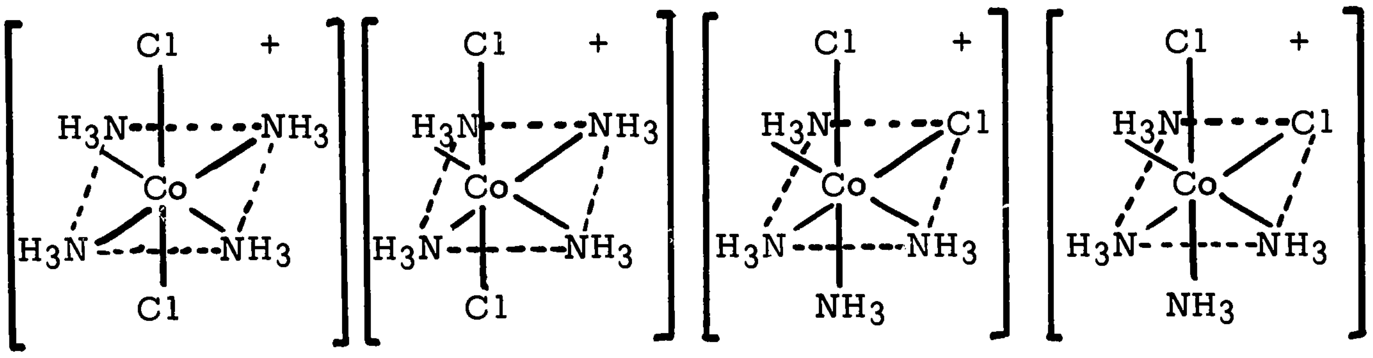


cis

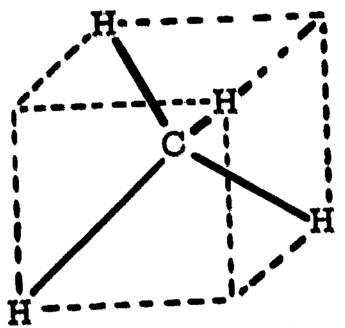


trans

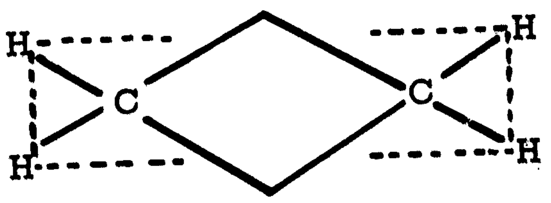
Finally, the two isomers of the ion $Co(NH_3)_4Cl_2^+$ suggest an octahedral structure around Co:



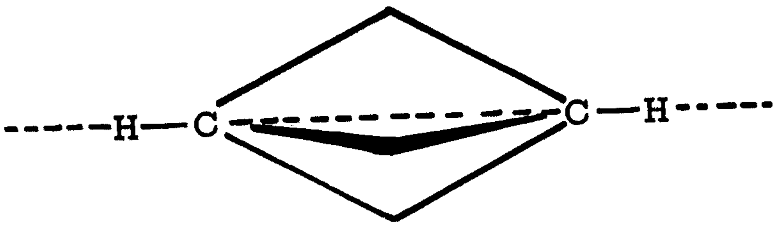
From these observations, we assign a number of directed "hooks" or "covalences" to different central atoms. A large number of plausible <u>molecular structures</u> can then be deduced from <u>molecular formulas</u>. For example, knowing that H has one hook and carbon has tetrahedrally directed hooks leads to correct predictions of the shapes of C_2H_2, C_2H_4, and CH_4:



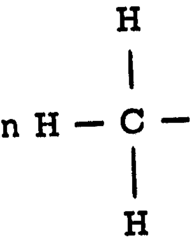
tetrahedral
methane
molecule



planar
ethylene
molecule



linear
acetylene
molecule

The discovery of X-rays and the serious application of X-ray techniques to the determination of molecular structure ushered in the next period in the study of chemical bonding. As more information became available on the shapes of molecules and finer details of molecular structure, such as bond lengths, bond angles, and bond energies, a better model for chemical bonding was needed. Chemists wanted to understand why H_2 was more stable than H or H_3, and whv carbon had four "hooks." The big development in this period was the concept of electron sharing in bonds such that each atomic participant achieved a configuration equivalent to that of an inert gas atom. Thus, we represent H_2 as H : H or H — H, in which each hydrogen by sharing in the <u>two</u> bonding electrons "feels" like He, which has a chemically stable electronic structure. In order to "feel" like Ne, carbon must surround itself with eight electrons: this it can do by making four bonds as in 

$$\begin{array}{c} H \\ | \\ H - C - H \\ | \\ H \end{array}$$

. Fluorine also wants to achieve the Ne configuration, explaining molecules such as $:\ddot{\underset{..}{F}}-\ddot{\underset{..}{F}}:$ and $H-\ddot{\underset{..}{F}}:$. In the transition metals, examples can be cited in which the central atom effectively achieves the Kr configuration, as for example $Fe(CN)_6^{4-}$.

The useful rules of 2, 8, and 18 in deducing representations of chemical bonding came from the concept of the stable inert gas configuration.

Of course, there are many exceptions to the rules of 8 and 18. It is useful to point certain of these out, because the exceptions themselves form an interesting pattern which can be interpreted later in the framework of orbital models of bonding. Representative exceptions to the octet rule are PF_5 and SF_6, whereas $Cr(CN)_6^{3-}$ and $PtCl_4^{2-}$ are two of the vast number of exceptions to the rule of 18.

The great discoveries in theoretical physics in the late 1920's, coupled with substantial advances in the experimental methods of structural chemistry, led to the development of models of molecular electronic structure which are still under scrutiny by contemporary workers. Spectroscopic experimental techniques designed to explore in great detail the electronic, vibrational, and rotational motions of molecules, gave chemists much needed information on precise bond lengths and bond angles of discrete molecules. Magnetic resonance methods gave additional information on electronic structure. The magnetic and electric dipolar properties of molecules became known to experimenters. No longer were "lines" sufficient for bonds, nor "dots" sufficient for electrons. Models were needed which allowed formulation of electronic excited states, as well as the ground state. Furthermore, we need to know the "shapes of bonds" to interpret many molecular properties.

This is the appropriate time to introduce the molecular orbital model. In this model we assume orbitals and discrete energy levels for molecules, in analogy to the modern model of atomic orbitals and energy levels. The properties of bonding and antibonding molecular orbitals are introduced in the case of H_2; subsequent discussion of H_2^+, H_2, He_2^+ may include interpretations of bond lengths, bond strengths, and magnetic properties. The shapes and relative energies of molecular orbitals for the general homonuclear diatomic molecule provide a framework for the discussion of bonding (or the lack of it) in Li_2, Be_2, B_2, C_2, N_2, O_2, F_2, and Ne_2. It may be helpful to "derive" the shapes of the molecular orbitals by making appropriate linear combinations of atomic orbitals. It is probably good to admit straight out that the relative energy levels come from spectroscopic experiments and from the magnetic properties of diatomic molecules. After all, atomic energy levels for the many-electron atom are asserted on the same basis and the student already has some mental picture that an energy level is associated with an orbital.

Bond lengths, bond strengths, and magnetic properties can be interpreted for B_2, C_2, N_2, O_2, and F_2 in terms of the net bond order deduced from the molecular orbital structure:

Bond order: $B_2 < C_2 < N_2 > O_2 > F_2$
Bond length: $B_2 > C_2 > N_2 < O_2 < F_2$
Bond energy: $B_2 < C_2 < N_2 > O_2 > F_2$

An added bonus from the molecular orbital model is the explanation of the paramagnetism of O_2, which is a mystery if each oxygen has achieved the Ne structure as in $:\ddot{O}-\ddot{O}:$.

Before leaving the diatomic molecular orbital model, it is a good idea to stress very strongly its highly approximate nature. The student should realize that this model is not the last word by any means. Here one or two problem spots may be cited to plant a healthy element of suspicion in the student's mind. One place where the simple molecular orbital theory fails is in the Li_2 and Li_2^+ molecules. The simple theory would predict Li_2 to be more tightly bound than Li_2^+, but experimentally the reverse is found to be true. This puzzling trend should serve to stimulate student thought and discussion.

There is a limit, naturally, to the useful extent of development of the delocalized molecular orbital model (for freshman students). Two or three polyatomic molecules as examples, however, will serve as stepping stones to concepts of energy levels needed later for the development of models for metallic bonding and the ligand-field theory of transition-metal complexes. The delocalized molecular orbitals for the linear triatomic molecule BeH_2, and the π orbitals for the benzene molecule, are reasonable choices. After presenting BeH_2, the localized hybrid-orbital model can be developed as a means of pinpointing the bonds in polyatomic molecules.

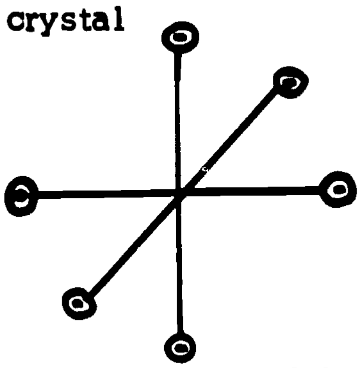
The concept of hybridization and the "need" for it is one of the most difficult and important ideas to get across to the student. Hybridization can first be introduced in the case of Li_2, by pointing out that electron density can be stuffed into the region common to the two Li atoms by contaminating the 2s Li orbital with a little 2p character. How much 2p character should be mixed in is a matter of some speculation, but it can be argued that an optimum value (a balance between the larger overlap gained and the higher energy of hybrids because the 2p orbital is higher than 2s) is about 10% 2p character for Li_2. Another viewpoint on the need for hybridization comes from a discussion of the B_2 molecule. The ground state of this molecule is $^3\Sigma$, meaning that there are two unpaired electrons in the π bonding molecular orbitals. This in turn shows that the π bonding level is filled before the σ bonding level constructed from the 2p valence orbitals. The unexpected, higher energy of the $2p\sigma$ bonding level can be rationalized as a direct consequence of the stabilization of the $2s\sigma$ bonding orbital by hybridization. As a result of the 2s-2p hybridization, electrons in $2s\sigma$ are more stable, being more concentrated in the bonding region, but the concomitant and necessary 2s hybridization into $2p\sigma$ removes some electron density from the bonding region for this orbital, raising its energy.

The use of the hybrid orbital model as a means of getting electrons away from each other should be explained further through the use of several other examples. Good examples are H_2O and NH_3, where it can be argued that the sp^3-1s bonding model is better than the simpler 2p-1s model, because the observed bond angles are $105^\circ(H_2O)$ and $107^\circ(NH_3)$. The introduction of 2s character into the bond orbitals provides a mechanism by which the bonding electrons can be better separated, without any loss of stability due to a decrease in overlap of the appropriate valence orbitals. Then the decreased interelectronic-repulsions known for 3p orbitals of sulfur atoms (relative to 2p oxygen) account nicely for the 92° angle in H_2S.

The groundwork has now been laid for a discussion of bonding in condensed phases. This is a very important topic, because most chemistry is not done in the gaseous state. The types of solid lattice structures can be outlined based on the principal bonding force in operation: (1) the metallic bond, characterized by relative freedom of electron movement; (2) the weak van der Waals bond in molecular solids, described as an (instantaneous-dipole) - (induced-dipole) force; (3) the strong and apparently localized covalent bonds in the non-metallic network solids; (4) the ionic bond, found in lattices such as NaCl. The types of bonds found in condensed phases are directly related to the electronic structures characteristic of the atoms and simple molecules which make up the materials in question. This relationship is a big bonus to the student.

The transition metal complexes are excellent subjects to use in illustrating the utility of molecular orbital theory. In our opinion, far too little attention is given to this vital area of modern chemistry. With a background of molecular orbitals and energy levels in molecules such as H_2, N_2, O_2, BeH_2, and C_6H_6, it is relatively easy to introduce the idea of a splitting of primarily d orbital energy levels in octahedral complexes because of covalent bonding. An explanation of the colors and magnetic properties of selected octahedral complexes should be presented.

It is in the spirit of historical presentation of concepts of molecular structure to outline briefly the hybrid-orbital theory for two or three complexes. It can be pointed out that the interesting colors of metal complexes could not be explained using the hybrid-orbital theory of localized bonds. The crystal-field model takes a 180° turn away from the hybrid-orbital model, its basic tenet being that the electronic structural properties of metal complexes can be interpreted within the framework of an ionic model. This model lends itself to classroom presentation, because it is relatively easy to convince the student that in an octahedral crystal field of point charges the five metal d orbitals are not of equal energy. This leads to the assertion that there are in fact two d orbital levels, called t_{2g} and e_g, and that they just happen to be split by about the energy equivalent to visible light frequencies. Thus, the colors of most metal complexes occur because of light absorption accompanying electrons jumping from the lower t_{2g} level to the upper e_g level.



octahedral crystal field

It is wrong to leave the student at this point. Recent calculations and correlations show that this electrostatic part of the $t_{2g} - e_g$ splitting is not nearly large enough to explain the effect; furthermore, it is of the wrong sign! The latest viewpoint is that covalent bonding involving the σ d orbitals (d_{x^2-yz}, d_{z^2} in the usual notation) gives a bonding $d\sigma$ level and an antibonding $d\sigma$ level. The antibonding $d\sigma$ level is the e_g level of crystal-field theory, but the major contribution to its instability relative to the t_{2g} level is due to its involvement in a delocalized σ molecular orbital network. No new concepts are needed in order to discuss energy levels in metal complexes. The origin of the splittings in molecular orbital levels is the same as in H_2 and benzene.

Concepts of chemical bonding and molecular structure can be profitably used and strengthened in a tour through representative parts of the periodic table. In this all-important part of the course, it is a good idea to discuss the chemical transformations of molecules as a systematic function of structure. Some nonmetallic elements with rich structural chemistry are boron, carbon, nitrogen, oxygen, phosphorus, and sulfur. A great many structure-reactivity correlations can be made using these elements as examples.

THE GENERAL CHEMISTRY COURSE:
SOME PRESSURES, PROBLEMS, AND TENTATIVE SOLUTIONS

Robert I. Walter

Haverford College
Haverford, Pennsylvania

My purpose this afternoon is not to give you "the word" on the general chemistry course. As far as I am concerned, there is no "word." All of us must design our programs to fit the abilities and backgrounds of the students who happen to come our way. I would like to survey what seem to me to be the directions in which the general chemistry course, with many exceptions, has moved during the recent past.

Until 25 years ago, there was a dreary uniformity in the way chemistry was taught in this country. Students attended a general chemistry course--some chemical equilibrium and a lot of descriptive chemistry--and then completed a year of analytical chemistry, followed by a year of organic. In their senior year they studied physical chemistry and perhaps had an opportunity to take a semester of advanced work. Teaching has become much more exciting over the past 25 years because people have tried a variety of new course schemes. The undergraduate curriculum has been subjected to a number of pressures during that period, and many of these pressures focus on the freshman course. I shall try to say more about the freshman course than about the curriculum in general.

One source of pressure is the students themselves. The demands of students on their education these days are much more outspoken than would have been the case 25 years ago. Students now let us know what they think. They are just as inclined to be short-sighted, and in many ways prejudiced in their views as they might have been earlier. These are properties of youth, and one can't get away from them if one is teaching young people. There have been all kinds of responses to these student pressures, and these include curriculum changes in some of our strongest educational institutions. Two examples are the reduced emphasis on and earlier presentation of quantitative chemistry, and the development of courses in biochemistry.

A second source of pressure is the rapid rate of change in the practice of chemistry. The most obvious illustration of this has to do with analytical chemistry also. Twenty-five years ago most schools offered a semester of sophomore qualitative analysis, a semester of volumetric, and some time later in the curriculum there was a third semester of gravimetric analysis. At that time, no one offered a course in instrumental analysis, and indeed, there were relatively few instruments in use in analytical work. The need for this course is a development of the past quarter century. This pattern was a sort of vestigial remnant; a kind of appendix on the chemistry program. It came from the days when most chemists who completed a degree in chemistry became rock analysts. Naturally, we invented various excuses for continuing to offer these courses. They were supposed to teach laboratory technique, descriptive chemistry, and chemical equilibrium calculations. There is good reason to doubt that they did any of these. There is one very strong argument for keeping qualitative analysis in the program: the interest which many students take in it. They really enjoy the laboratory work, and I think there is a serious lesson for us in this fact. They enjoy it because it poses problems for them which they have to solve for themselves, and if we can find other ways to give chemistry laboratories which also pose problems for the students, these will be equally attractive to them. Careful analytical work is rarely a source of pride or satisfaction to students today, and this may be bad for the future of the science. Not all problems can yet be solved by computation!

Another source of pressure on the freshman chemistry course is the improvement in high school curricula. If anything, this has made it harder for us, because we are now faced with a wide range of student backgrounds from no chemistry at all to the equivalent of a good college course. Worse yet, many students come to us thinking they know material which they really understand very superficially. Obviously we must provide for a great deal more flexibility in assigning students to the freshman program than was necessary 25 years ago. This is very difficult. Many of us have found that the best way to judge is to test their mathematical ability. This is a matter which I have never understood, because the selection of material usually presented in this course does not demand a great deal of formal mathematics. The requirement seems instead to be an ability to reason in the abstract which students usually do not pick up if they have not acquired reasonable facility in mathematics.

Still another source of pressure, reflected less in the freshman course than in the rest of the curriculum, is the graduate schools. Many of these now expect their students to select a research advisor and a problem within the first few weeks they are in the school. A student who has had some exposure to a research problem while an undergraduate has a much better chance to make this decision wisely. It is not unduly cynical to say that graduate schools expect more of the undergraduate program every year; they seem to be moving toward a requirement that all courses be out of the way by the time a man is admitted to graduate study. The time may be coming when those of us who believe in a liberal education must resist this trend, for we may be reaching a stage at which we train chemists, but no longer educate people.

There are also pressures on the curriculum and on the freshman course which arise from industry. Most of these take the form of a question. Why is it that you people don't teach "blank" to your students? "Blank" here is almost any topic in chemistry: surface chemistry, polymer chemistry, literature chemistry, chemical economics, and so on. Pressures of this same type arise from those of us who teach. All of us tend to reflect our own prejudices in our selection of course material. There is much to be said for teaching those areas in which one is most interested and most knowledgeable, but I think one has to maintain a perspective over the entire field of chemistry while he does this and sometimes we do not manage this.

Now, I should like to say something about the directions in which I believe the chemistry curriculum has moved. One of these I have already mentioned. Qualitative analysis used to be a sophomore course for everyone, became part of the freshman course, and has now disappeared altogether in many institutions. In some cases, quantitative analysis has also moved into the freshman course. This is possible at a serious level only if the student body is quite homogeneous. Both manipulative and intellectual deficiencies can cause problems here. The general chemistry course is for all of us the massive course which requires handling the largest number of students and the largest proportion of physically or intellectually inept students. When one moves new topics into the freshman course, a relatively unselected segment of the student body must then be brought to mastery of this material. The problem of physical ineptitude may become quite serious as the American population becomes increasingly urbanized, with little opportunity for mechanical experience during childhood.

A somewhat similar problem appears as a consequence of the transfer of topics from physical chemistry into the general chemistry course over the past two decades. This has happened everywhere; it is reflected in all of the recent textbooks. It implies a level of mathematical sophistication which cannot realistically be expected of the large cut of students who enroll in general chemistry.

The increased emphasis on physical chemistry in the introductory course has been accompanied by a decreased emphasis on descriptive chemistry. The consequences have been aggravated by changes which have also decreased the amount of descriptive chemistry offered in high school courses. This may be a mistake, for there is reason to believe that students master facts most easily and enthusiastically when they are younger. Their interest in logical reasoning or original thought develops later. A possible factor in the decline of descriptive chemistry in the introductory course is the parallel decline in lecture demonstrations. One valuable area of future Council activity might be to accumulate ideas for either lecture demonstrations or their new cousin, lecture experiments, from chemists active in research in the appropriate areas. These undeveloped ideas could then be made available together with modest financial support for investigation during the summer vacation. This type of work should interest many college faculty members. They could do it well, and the result could be a collection of lecture demonstrations and experiments based on modern developments in the science. Many college teachers are not in a position to develop ideas on which to base demonstrations, and few research people are willing to devote time to developing them properly.

I should like now to turn to some apparent trends in planning and teaching the general chemistry course. The transfer of topics from physical chemistry to the first course has in the past been rather indiscriminate. I believe that it is possible to teach any subject to a freshman, but only if one is willing to take enough time to do it properly, at the expense of other topics. One of the mistakes which we have made in the recent past is to try to teach freshmen too wide a range of topics from physical chemistry at a level which is too superficial for thorough understanding. There now appears to be a trend toward teaching fewer topics but each of them in substantial detail. Together with this, an interest is developing in arranging selected descriptive material so as to illustrate the theoretical principles which have been covered earlier. Efforts in this direction have been handicapped by a lack of appropriate material, but it seems likely that this will appear in a number of texts which are now being written. Many chemists hope that these changes will be part of a rationalization of the entire undergraduate curriculum in chemistry, based upon a thorough analysis and restructuring of the program. A program modified in this way has been in use for some years at Earlham College, and another scheme has been proposed at Cal Tech. It is interesting that the first course in the latter program is still called general chemistry!

APPLICATION OF A RESPONSE SYSTEM, TAPE RECORDED MATERIAL, AND OTHER NOVEL TECHNIQUES IN UNIVERSITY CHEMISTRY INSTRUCTION

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The Chemistry Department at Simon Fraser University has explored the application of a number of novel teaching techniques in lecture and laboratory courses at the university freshman level.

In lectures to groups of up to 550 students, conventional overhead projectors and FM radio microphones are employed. All material for the overhead projectors is prepared in advance. Students are provided at cost with photocopies of all projected material. Students then concentrate on margin annotations and pay more attention to the lecturer.

Lecture demonstration experiments are shown a number of ways. A modified overhead projector system is used to display experiments of the Alyea type where color or transparency are important. A large screen television projector and TV cameras on the lecture podium are used to project experiments which are opaque, or which are in other ways more suited for the TV medium. Experiments involving non-portable distant equipment are first video taped and then presented later in the lecture auditorium. 35mm slides and 16mm movies are also inserted in the lecture sequence where appropriate.

In lectures, and particularly in tutorials or problem working sessions, an electronic response system has been employed. Each student seat in the auditorium is equipped with a five position switch; meters at the lecturer's podium indicate the percentage of switches in the room dialing a particular position. This system is used to allow students to convey anonymously to the lecturer their degree of understanding of a particular item. The system is of most use when students convey to the lecturer that they have completed the working of a particular problem or that they are having difficulty with a particular segment of it. Not only is communication between the student and the lecturer very much improved but the pacing of material can more accurately be gauged to the capabilities of the audience.

All lectures are routinely recorded and made available later for student review in a listening facility. In addition, tape recordings are available which review the working of problem sets and which provide supplementary lectures on difficult areas.

Recorded material has also been employed in the freshman laboratory, coupled with an individual laboratory booth for each student. The latter is 6 feet in width and is surrounded by walls extending to above eye level. Each booth contains all the chemicals and glassware required for a given week's experiment together with a tape player and 8mm loop projector as may be called for.

Students may enter and leave the laboratory at any time; their schedule is decoupled from that of the instruction staff by the use of recorded materials. The material offered in a given week is not limited to one week's exercise, since the materials in a booth may readily be changed from one experiment to another should a student request this. Students who experience difficulty may obtain advice or summon help by means of an intercom unit in each booth.

Staff spend much less time in the repetitive instruction of routine techniques. They spend more in individual counselling of students and on checking for unsafe practices. Each student each week is examined by a ten minute quiz in addition to inspection of his laboratory notebook. This weekly session also provides an opportunity for individual difficulties to be ironed out.

The capital expense of this laboratory is not appreciably greater than that of a conventional laboratory course. This follows from the fact that expensive items such as balances are not all required simultaneously by the students and a smaller total number is adequate. This offsets the cost of tape recorders and other special items.

The reception of these techniques by students has been generally a favorable one. This extends beyond the mere novelty effect, which however by itself may be an appreciable teaching aid. In general we are encouraged and intend to pursue this line of experimentation.

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THE INTRODUCTORY LABORATORY - IDEALITY VS. REALITY

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The thing I would like to talk about first is something on which I think most of us can agree, that is, the ideal laboratory. We all know what it should be. Then I would like to talk a little bit about the real laboratory. Finally, I would like to add some commentary -- the prejudices that I have developed over the years.

I think that we will all agree that the first requirement for the ideal lab is that we have an ideal student. We would like this ideal student to be able, interested, and to have lots of time. Now we get to the harder part because in addition to an ideal student, we also need an ideal teacher. In the order of decreasing importance, the teacher should have lots of time available and he should be able and he should be interested. (You can argue about the order but certainly these are ingredients.) This ideal laboratory should have a kind of apprentice - master relationship,say,with an instructor who has only two students to worry about. Then we add to the ingredients of the ideal lab what we are going to do. First (if you think you have heard this before, you may have) we would like to teach some basic techniques and methods. We really want to teach them more than basic techniques, however; we would like to show them that there are some regularities about chemistry, there are some expectations in the behavior of chemical systems that we hope will be fulfilled. After we had led him down this garden path, we would perhaps like to show him that not all systems behaved ideally. In other words, if you want a very primitive kind of example, first we put him to work with the ideal gas law using helium and then we give him something like acetic acid vapor as a case where ideal behavior is not followed. This is a perfectly reasonable thing provided we can do it without making it too complex. The third thing we want to be able to do is to answer a question something like this: do the irregularities stem from something in nature or something in the technique? In other words, if he finds out that PV is apparently not equal to nRT, is this just because n and R and T are not too well known, or that his measurements are not accurate enough or that PV is not equal to nRT in this particular case? This is very important. The fourth item, which is really a part of the third, involves the development of what we might call critical judgment. I think we have to give him a chance to test what he suspects. In other words, give him a chance to repeat his measurements, to perform in replica his experiments, to design an alternative experiment. I think these also are the kind of ingredients you have in a research problem. If you run into something that is unexpected, the first thing you do is design an alternative experiment to try out your explanation. This is the ideal laboratory.

Now I will go over to a real laboratory. In order not to insult anybody, I will talk about the laboratory which I will say we have at Johns Hopkins, a real laboratory. I will discuss how well, how closely, we approach the ideal laboratory. First of all, let us look at our student the country over. (I refuse to look at the instructor.) Of all the students we collectively feed into the freshman chemistry course, (something like 400,000 or 500,000) only 0.3% end up going to graduate school and getting their Ph.D. in chemistry; 99.7% of them go elsewhere. Let's assume that the 0.3% going on to get their Ph.D. in chemistry are able, interested,and have lots of time, that is, 0.3% of the students are ideal. The point that I am trying to make is that if we say that we design the course entirely for the chemistry major with the idea that they all do research in graduate school, we are considering only a very small fraction of the total. We have to design chemistry for all types of students and I think that this is probably best anyway. But it may well be that those students who are truly interested are a minute fraction of the total.

As I said earlier I refuse to discuss the teacher. Obviously they have an ideal teacher.

Some years ago we revamped our laboratory and we did not simply move down things from the physical chemistry laboratory -- although it may look that way -- but we actually decided what experiments would be interesting to do. Then we wrote the book on the basis of these experiments. When, after the first year, we questioned the students as to what they thought about the course, their principal complaint was that there was no correlation between the lectures and lab. At that point I decided correlation is a problem that had no solution so I have forgotten about it.

I think maybe we can best discuss the real lab in terms of the four points cited in our discussion of the ideal laboratory. We achieve the first objective and teach them some techniques and methods. If we look at the second, i.e., we should demonstrate for them that some systems behave ideally, I think we can't always do this from the standpoint of the students. In other words, the systems on which they do gas law experiments should really obey the ideal gas law but according to their results they often do not. Point number three: Is this irregularity due to nature or is it due to their experimental techniques? Well, they make a stab at this sometimes in their laboratory reports. The big drawback to this particular real lab, and I suspect to many, is that there is very little of this kind of process that takes place. They get their results, and there is always a question: Are their results correct or not? There is very little opportunity for them to go back and redo the experiment, and there is very little opportunity for them to devise alternative experiments to check out their hypotheses.

I think the real trouble with most real labs is a number of things. Let me review for you a little bit of the history of our lab at Hopkins. The first year of the new lab, things were pretty horrible, confused -- the students didn't mind though, they thought we were doing something for them. The second year we had ironed out most of the difficulties -- things ran a good deal more smoothly -- we were able to anticipate some of their problems. You see, the first year we were 2, 3, or 4 weeks ahead of these students. We had outlines of what we wanted them to do and we got the apparatus into the lab sometimes five minutes before they came. We had tested out the experiments on a small scale with two students, and then we had decided whether to go into full scale operation. At any rate, the first year was pretty bad. The second year was much better. Everybody was enthusiastic. By this sixth year we have taken care of almost all the quirks that had existed. We now have the procedures pretty well worked out so that the students can follow them in detail. We have realistic schedules, so much for each experiment -- some experiments taking as long as a month. We also have fraternity files filled with what the results should be on the experiments, and so if the student really gets fouled up he can find out what the answer should be. Finally, we have inertia on the part of people connected with the course. By this sixth year we are well organized. We are well organized and deadly. I think much of the enthusiasm has gone out of this laboratory by now. OK, so that's a real lab.

Let's talk now about some of the prescriptions I would make, but not necessarily take. What do I think could be done? Well, first of all we have to obviously be aware that 99.7% of the students aren't ideal by definition. What else could be done as an alternative to the laboratories? This issue has been discussed a large number of times: there is a possibility of film loops, there is a possibility of laboratory by film or TV. There is all this sort of thing. In at least one, however, the laboratory is like old age: neither is too bad compared to the alternatives.

I think perhaps you can soup up things a little bit in the lab by trying lecture experiments. One of them I recommend highly -- (by Art Campbell in the Journal of Chemical Education about three years ago) is the blue bottle experiment. Read it over, try it out -- it's lots of fun and see if you can't work up some of your own. This will tell you what a lecture experiment is like. I think that there are probably many things that you aim for in the laboratory that you can actually accomplish in a lecture experiment without going to the bench, but nothing is quite like the real experience. You have to get the students to the point where they have to make decisions about how much to add to that and how much to this -- even to trivial things like which beaker should be used to put something in. These simple aspects of laboratory are ample justification for its existence. What I would suggest, however, is that the newer your laboratory is, almost regardless of what you are doing, the closer it's going to be to the ideal lab, and the older it is the closer it is going to be to the real lab.

THE INTRODUCTORY CHEMISTRY LABORATORY

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I would like to divide my talk into a half-dozen sub-topics. These are:

1. A Commercial Process (of interest to academic chemists)
2. Then and Now
3. Prophecy
4. Ideality *vs*. Reality
5. Alternatives to the Laboratory
6. A Message

All of these topics, of course, deal with the introductory laboratory, but we shall not ignore in our discussion the lecture and later courses which, of course, impose restraints on what you can do in the laboratory.

1. A Commercial Process

Each year roughly 10^6 high school students take a course in chemistry. Roughly half this number take an introductory college chemistry course so that at this step, we have a 50% yield. (In reality, we have less because many who take the college course have not had the high school course.) Of this starting material, 10^6 students, we end up with a yield of 10^4 students graduating as chemists. Thus, this two-step process gives a yield of 1%. If, with a common prejudice, we focus our attention on the research chemists produced, the Ph.D.'s, we find about 1500 to 2000 students will obtain their Ph.D.'s. Therefore, this multistep synthesis has an ultimate yield of about 0.2% (or 0.4% based on colleges alone).

Even in the face of the above statistics, however, most chemists tend to put most of their efforts into the 0.3% of students who go on to get their Ph.D.'s. Furthermore, we often design the introductory course with only the needs of the 0.3% in mind. The attitude commonly taken parallels a statement of "Engine Charlie" Wilson: "What's good for General Motors is good for the whole U.S." Chemists say: "What's good for chemists is good for everyone." This argument, while appealing, may not be true.

There is one other point that causes me some concern. We tend to judge the success of our introductory chemistry course by the number of majors we produce. I think we are doing an equally good job when we demonstrate to a student that chemistry is not his kettle of fish. I realize this criteria of success is not easy to apply nor does it provide convincing arguments for deans, heads of departments, etc. Nevertheless, to judge the success of a program by the number of majors alone is probably a fraud.

2. Then and Now

To be specific I define then as 1947 and now as 1967. The accompanying table represents the curriculum then and now as practiced by a number of institutions.

	1st year	2nd year	3rd year	4th year
Then	Intro.Inorg. Chem.	qual. quant.	Organic Adv Quant	Physical + others
Now	A. Intro.Chem. qual.	Organic quant.	P. Chem. Adv.Quant.	Inorganic + others
or	B. Intro.Chem. qual, quant	P. Chem.	Organic	Inorganic + others

I don't mean the "now" curriculum is the most common, but I think we find this form at most forward-looking institutions. It probably represents what the average curriculum for majors will be shortly.

3. Prophecy

If a chemist trained in the thirties or forties was put into suspended animation, then resurrected in 1967 and put into an Introductory Chemistry course, he would say, "Aha! Physical Chemistry." Perhaps by 1987 we will be more honest and call the introductory chemistry course with its attendant sophistication Physical Chemistry. Then in the second year the student will probably take what we now call Organic Chemistry with some admixture of Inorganic Chemistry. Following this will be courses with names we haven't thought of that will probably deal with the more mathematical aspects of structure. Quantitative analysis as a separate course will vanish--it's already on the way out. For what it's worth, this is my guess.

There is another possibility, however. Hammond at Cal Tech has proposed that the traditional divisions of chemistry into organic, physical, inorganic, and analytical be reexamined. Overlap of these divisions is very strong. For example, the inorganic chemistry of complex ions often deals with compounds that are mostly organic by weight. Hammond proposes that we adopt divisions such as: Structural Chemistry, Chemical Dynamics, Syntheses, Energetics, and Theoretical Chemistry. Clearly, the inorganic and organic chemists studying mechanisms of reactions are more closely related than they are to synthetic chemists (organic or inorganic); the first group of chemists are studying chemical dynamics according to Hammond. Given this point of view, our courses should reflect this newer, more meaningful, division. This implies one year courses in Dynamics, Structure, and Synthesis rather than physical chemistry, organic chemistry and inorganic chemistry. Although the logic of Hammond's position is obvious, it is my belief that the changeover to this new labelling scheme will not become wide-spread for at least a generation. Chemists are very conservative. (It is amusing to note that with this new labelling of chemistry, the first year course of the proposed new curriculum is called--"General Chemistry." This is the only part of the package now actually being tried at Cal Tech.)

4. Ideality vs. Reality

In my mind's eye the ideal lab should permit the following:

a. Teach the student basic techniques.
b. Show the student there are regularities in chemistry--predictions

he can make with reasonable hope of their being correct.

c. Show the students not all systems obey these predictions.

d. Permit him to recheck his results or even design alternative experiments so that he can decide if the failure of his prediction in case c is a fault of nature or his technique.

e. Give him a chance to subject his hypothesis to experimental test.

One of the most important aspects of the above is decision-making and experimental design by the students. It is here he captures the true flavor of the laboratory in real chemistry. This, I believe, is why qualitative analysis generally appeals to students--not the unknown aspect. Quantitative analysis is generally boring and it has unknowns. But quant. also has rigid procedures whereas qual., properly presented, offers both a standard procedure and an opportunity for students to design and carry out alternative experiments.

The closest to the ideal lab (by my criteria) is that currently in use at Cal Tech by Gray and Hammond. The sixteen students are broken down into eight lab sections of two each. Thus, one pair of students has Gray for a lab instructor. (This is truly an apprentice-master kind of relation--with a most enthusiastic teacher.) Initially, they synthesize trisacetonylacetonatochromium (III), purify it and characterize it. In the characterization they can use several methods: analysis, spectroscopy, paramagnetism, etc. Several cross-checks are required, but the student has some options. After this the student can carry out further synthesis, e.g., he can brominate the ligands, nitrate them, etc., but he must again purify the product and use several techniques to characterize it. From the start a number of options are available as to the path chosen by the student, but he must use professional standards in carrying out these steps. Future plans call for reactivity studies on the student's own preparations. It has been emphasized that for success such a program must be flexible and provide lots of time for the student. It sounds to me like this is an exciting experience for both student and teacher.

Most real labs have more than two students per instructor and more than sixteen students *in toto*. At Hopkins we have slightly over 300 in the course. This alone raises some logistical problems and we often compromise with reality.

Let me first talk of correlation of lecture to laboratory. Some years ago, we completely revised the lab at Hopkins. First, we got together a series of experiments that we thought were both interesting to students and rich in concepts. Then we wrote the lectures. The purpose of this procedure was to emphasize the correlation of the two. At the end of the year we passed out a questionnaire to the students. One of their principal complaints was lack of correlation between the lecture and the lab. I think this correlation aspect is a bugaboo we should get rid of. Provided the student has sufficient background from the lecture to understand the procedures, we should not strive for a one-to-one correlation between lecture and lab. I now believe not only is it unnecessary, but it may be impossible from the student's viewpoint. Furthermore, if we achieve a force-fit, it may relegate the lab to an inferior position compared to the lecture.

Let me return to general impressions of the lab course at Hopkins. The first year of the new course was quite demanding. All instructors were only one step ahead of the student. (Testing, of course, had been done over the summer, but this just showed if the experiments were reasonable, not the student's reactions to them.) Schedules were very flexible and could be readily expanded if the need arose. Often, we fouled things up. The students didn't mind, however. They felt we were doing something for them. By the second year we had many of the difficulties in hand but not all. The students were even more enthusiastic. By the sixth year all the quirks were taken care of. Various "saves" along the way were available for the student who fouls up part one of a sequence. Schedules were tightened up. Fraternity files were full of old reports. The professor in charge can now rest easy--everything is organized--all instructors know what to do. Somehow, however, some of the excitement, the newness, the enthusiasm, the investigative aspect has gone out of the lab. I firmly believe once inertia governs a lab program, rigor mortis is setting in. This is one of the principal problems with a real lab.

5. Alternatives

What are the alternatives to the lab? The ones considered by AC_3 in a recent report are: films, TV, programmed learning, and lecture experiments. For all the real problems connected with a real lab, the lab--like old age--is not so bad when you consider the alternatives.

The most interesting (to me) of the proposed alternatives (as a teaching aid, not a substitute for lab) is the lecture experiment. A lecture experiment, according to Art Campbell, its principal proponent, is not a demonstration but a real experiment. In my view of a lecture experiment, the lecturer walks into class and says: "Today we will perform an experiment with the equipment you see on this desk. I will play two roles. First, I will be your technician--your hands. I will do what you tell me. Secondly, I will be your research supervisor. If you propose an experiment, I will try to poke holes in its design. If I can't, we'll try it out. Now, just to get you started, let's see what happens when we*." Something appropriate is done at * to start an observation. Then the class is quizzed. What happened? Did it happen immediately, slowly? Such direct questions directed to individuals usually generate blank looks. Then you warn them to watch and record observations and you repeat the initial action. You're off! From here on dialogue determines the course of the experiment. The lecturer has to shoot down their explanations by logic or have students design experiments to test them. It's exciting and trying to the teacher, and I presume effective with students.

6. The Message

My message is simple. Experiments in the laboratory have to be tailored to all the students in the course. Their needs vary from school to school. Work up your own set of experiments and change them from time to time. It avoids inertia. Although it makes scheduling difficult and promotes disorder, it also provides the student with excitement and a feeling that he is an investigator. If you take such an approach, the student will not make use of every minute in the laboratory, but the time he uses may be much better spent than in a "packaged lab" that "works out right" with a tight schedule.

I would further like to call your attention to the lecture experiments typified by the "Blue Bottle" reported in the Journal of Chemical Education with a "script" by Art Campbell. Time taken from the lab for experiments such as this is, in my opinion, time well-spent.

PLANS FOR A CORE CURRICULUM LABORATORY PROGRAM

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One of the things that happens very early in a teaching career is that you find out how quickly you get out of touch with the younger generation through your jokes and through your references to "contemporary things" that they haven't experienced. The last time I was really brought up short was at a lecture to some high school students at Binghamton, New York about two years ago. The introducer decided to give them my complete professional history and it took 20 minutes. Being pretty exhausted at the end of this, I got up and tried to generate enthusiasm for the meeting by saying, "Have test tube! Will travel!", and they all looked at me rather stonily. Even my TV experience was out of date. And thereby hangs our problem--one of being, not only up-to-date, but rather futuristic as well. I should like to make just a few remarks from my own self-generated thoughts on this problem which I entitled "Curricular Response to a Changing World." I have noted that as educators we find that society is using us to prepare the next generation for the world by passing on its own experience through education. Our own experience is pretty passe for what's in store for the next generation, for a major feature of our experience even now is that the world changes very rapidly. This is an accelerating phenomenon that daily makes our task more difficult. I thought with some amusement recently that my grandfather was present as an Indian agent in Arizona at the capture of Geronimo and lived to "see" the Russian Gagarin going around the earth in a sputnik. That's quite a change for one lifetime. Then, again, being a parent with teen-age children who inform me daily on how out-of-date I am, I think how right they are a lot of the time to reject our experience utterly in shaping their own views and own thinking about the world; and then, often I think how wrong they are not to take cognizance of those permanent values that we have secured. We have the problem of defining for ourselves and the next generation what is both permanent and worth passing on from our experience. How can we use our own experience with change to prepare them for change? I think that this is a hard problem and that we are just becoming aware of it.

The selection and packaging of material for chemical education has always been a problem. It has been a problem because we depend so much on other subjects. One has to study math, to study physics to be a good chemist. One has to study German, or one used to. (Now I understand the industrialists to say that they translate everything for their men so they don't have to bother with language anymore.) I still think it is useful for communication in chemistry to know German. Now, imagine a freshman coming to college unprepared in German and still, having been fascinated by his Gilbert chemistry set, wanting to study chemistry. How can we include all the required courses, culture courses, and chemistry courses needed for the junior year, and feed the natural instinct of most chemists to be very interested in biological systems too? We have an impossible crowding of the curriculum. This crowding has been a feature of chemistry for a long time. I think in a sense we are more conditioned to thinking about our curriculum, thinking more about streamlining our practices so that we can work in needed subjects, than others, and yet I don't think any of us is really satisfied with the kind of job we do in this regard. Now, at the research level, we are not only expanding the amount of material about which we <u>can</u> talk, about which we <u>want</u> to talk to our students, but we are expanding the details about the material already in our repertoire. Just think about where in your chemical training you learned the things you are teaching your freshmen. You will find that a lot of it came after your training was formally finished. And yet a lot happens almost daily in the chemical world that is accessible to you and to the freshmen. There is nothing difficult about discussing xenon tetrafluoride and yet that came into our experience no more than two or three years ago.

The hard fact for us as teachers is that in order to bring students to the frontier and have them prepared to be chemists when we give them up to the world, we are going to have to give up in our teaching much that is very dear to us. That first intellectual excitement of working out a laboratory problem, a research problem, or just a problem (of a particular kind) in a text that really appealed to us--that really hit the spot--that got us into chemistry in the first place--may be something that isn't part of the basic, fundamental material which must always be part of the chemist's repertoire. We have a problem that existed in a mythical stone age university described in a popular magazine a few years ago. Their curriculum contained three courses. They taught Fire-making, of obvious utility for the world into which their students were going. They taught Stone Working, and they taught Saber-tooth Tigers. Saber-tooth tigers were extinct but they thought they should keep it in the curriculum for cultural purposes. Now that's not, per se, a bad thing. We must keep our heritage in the curriculum for cultural purposes to a reasonable extent, but the Saber-tooth Tiger poses a dilemma. How much can we discuss him without delaying unnecessarily a student's professional progress? How much can we ignore him without impairing the student's basic understanding of his subject? We have our own saber-tooth tigers in chemistry. We have them in our college curriculum as a whole. What can we afford to dispense with in order to prepare the student for, not the next world, but the next generation of this world?

I think the dilemma I encounter most, the most hindering at least to changing curricula in chemistry, is the dilemma of what we call descriptive chemistry. I think on the surface at least, and really a great deal below the surface if we examine why we do chemistry--why we study chemical systems--what is the end of our efforts, we find that the end is the descriptive material we want to know. We also want to understand the meaning of our knowledge and that is part of the end. But the knowledge itself put away in books where it is accessible to the next generation, used by them, is certainly an end in the study of chemistry.

It hurts, and is painful to say, that this piece of knowledge which I know and of which perhaps I was a discoverer or co-discoverer, has to be edited out of my course for the next generation. The fact is that this editing has been going on, and it has been going on a long, long time. For example, a few years ago I became interested in the reduction of nitric acid. When I reduced nitric acid with stannous ion in excess, four equivalents of oxidation took place per mole of nitric acid. If you look up your list of nitrogen oxides, you will find that N_2O has the right oxidation number to be the product of this reaction. Our "descriptive chemistry" tells us that nitric acid is reduced to NO in dilute acid and NO_2 in concentrated acid. I thought I had discovered a new reaction of nitric acid, giving N_2O as a product. I checked the literature and found that this reaction had been done before, not by one of my contemporaries, but in 1829 by a man named Gay Lussac, of whom you may have heard. The reaction of aqua regia with stannous chloride was a saber-tooth tiger in a sense. It disappeared from general knowledge, but no one kept it in the curriculum for cultural purposes. There is great detail in Gay Lussac's writing about this reaction. It was a preparation for laughing gas--he gave instructions on how to avoid explosions. It was rather interesting reading, but it has not been deemed so fundamental that it would be pertinent for textbook work, it isn't in any advanced inorganic books, it isn't advanced material. It is a fact probably as important in itself as a lot of facts that we now use in our teaching. Maybe they too will disappear one day.

Other examples of what happens to descriptive chemistry and what is perhaps wrong with descriptive chemistry that should give us some heart about doing the editing job are the number of things in texts like the nitric acid giving NO which are half truths. I think if you took a list of redox equations presented to a freshman student for balancing, you would find very few, if any, on such a list of reactions that would go stoichiometrically in the way presented and yet the impression gained by the freshmen from doing a few exercises like this is that this is the way things are. I think in our own work we tend to forget this. Most of the equations we balance are ideal, just like Boyle's Law is ideal, and we forget the function of ideality when we teach equation balancing. I know that in every one of these lists of redox equations that I have seen there is an equation for oxidizing sulfite ion with dichromate ion and you have all balanced this a hundred times and then corrected 150,000 students who forget that the chromium appears twice in dichromate and can't balance the equation. It is a wonderful exercise because it has a gimmick with which you can fool a student on a quiz and so on. However, sulfate is not the only product of that reaction as the books say. In fact you can adjust the conditions so that half the sulfur ends up as $S_2O_6^=$ --another fact which probably very few students in any of our graduate schools even know about--they probably don't even know of the existence of $S_2O_6^=$ --a very stable, well behaved ion. Again the descriptive chemistry we do is already very selective and often misinformative. It is certainly idealized and I think in our teaching we often miss the boat in not showing how we idealize things to achieve simplicity of thought and explanation.

I have seen at least three texts and problem sets that illustrate chemical nomenclature of the oxy-ions and oxy-acids by not using the chlorine compounds but by using the bromine compounds instead. This is just to be different from other standard texts, to show we don't have to copy the other fellow. In all these books that use bromine, we find perbromate ions (BrO_4^-) which have never been made, never been observed. One might regret that in chemistry, where we have so many real examples to teach with, we select a compound that doesn't exist for a fundamental discussion. I don't think this is bad. Perbromate ion is a concept which we can imagine existing, and none of us would be surprised if someone should do the reactions that are necessary to form it. I don't think it is bad to use it in teaching nomenclature. But I find it paradoxical that we find ourselves selecting for examples things that are nonexistent while the field we teach is so full of existing facts that we can't possibly impart even a small fraction of them to our students. How important then, are the facts of descriptive chemistry to the beginning and terminal student?

We now come to the point: Why do laboratory work? Why are we so unhappy with it? Why are we talking so much about changing our laboratory programs? I have first to explain why this talk will be so uninformative as to what is being done at Illinois. I have been at Illinois only six months and I'm still learning about what is being done in undergraduate teaching. At the end of this report is a brief outline of the experiments that are being used in the freshman course, and a very tentative outline of the core curriculum courses being planned for the second and third year.

I think a very significant point should be made here. That is, that the early discussions of a possible core curriculum laboratory program in which traditional intradepartmental boundaries were removed began well before publicizing of the Hammond curricular reform began. It often happens in science that when a discovery is ready to be made, several scientists are apt to make it virtually simultaneously and independently. I feel that the parallel and independent thinking of our core curriculum committee men and the Hammond curriculum reorganizers at Cal Tech represents just such a common discovery of an educational nature. The quick uptake by so many of us who follow the leaders, (with what I hope is a discriminating eye), is further indication that these ideas constitute an important new track for chemical education.

Our planning for a core laboratory at Illinois is not yet to the point of developing any experiments as elegant as Harry Gray's, but the pattern is the same. Laboratory work is to be divorced from traditional course work. Experiments emphasizing techniques are to be the heart of the core program. Laboratory work as an investigative process is to be emphasized as the reason for doing it. At the end of the core curriculum hopefully, a student will have learned modern laboratory techniques and also learned the raison d' etre of laboratory work. He will then be ready for specialized training in a particular field and introduction to research problems.

Basically it is an attitude that Harry Gray and our core committee are both trying to sell. I hope you won't let the fact that Harry works with two AP-5 students and all the resources of Cal Tech obscure the importance of the attitude. Most of you cannot match the equipment or the supervision Professor Gray describes, but you can match the attitude and develop investigative experiments to fit your situation.

I have found the investigative attitude extremely stimulating to students in any form of work with aqueous solutions. In qualitative analysis labs students are urged to be prepared to discover new facts (or old ones that are extinct). Examples of discoveries my students have made are formation of white $AgNH_3I$ when conc. ammonia is added to yellow AgI (recorded in Mellor's old treatise on Inorganic Chemistry) and a polymeric $[Cr(III)]_m (OH^-)_n$ which precipitates sulfate ion (new).

Many of you are familiar with my evolving experiment on $[Cu^{++}(NH_3)_4H_2O]SO_4^{=}$. Students prepare it, analyze for NH_3 acidimetrically and for Cu iodometrically on the same sample. They heat the material and try to discover formulas of various $Cu(NH_3)_nSO_4$ species. Last fall a whole lab section discovered a new titration which should prove useful for Cu^{++} in the presence of other oxidizing agents. Feeling unsure of the starch - I_3^- endpoint, students added $S_2O_3^{=}$ until CuI dissolved quite sharply. The mole ratio of "excess" $S_2O_3^{=}$ to CuI was 2:1. It is a variation of the old "hypo" reaction for dissolving AgBr in fixing film. The students had discovered a reaction which I've not yet found in the literature.

A word of warning is important here. Using an investigative experiment in a large class where supervision is in the hands of teaching assistants is not so easy as in a small school where the professor runs the lab. Often new teaching assistants have never conducted an investigation themselves and they may be worse about asking what to look for than the students. With 1,200 students investigating $Cu(NH_3)_xSO_4\ (H_2O)_y$ last fall, the Cu/NH_3 mole ratios became remarkably constant for the last 500 reports. The habits of memorizing and regurgitating, of finding predestined answers, drilled in by previously employed educational techniques are very difficult to transform into habits of thinking through a problem, analyzing data, and simply seeking and finding new things for oneself. You must be careful not to penalize the student who really seeks his own information and does not get the pretty idealized answers of the dry labbers. I firmly believe, though, that a good technique of teaching should be used, not avoided, just because many students are passive rather than inquisitive.

Laboratory work can be interesting and well motivated if it is not just a demonstration of principles learned elsewhere. Qual has usually been successful because it offers the student a chance to investigate, to reason from what he sees and draw conclusions on his own. We must have experiments, not exercises, in our labs. Laboratory work is tedious. Information comes slowly from laboratory effort. There must be the possibility of learning something interesting, or of solving an intriguing problem if the student is to be enthusiastic and if we are to be able to justify the imposition of such a slow learning process on his already too busy schedule.

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First Year Majors Laboratory
University of Illinois

<u>First Semester</u>

Weighing and glass working
Syntheses
  $K_3Fe(C_2O_4)_3$
  $NaHCO_3$

$Sn \rightarrow SnO_2$ for combining weight

  Filtering
  Gravimetric analysis

$NaHCO_3 \rightarrow CO_2$ gasometric analysis

Vapor pressure - Solvent and Solution

Acid-Base Titrations

Freezing Point

Calorimetry

$H_2O_2 + I^-$ kinetics

Include temperature dependence

Distribution equilibrium

Benzoic acid dimer $\rightleftarrows$ 2 COOH (aq)
  in benzene

<u>Second Semester</u>

Preparation and analysis of
  $BaCl_2 \cdot 2H_2O$
  H_2O - Loss of weight
  Cl^- - Fajans
  Ba^{++} - by difference

Spectrophotometric Analysis

  Spectronic 20

K_i for HIO_3

Iodometric analyses. K_{sp} for $Cd(IO_3)_2$

Soda Ash

Qualitative Analysis

  Ionic Equilibria

Magnetic Susceptibilities (1st time this term).

PROPOSED COURSE OUTLINES FOR CORE CURRICULUM LABORATORY

Sophomore and 1/2 Junior Years

I - CHEMICAL SYNTHESIS AND STRUCTURE DETERMINATION - 1 semester, 1 conf., 1 lab.

A - Properties of Matter

isolation, purification, and characterization of compounds; the determination of characteristic physical properties.

~2 expts. one org. and inorg., eg; isolation of natural product: 3-4 weeks.

techniques: simple weighing and volume measurements, determination of mp and bp; recrystallization, distillation, sublimation, column and thin layer chromatography, extraction, drying agents, solubility relationships, heating, identification by comparison.

B - Reactions and Structure

a) simple synthesis; goals of synthesis, control and direction of chemical reactions; prepare, purify and characterize a solid and a liquid.

~2 expts., 2-3 weeks.

b) multistep synthesis; qual. use of spectroscopy and other techniques for following reactions.

2 expts., 4-5 weeks.

C - Qualitative Structure Determination

use of characteristic reactions and spectral properties in identification of 2-3 unknowns from a limited list of possibilities; deductive logic and chemistry.

expts.,4-5 weeks.

II - DYNAMICS, STRUCTURE AND PHYSICAL METHODS - 1 semester, 1 conf., 1 lab.

A - Non Spectroscopic Methods; Quantitative Work; Error Analysis

following the course of a reaction by titration; kinetics and rate measurements; mass action law; electrochemical properties.

2-3 expts., 2-3 weeks.

techniques: quantitative weight and volume work; quantitative transfers; titration technique; measurement of electrochemical properties.

B - An Introduction to Electronic Measurement

use of amplifiers, oscilloscopes, choppers, phase sensitive detectors, optical spectroscopy; optical scanning for kinetics, time dependence of spectra.

1-2 expts., 1-2 weeks.

C - Spectroscopic Methods

general spectroscopic behavior, review quantum states, transitions; Beer's Law.

a) reaction rates and catalysis; electronic spectroscopy; quantitative measurement;

1 expt., eg: catalysis of oxidation of Cr^{+3} by Ag^+ followed by uv-vis; 1 week.

b) rates and equilibria; concept of the energy of activation; temperature effects on rates;

1 expt., NMR measurement; rotation in amides, 2 weeks.

c) kinetic vs thermodynamic control; two diff. products, relation of structure to rates; use of concept of Eact; spectroscopic analysis.

1 expt., 2 weeks.

D - Equilibria

d) relationship of K and temperature; determination of enthalpy and entropy; follow a reaction by IR;

1 expt., 2 weeks.

e) relation of structure to equilibria; approach equilibrium from each side; determination K and k_1, k_{-1}; follow spectrally.

1 expt., 2 weeks.

III - CHEMICAL FUNDAMENTALS

A - Macroscopic Properties, Thermodynamics, 1 semester, 1 conf., 2 labs.

experiments covering: equilibria, calorimetry, enthalpy (one expt. measuring all these would be very neat), E.M.F. measurements, T dependence, free energy, equilibrium and response to changes in T, P, V, and other external stimuli, and diffusion processes or osmotic pressure would be covered, activity coefficients.

B - Molecular Structure and Microscopic Properties, Statistics, Quantum Mechanics, Atomic and Molecular Absorption and Emission, Scattering Processes

Laboratory work using: atomic absorption and emission spectroscopy, vib.-rot. of HCl and CDl, temp-dependence development of the partition function, extension experimentally to polyatomics and concept of functional groups, magnetic resonance, relaxation, spin-spin coupling, and concept of the chemical shift (computer analysis), electronic molecular spectroscopy (Hückel m.o. concept and computer diagonalization), dipole moment, temperature dependence (CH_2Cl-CH_2Cl) and light scattering.

THE GENERAL CHEMISTRY LABORATORY: AN EXPERIMENTAL APPROACH

Jerry A. Bell

University of California
Riverside, California

I'd like to subtitle this talk, "The Opportunity to Make Mistakes." There are too few chances left for college students to experiment and make errors without being penalized, usually by the loss of grade points. For some, the laboratory portion of a general chemistry course can offer this opportunity.

I agree with Professor Sienko who said in his talk to this conference that there was no question that the general chemistry laboratory was a necessary part of the introductory course. The laboratory is, (or should be) one of the first honest looks a student gets at science. (Thus far my remarks have mostly been appropriate to the students that plan a science-based career; for others, lecture experiments, about which a few remarks will be made later, are probably more valuable.)

To indicate how I have tried to put these ideas into practice, I would like to describe in moderate detail the laboratory program I use at UCR for an honors general chemistry course, Chemistry 4. The students are advised to take or not to take this course on the basis of a "chemistry" placement examination that is really a mathematics examination disguised as chemistry. Success in seeing through this cover, as well as in solving the algebraic problems posed, means that the student will have a good chance of success in the mathematically oriented Chemistry 4 course. The course meets in three lecture sessions and two three-hour laboratory sessions a week. The laboratory sections are held to fewer than twenty students, about fifteen if possible. (A number of the ideas introduced in Chemistry 4 have been adapted and adopted for the more conventional Chemistry 1 which meets in only one three-hour laboratory session a week. Thus, these ideas, while not wholly applicable to the more conventional courses, can be usefully adapted.)

The laboratory experience is used both to reinforce lecture material and to present new concepts and information, in particular, descriptive chemistry. In order to see how the laboratory sequence fits into the course, I shall outline the sequence of lecture topics: Stoichiometry, Gases and Temperature, Thermochemistry, Second Law, Equilibria, Electrochemistry, Atoms and Molecules, Chemical Properties, and Kinetics.

The laboratory sequence (with a few comments on the experiments) is as follows: The first experiment is the gravimetric determination of chloride in a chromium chloride hydrate. (Almost all the experiments are quantitative and involve precise weighings so single pan balances are a necessity to make such a program feasible, unless the students are to spend all their time in front of a balance. Each sample a student gets should have some meaning for him, aside from a number in the instructor's gradebook. His object in the first experiment is to get results accurate and precise enough to determine the empirical formula of the salt by analyzing only one of the three components.)

Next the students synthesize and analyze $(\mathrm{Coen_2Cl_2})\,\mathrm{Cl}$. (The analysis is done by ion exchange. A stock solution of $(\mathrm{Coen_2Cl_2})\,\mathrm{Cl}$ is made up for the analysis; the solution is initially a deep green but by the next day has changed to maroon. Later the students get a chance to study the kinetics of the transformation as well as other related analyses that lead to at least a partial answer as to what is going on.)

Thermochemical measurements are carried out ice calorimetrically or by adiabatic calorimetry on the Mg + HCl and MgO + HCl reactions. (The ice calorimeter is made an option since often the pedagogical impact of the thermochemistry is lost in wonder at the principles of the calorimeter.) Indirect calorimetric measurements based on the temperature dependence of equilibria are also carried out for a solubility system, naphthalene in diphenylamine. (A few students take the option of doing an isoteniscopic determination of vapor pressure or a study of the aniline-sulphur dioxide system. The latter study requires a vacuum system.)

Equilibria, especially ionic equilibria, are further studied in the systems propionic acid-water- carbon tetrachloride, Ca $(IO_3)_2$ solubility in acidic solutions, and bromcresol green (Bjerrum method) as a function of ionic strength. With the background now gained, electrochemical experiments are readily carried out and interpreted. After some experience making cell measurements on some conventional cells, a class experiment is done in which the instructors carry out equilibrium constant measurements on the silver ion-hydroquinone reaction both analytically and electrochemically; (the students take down the data and do the data analysis for themselves. This is the first of the lecture experiments in which the students participate intellectually but do not carry out the actual manipulations themselves.)

At this point we are ready to study atoms and molecules but we run into the fundamental difficulty that easy experiments are hard to interpret and easily interpretable experiments are usually very difficult or expensive to carry out. My answer has been to introduce a number of lecture experiments. First we take the temperature of the sun, which is assumed to be a black body. (This dramatizes Planck's contribution and the interpretation gives some experience in calibrating somewhat non-straightforward equipment. It has also afforded a number of interested students the opportunity to learn how and, to use the campus computer facilities for their data reduction.)

Further studies involve model building and discussion in the laboratory of the basis for the models in terms of spectroscopic studies. A very subtle structural effect, optical rotation, is introduced by an experiment in which the students synthesize and resolve $(Coen_3) I_3$ into its optical isomers.

The effect of structural properties on chemical interactions is indicated in a study of the acetone chloroform system by NMR. (Again this is a lecture experiment in which the instrumentation is explained and operated by the instructors and the data are given to the student after the demonstration. The data and the experiment are presented in J. Chem. Ed., 44, 200 (1967). A secondary purpose of this experiment is to introduce NMR to students who will find it used again, almost immediately, if they take UCR's organic chemistry course.)

At this stage, four weeks are allowed to the students to do anything they desire in the laboratory; go further with an experiment, do another experiment from the text, Bell, Chemical Principles in Practice (Addison-Wesley, 1967), examine the difficulties with an experiment, or develop an entirely new experiment. (This part of the program, inaugurated this year, seems to have been a success in allowing each student to work at his own level and pace on something that interests him.)

Penultimately the students do two kinetics experiments: an investigation of the $Coen_2Cl_2^+$ transformation and either the iodination of cyclohexanone or the enzyme catalyzed inversion of sucrose. (The cyclohexanone reaction can be used to introduce kinetic isotope effects, their effect on rates and the mechanistic information derivable therefrom. The enzyme reaction introduces the students to the complexities of biochemical systems and is particularly valuable for those students who will not take any further courses in this area.)

So far, you see, almost everything we have done is quantitative, but qualitative work, especially order-or-magnitude, reasoning, is stressed throughout also. (Many tests of ideas and test-tube experiments are suggested and are carried out by the students or instructors.) To further emphasize the necessity for qualitative tests, chemical observation, and deductive reasoning, we do, at the end of each quarter, a final problem. (Nine numbered test tubes containing nine solutions are given to each student. The problem is to match the numbers with the list of solutions without using any external reagents. This problem is extremely popular and generates a large amount of enthusiasm as well as reinforcing and introducing a great deal of chemistry.)

We hope that the ways of attacking problems and thinking them through that we have tried to develop will enable the students to finish successfully the final problem with a real sense of accomplishment, and will start them with a boost along their path toward an education in all areas, not simply chemistry.

THE "INTEGRATED" LABORATORY

Harry B. Gray

California Institute of Technology
Pasadena, California

We would all agree that some work needs to be done in the laboratory program in chemistry. However, it is not my purpose to criticize the present laboratory at all. Instead, I think that I will devote most of my remarks to the plans some of us have for a new laboratory in chemistry. We haven't used the term "integrated laboratory"; I use it now because it was suggested to me as the title for this opening talk. (I suppose that one could call it integrated laboratory -- we have stayed away from this term because we are not sure what we are integrating.) The problem with the first-year laboratory, I think, is that we are constantly attempting to correlate the experiments in the lab with something that is going on in the lecture, and this correlation, which is forced, has led us into fairly petty experiments and short-range goals. I believe that instead we should try to correlate the laboratory with the laboratory. In the long run, that is, to design a laboratory covering a three-year period which steadily builds up the student's proficiency in laboratory techniques and methods and finally gets him to a point after three years that he is able to design and execute real experiments. And so for the purpose of opening this conference, my collaborators* and I have drafted a resolution which does not have to be adopted by this conference but will certainly be adopted by me as a guiding theme.

The central purpose of the new laboratory in chemistry is to teach students how to design and execute real experiments. The program should encourage the student's curiosity and develop his ability to observe precisely, as well as his power to apply previous experience critically. It must stimulate his imagination with experiments that he can recognize as worthwhile and simultaneously insure a thorough exploration of fundamental techniques used in modern chemical research.

I will have to give you two versions of what's going on. One version is due to George Hammond, Charles Wilcox of Cornell, Michael Smith of Cal Tech, and myself, and the other version is what will probably happen at Cal Tech next year. (Actually, the reason I am grateful to accept all invitations to speak on this subject is that people at Cal Tech regard me as a suspicious character; naturally, I am pushing this program at any place where anyone will listen.) Here is the situation as it stands now. The lecture program has to some extent forced this overall revision of our laboratory program; we are now attempting to put in a three-year new curriculum in chemistry -- the first course being General Chemistry and the second course being Structural Chemistry (a sophomore course), and the third course being Chemical Dynamics. Before you work yourself up to a point of frustration over this term "Chemical Dynamics," we will simply say that it has to do with all matters involving reactions and reactivity. And if you like, then, there is an attempt in this program to realign chemistry along these borders of research today and to fuse together organic, inorganic, physical, and analytical chemistry in this sequence.

Now, so much for the lecture part of it. The laboratory program which is being designed does not necessarily have to go with this sequence. In fact it may very rightfully

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*Charles Wilcox and George S. Hammond

stand on its own. As a matter of fact it may be the only part of the program which has any sort of acceptance at all, and it is not new because too many places around the country have been playing with the idea of a longer range, better correlated laboratory program. We are certainly not the first people to suggest this strategy.

In the new laboratory, as we see it now, the first two years will be rather closely linked and will be devoted to learning techniques and methods of doing experiments. In fact there will be a clear-cut division of the first two years of the experimental work; a large hunk of the laboratory will be devoted just to experimental techniques and methods for doing various types of measurements, and a second, probably larger, hunk will involve application of the techniques and methods to a rather long-range correlated experimental program which I call "experimental sequences." Chemical systems for the experimental sequences are chosen for their richness in reactivity and structural behavior.

The first year of the program has to be suitable for a general chemistry course. Thus, one would do the parts which make up general chemistry -- chemical synthesis, chemical structures and chemical dynamics. These will be looked at in the experimental sequences which will become available for the first year program. This will rid us of that awful formula (one lab day) = (one experiment). We feel that the short-range approach so badly stifles chemistry that students do not have the chance at all to find out what chemists actually do. In the specific program I am going to outline, a third of the course will be devoted to learning techniques and methods and the last two-thirds of the course will be one or two "big experiments." There will be only one experiment in the entire year if you like.

Now, in the second year, essentially the same types of techniques will be involved, or the selection will be from the same group of techniques. Again, there is emphasis not on designing your own experiment, building your own equipment, but on using equipment and techniques that are readily accessible. The experiments are fairly carefully planned out, but the emphasis here will be on physical and chemical methods for the study of structure. These may take the form of classical "proof" of structure of an unknown material, a kind of experiment that most students especially enjoy, or the experiments may be designed to extract special information concerning substances of known gross structure. Measurement of dipole moments would be an example of the latter type of work. In particular, spectroscopy will be brought in heavily during the second year sequence. The sophistication, since all three years are rather closely correlated, builds up in the second year but one is still doing black box experiments. The courses are built more around discussion of the actual experiments that are going on and the results that come out.

The third year parallels the lecture discussion of chemical dynamics. It is in this year that we allow the student to design and execute his own experiment; and the design and execution of an experiment may involve actually building some new apparatus or substantially modifying some available apparatus. We hope to also teach students an appreciation of the chemical aspects of engineering experiments, for example, wise choice of reaction conditions to make a rate measurement convenient and meaningful. Again, the experiments that will be available on this level are ones that have been carried out somewhere before.

I should now like to outline an experimental sequence which we feel integrates a large amount of chemistry. The sequence is designed to increase the student's confidence in the techniques I have mentioned previously: all these techniques are involved in this one experimental sequence. The experimental sequence would be in the first year, but with emphasis on the structural aspects it would be ideal for the second year. We have two students in Chemistry 2 class testing the experimental sequence that I am going to tell you about.

Proposed First Year Program

I will designate a 3-hour lab as one lab unit - thus we have 2 units a week. We start with quantitative analysis; gravimetric analysis first, following Waser's lab at Cal Tech. One gravimetric experiment takes 5 units, introduction to volumetric techniques and a volumetric gas analysis takes 3 units, and the wet analysis takes 6 units. For the wet volumetric analysis the student can do a redox titration, or an acid-base titration, or any one of a number of quantitative volumetric experiments. Later the student will return to all of these techniques in the course of an experimental sequence. Thus he does nothing in the first part of the lab that he does not need later; there is a definite attempt to correlate the entire program. The first part of the program requires 14 units and so the first quarter is spent developing the very basic techniques of quantitative analysis.

This will not be a research project *per se*, yet it is a research type operation because the experiments will offer possibilities of great rewards. There will be some modifications involving experimental design so that the student can actually do a good experiment himself during the course of the year. At the end of the three-year program, the student should be able to move smoothly into a true research program.

The techniques that we feel should be mastered in the first two years of the program integrate the large amount of traditional chemistry as it now stands. In approximate order, these are as follows:

1. Quantitative analytical methods, including gravimetric analysis, volumetric analysis, both liquid and gas.
2. Separation of mixtures which will include development of techniques of distillation, sublimation, recrystallization, chromatography, and so on.
3. Development of methods to determine molecular weights; freezing point depression, boiling point elevation, osmotic pressure, etc.
4. Electrochemical methods.
5. Spectroscopy, including visible, ultraviolet, and infrared.
6. Magnetic susceptibility and magnetic resonance methods.

There are others, but these are the six areas that we hope will be covered in the first two years of the program. In the third year, the student would be exposed to glass blowing, machine shop work, electronics, and so on. He will be expected to put together his own experiment. An experiment in the third year might be to study reactions in a student-built shock tube.

Now, how much time each year for this program? For the first year, three hours per week in the lab, one lecture (or recitation if you like) a week for the laboratory. For the second year, six hours per week in the lab, one recitation; third year, six hours per week in the lab and one recitation.

This summarizes the program that Hammond, Wilcox, and I are proposing. I must say that I personally prefer six hours per week, and I think that if we design a laboratory which is sufficiently exciting and sound, the students are going to respond and say, "We want this laboratory and you can't limit us to only three hours a week!". This is certainly the initial reaction we are getting from some students in our new course, Chemistry 2. Student apathy over the country is simply because the labs, they feel, have not reached out enough and have not stimulated them. I think the reaction will be very favorable to a lab which is really a teaching lab and puts chemistry in a very exciting framework for students. Unfortunately, I can't tell you very much about the second year of the new program, and I certainly can't tell you anything about the third year at this early date. I am personally involved at Cal Tech in the first year lab. In Chemistry 2, we are testing experiments and next year we plan a larger scale operation.

Second Two Quarters

The experiment is called the synthesis, characterization, structure, and reactions of metal acetylacetonates. You might expect me to come in with some coordination chemistry experiments, and I am living up to this expectation. I offer no apologies for it, because I hope to show that this type of experiment does integrate ideas from structure and reactions in both organic and inorganic chemistry, in a way that we feel is really successful.

The first step is the synthesis of trisacetylacetonatochromium(III). We start with an aqueous solution of chromic chloride and add acetylacetone. The reaction involves substitution in an octahedral complex and so you start teaching ideas of reactivity in such systems.

This synthesis is carried out by hydrolyzing urea in the solution. It is a fairly interesting synthesis. It shows students how you trick things into going properly. The urea hydrolyzes to give ammonia and CO_2 comes off. As the ammonia is liberated, the solution becomes a little basic and the chromium system becomes more versatile in substitution, opening magnificent possibilities for talking about this in some detail. The protons come off the acetylacetone and are captured by the ammonia to give ammoium ions. A gas analysis of the liberated CO_2 can be done at this point if you like. Recrystallization of the trisacetylacetonatochromium(III) product is carried out until pure, red-violet crystals are obtained.

The second step is the characterization of chromium$(acac)_3$. The compound can be sublimed at 100^o so sublimation techniques are brought in at this point. It boils at 340^o. It is a monomer in all solvents and molecular weight determination by some method is done at this point.

The compound is paramagnetic to the extent of three unpaired electrons and magnetic susceptibility measurements can be carried out. If the necessary equipment is available, the paramagnetic properties may also be detected by observation of the effect that the species has on N.M.R. relaxation times in solutions. It also has a very rich visible spectrum. The idea of paramagnetism and energy levels in these types of molecules is brought into the discussion of this experiment. This experiment was designed so we could talk about spectroscopy and electronic energy levels, and here is a very rich spectrum with which to do this. At this point the students testing this said, "Well, we really want to examine the spectrum of acetylacetone by itself," and eventually they did look at it and it made a lot of sense to correlate the acetylacetone spectrum with the complex spectrum.

Chromium(acac)$_3$ has a very easily interpretable infrared spectrum which allows introduction to molecular vibrations. You see two types of CH frequencies in a not very complex infrared spectrum. Many people would want to do this in the second year of the lab.

You can brominate Cr(acac)$_3$, for example, and nitrate it, reactions which are worthwhile discussing; so one thing that is done in this sequence is halogen substitution. Halogen substitution in this six-member hetero ring goes very readily at room temperature. The bromine substitution product, Cr(acac-Br)$_3$, is a dark, red-brown crystalline material. One does crystallizations and separations, etc., again. We emphasize the techniques involved in chemical synthesis at this point. You can see that the magnetic moment does not change with substitution out on the edge of the complex -- the environment around chromium(III) has not been grossly affected. However, some fairly interesting changes take place in the electronic spectrum and the infrared spectrum drops out of one of the CH bands, leaving only one CH band. Cr(acac)$_3$ has bands at 1560 and 1520 cm^{-1}, and Cr(acac-Br)$_3$ has a single band at 1540 cm^{-1}. You can go back then and think about this problem, and think about the detailed assignments of this spectrum, but here it's again open for the students. The halogen substitution is the thing that is done and there is a choice of determination of molecular weight, or analysis for bromine or chromium. What you want to do here is optional in this sequence, but all of the possibilities are presented to the student. He develops his own pattern of working through. The only thing that he has to present is evidence at the end of the year that he has covered the techniques that we have outlined to be covered; at the end of the year he writes up the entire experiment, what he has learned, and so on.

The choice of nitro substitution is presented to him, continuing with the organic type reactions in this sequence. Nitro substitution can be done fairly readily with acetic anhydride and copper nitrate. It does not go in the absence of cupric ion very readily at all and so one can talk about reaction mechanisms and homogeneous catalysis.

The complex which is the final product is the nitrated pseudo-aromatic ring system -- you see now we are building up larger and larger molecules, and a student has the feeling that at this point he is really doing chemical synthesis. He doesn't dread doing the analysis at this point -- he really wants to do it, we found out -- but one thing we did do, I found out, is slightly underestimate the time required for each step for just making the stuff. I had down two periods -- it took about seven!

There is a presence factor in the lab and that, I think, is what we are trying to teach. Students have to fool around with recrystallizing, learning to work with things, and working with their hands. It takes some time to get going! The infrared of Cr(acac-NO_2)$_3$ can be looked at with some profit. There is an enormous shift in the visible-ultraviolet spectrum due to the nitro substituent and that can be discussed, particularly in a structurally oriented course.

Correlated Studies

For one thing you can make and measure properties of other acetylacetone complexes. The cobalt(III) complex is not made in the same type of synthesis because of some differences in substitutions at Co(III). One reason the cobalt complex is of interest specifically is that it allows introduction to the nuclear magnetic resonance technique. The Co(acac)$_3$ complex is diamagnetic, as measured by the student, and we may conclude that the three extra electrons (over Cr(III)) have paired; thus the energy level being filled in octahedral complexes in going from Cr (III) to Co (III) must have an orbital degeneracy of three. Co $(acac)_3$ can also be brominated and nitrated in exactly the same way as Cr $(acac)_3$. So the "aromatic substitution" part of the experiment could be done here instead of earlier.

The final point is the synthesis of copper acac. This compound is made to emphasize differences in structure and to bring in one final technique in this program, i.e., the technique of electron spin resonance. Because the copper compound has one unpaired electron, it shows the nuclear spin of Cu nicely. Furthermore, this is a square planar nuclear compound. The substitution reactions of this compound are vastly different from the six-coordinate ones. You can make the bromine derivative of Cu $(acac)_2$ and compare its reaction with acac with either the chromium or cobalt complex. This copper complex is much more reactive for exchange of ligands and you can talk about ideas of structure and reactivity.

What I have described is perhaps a coordination chemistry experiment, but I think you can see that this is a type of experiment which truly integrates ideas of inorganic structure and reactivity and organic structure and reactivity. We have others which are pretty much organic in a sequence all the way through. Two types of manuals are being developed from our program -- one will teach basic techniques and basic operations, whereas the other will be devoted to these master sequences, with one manual for each sequence.

I hope that in this short time I have been able to communicate some of the things we are doing. It is in a very early state and to some extent I am singularly poorly qualified to discuss this program, but I thank you very much for inviting me.

STRUCTURED CHEMICAL EXPERIENCE IN UNDERGRADUATE LABORATORIES

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One hardly knows where to start when considering undergraduate laboratories or new approaches to the teaching of undergraduate labs. A great range of possible approaches is available. On one hand you may look at the basic underlying philosophy behind the laboratory operation, and this very easily leads to Olympian considerations; on the other hand you may talk about the nitty-gritty of particular experiments, what you should do first, next, and so on. Let me attempt to make clear this Olympian view through a specific example. A few weeks ago the newspapers carried reports on a five-year international study of education and performance in mathematics. The United States came out eighth among the countries tested, behind Japan, Belgium, The Netherlands, England, Scotland, Australia, and France; Russia did not participate in the experiment. The conclusions as to why the U.S. ranked so far behind the leaders were phrased in this Olympian vein: "There is little doubt that in Japan where youth is under very real pressure to succeed in school or fail miserably in the highly competitive economy, mathematics assumes great importance. In the U.S. and Sweden, perfect examples of the affluent society, there is little pressure to take the tough and demanding courses." And again, "It has also been suggested that the Japanese devotion to order, characteristic of the entire social complex embedded in Confucianism, is akin to mathematics. Perhaps most important, mathematics plays a significant part in the total culture; the children are introduced to numbers at an early age at home." These things may be true but may not be of much help when one attempts to devise better ways of teaching mathematics. Similar approaches will not be of much immediate help in deciding how we can change and perhaps improve organic laboratories. It may be that the basic difficulty holding us back in organic laboratories has to do with some cultural flaw in the American character, or our governmental policies in some area of the globe, or the fact that graduate students are being paid too much and aren't working as hard as graduate students did when we were in graduate school. We might discuss these things, but that is not the approach I intend to take. Another extreme is based at the single experiment level. A good example of this is the question: "Why doesn't this experiment in 'Experimental Organic Chemistry' work?" You can raise such questions at a later time and I will be glad to try to answer them. But I prefer now to spend the available time discussing how one should go about planning for an organic laboratory experience, how one should go about structuring organic laboratories so that they will provide a meaningful learning experience for the people taking the course. As I go I'll state pretty bluntly my own prejudices, not that I think this may convince you or that you'll be won over, but so that you may have something quite concrete to attack in the discussion period.

John Holt has said the only answer that really sticks in a student's mind is the answer to a question that he asks or might ask of himself. If this is so, then one has to go about structuring the organic laboratory or any laboratory so that the students are led to ask questions which become important to them. They are their questions, and they'll be solved.

What sort of experiments can be done that will lead to the greatest pleasure for the students and will involve the least possible instruction, interference, and correction by the teacher? Perhaps another question we should raise is, "Do we really believe in the importance of experiments over theory in chemistry, or are we going to make our labs nothing more than devices for packing in the recipes faster?" I think that chemistry really is fundamentally experimental in nature; I think you can teach chemistry through experimentation. To do this the experiments have to be efficient, up-to-date, and attractive; through the experiments the students are going to learn chemistry. They're also going to experience a certain excitement and involvement; they'll develop the mental and manual skills needed for further work, if the structure is properly prepared.

The first specific question that comes along when you come to structuring an organic course is, "For whom will the course be taught?" How you answer this question will greatly influence what you put in the course. Let me give some statistics on undergraduate enrollment at Illinois last fall to emphasize this point. In the freshman courses we had some 2000 students. In the first semester organic courses last fall we had 550. In the second semester organic laboratory course, the enrollment was down to 70, and in the last semester of organic laboratory given, the enrollment was 7. It is clear that if we are teaching our courses only for the chemistry majors who are going on to become professional organic chemists, we're teaching the first semester of organic laboratory for something on the order of one percent of the students. And if we structure the course with only these students in mind, we may seriously short-change some ninety-nine percent of the students, even if the course in the catalog is designated "for non-majors."

Let me give some quotes to bring out the seriousness of this problem. This is something often really neglected when we actually get down to the business of planning the courses. The first quote is taken from a report of a major university in this country concerning their plans for new laboratories. "Our second year course would have non-majors enrolled. It would be better to adapt the sophomore courses to handle this service load... rather than to teach non-chemists. This service load will place limitations on optional experiments." This comes from a noted educator: "The work that the schoolmaster is doing is inestimable in its consequences. He is laying the foundation of the careers of men who are to lead the next generation. He is also knocking all the best stuff out of a great number of them." This is not an exaggeration. We tend all too often, I feel, to teach the courses concentrating only on the successful one percent of the students and being fairly hard-boiled about the failures. I think we need to really consider this very carefully when we're deciding for whom courses will be taught.

The next question is, "What is the course going to be about; what will we attempt to achieve in the course?" Here there are really two highly polarized views; they may be expressed with the following two quotes from curriculum reports of major universities. "The central purpose of laboratory instruction is to teach students how to design and execute experiments. The experiments should increase his power to apply previous experience critically." Contrast this view with the following alternative position. "The main emphasis is to be on practical lab operations and not illustrations of chemical principles: i.e., to train students to work with their hands and to work with simple lab apparatus. The fare should be based on thoroughly tested recipes."

What about content? What sort of experiments should be put into a course? One can generate the content initially by making a list of the various techniques that should be covered; in organic this would include recrystallization, distillation, chromatography of various sorts, perhaps a sealed tube reaction, etc. Next, one would need a list of the chemistry to be taught or illustrated, such as the difference between kinetic and thermodynamic control, determining the order of a reaction in a kinetic experiment, structural elucidations, multi-step syntheses, etc. Then one would have to list the limitations dictated by experience and the currently available institutional facilities. And these limitations are very real matters of time, equipment, money, space, student attitude, and staff attitude. By combining these three elements--techniques, chemical principles, and limitations--one can make the necessary combinations and accommodations and come up with a list of experiments. Now, in working out this compromise one may need some guide lines going beyond the limitations of time, equipment, and so forth. I would suggest a number of criteria for matching techniques with principles and limitations.

The first and really most important is to do what experiments you do well, as well as they can be done. This means operating without "jerry-rigged" equipment and foregoing 15-minute distillations through columns having 1.1 theoretical plates and calling the exercise fractional distillation. If there are no funds to acquire what would be regarded in a good academic or industrial lab as adequate instrumentation or equipment, don't do experiments which require them. It's better to do other experiments with simpler and cheaper apparatus, and to do them well.

Another criterion suggested has to do with choosing the examples: I don't think it is wise or possible to try to choose examples that will cover the gamut of synthetic reactions in organic chemistry. Experience in learning is not at all a linear thing. Students have their point of real take-off at different times; shortening this time or this induction period should be what we are aiming for. One must try in the initial experiments to help the students develop up to their take-off point, where they are ready to work quite independently, to do for instance a type of reaction they have never carried out before because their experiments earlier have accustomed them to think for themselves and given them the freedom to think for themselves. Experience isn't linear, so don't select experiments as though it were. Choose experiments that you think will contribute most to helping the students achieve this self-sufficiency and confidence in brand-new situations.

I think it's important to select experiments having a wide range of difficulty and of possible outcomes. If all the experiments result in either success or failure, the outcome will be many dissatisfied, discouraged students going through the course having an unsatisfactory, negative experience. If experiments can result in a variety of outcomes ranging from perfect success through many intermediate levels down to complete failure, students will have much more freedom for learning and improving their performances.

The laboratory should tie in with the lecture material closely. If they do,they can reinforce one another. If they are taught as separate entities,quite often the overlap will be so small that it will simply serve to confuse the students. In a number of schools the practice is now developing of delaying starting the organic laboratory until the second semester or quarter. I know of no justification for this other than justifications based on expediency. After the first term about two-thirds of the people drop out, and then the survivors can be given a laboratory experience. It may be that the two-thirds of the people lost in the first term would have gotten into the subject matter much more directly through laboratory experience that would make the lecture material comprehensible or provide some stimulation for learning the theoretical background. It may be that their whole attitude toward chemistry and science may be warped by a bad experience based on a diffuse theoretical contact with chemistry rather than a concrete, enjoyable laboratory experience.

Another big factor in designing the experiments for a laboratory course hinges on whether the course is to be answer-oriented or problem-oriented. Much of the push for more rigorous educational standards in this country in the last ten years (since Sputnik) has been entirely answer-oriented. The drive for higher standards has always been in terms of more right answers per unit time. Students can be kept so busy getting right answers that they have no time to think. One of the young staff members in physics in Urbana maintains that the students are much too busy; they are in laboratories or lecture halls such a large fraction of the time that they don't have any time for study. If a student is in laboratories or lecture halls forty hours a week, when is he going to really learn something, really study through material for himself? Even a problem-structured laboratory must provide students with the freedom and time as well as the equipment necessary for seeing a problem and then going ahead toward a solution. One can't be too preoccupied with laboratory scheduling and meeting firm deadlines, or the problem-oriented lab quickly reverts to an answer-centered routine.

Another difficulty in planning an organic laboratory is that it always has to be revised, and revision is work. Let me make this point explicit by commenting on a lab text I wrote a few years ago. At the time I tried to make the text as up-to-date as possible, but in going through the book now there is hardly an experiment which doesn't need revision. We now use electrically heated, air-cooled melting point baths in place of the old Thiele tubes. Mettler and Sartorius top-loading balances have replaced the slower and less accurate instruments. In our thin-layer chromatography experiments, we used microscope slides dipped in the absorbant suspended in a volatile solvent. This is still done in some research laboratories but most analytical thin-layer work is now done on precoated plates sold by Eastman and other companies. The importance of preparative thin-layer chromatography has grown to such an extent that this would have to be included in any revision. The temperature controller we described in the text for the kinetic bath is now completely obsolete. A mercury controller and relay of the sort you're all familiar with has certain disadvantages: the mercury may be spilled, the glass housing may be broken, etc. We now use a fully proportional temperature controller based on a thermister sensing element.*

The VPC instrumentation picture has changed radically in the last two years. Carle now has good instruments selling for around $300, and it is possible to build a very good recorder for VPC work for around $100.

I've said nothing about basic changes in experiments. Let me now mention just one example of the need for doing this. We have in our lab text a qualitative organic scheme based on sodium fusion for elemental analyses. Just a few weeks ago while correcting unknown reports in our advanced qualitative organic analysis course, I noted that the students did very well on their general unknowns but poorly on elemental analyses. They had trouble recognizing Prussian Blue and with the fluoride test. In class I attempted to place these results in some perspective by emphasizing that sodium fusions are now used only rarely in research applications. Other methods, such as mass spectrometry, are available. After class I tried to remember the last time I had run a sodium fusion in my research work, or how long it has been since any student in my research group had run a sodium fusion, or the time since I had seen a sodium fusion reported in a research paper.

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*R. Anderson, J. Chem. Ed.., in press.

It's been a long time. Why are we teaching students to run sodium fusions? It's traditional. Might there not be better uses for the time now spent on these fusions ?

What about incentives? Why should a student walk into the organic laboratory and work hard, with great curiosity and drive? The same problem concerning incentives comes up in any educational setting. On the University of Illinois campus there has been, over the last two or three years, an experimental pre-school program. Some of you may have read about this Bereiter-Englemann project in a recent issue of Harper's.* These men have developed an intensive academically oriented educational program for three and four year old kids from culturally disadvantaged backgrounds. The children in the course of the two-and-a-quarter hour session each day have three twenty-minute periods of work. One staff member and six children exchange questions and answers in a very intense atmosphere. It is not unusual for the teacher to get off over 200 questions in the course of this twenty-minute period and for the children to answer these questions in full sentences. When the experiment first started they had some trouble: the children weren't terribly anxious to participate. The teacher would ask a question and the children wouldn't respond. After some trial and error the staff evolved the effective technique of distributing raisins for right answers. Some of the children had iron deficiencies and so the practice could be justified. For the first six weeks of the course they used these raisins for rewarding the children and were pretty tough about it. If a child didn't respond or gave a wrong answer he was told, "Too bad, Johnny, you can't have a raisin, that's the wrong answer." After about six weeks the children were really good at getting raisins, and at that point they were cut off. "You're big kids now, it's still important to answer the questions and learn, but no more raisins." And the performance of the children kept up at a very high level. They didn't need the raisins any more, they operated under their own steam.

One of the teachers in the project had an uncertain moment in a local grocery store: she bumped into her daughter's second grade teacher and was asked, rather critically, "Is it true that you're now bribing the children with raisins?" Her embarrassed admission, "Yes, we are using raisins," was rejoined with a quick smile and the admission, "I use cookies!"

Well, we can't use raisins or cookies on college sophomores. What are we going to use? Certainly the thing we've used most in the past has been fear, or a grading system which meant fear. This doesn't work. It works only in making the students docile and unhappy and it's not going to contribute to any worthwhile, meaningful learning experience. A few years ago a student in our beginning organic lab course was supposed to make an acetate derivative of glucose and he turned in as his product sodium chloride. The identity of the white crystalline material was soon determined by the graders and appropriate steps were taken. When the student appeared before the special committee on academic discipline of the Liberal Arts College, he argued that he shouldn't be thrown out of the course or out of school; rather he should get half-credit for the experiment because, although the purity of his preparation was poor, the yield was excellent. This is the sort of myopia we inculcate in students when we attempt to push them around constantly with grading systems. The students are under terrific pressure as it is. They don't need the extra pressure that comes with a rigid grading system.

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*Harper's Magazine, January 1967, p.55.

During my first semester teaching organic laboratories at Illinois I observed a student trying to recrystallize something from a mixed solvent system; he had selected ethanol-hexane and it wasn't working very well. He showed this discovery to his neighbor and broke out into wild laughter. He was under terrific pressure and the laughter was his way of releasing it. He realized that he had goofed badly; all his life in school he'd been operating under a system asserting that if you goof, you're stupid, and the grading system will get you.

What can one do for incentives if you discount the suitability of a harsh grading system? I think you're forced to design experiments that are interesting and give a student something to show for his work. If at the end of a preparation the student can cap it off by running an interesting thin-layer chromatography comparison with authentic materials, or if after a distillation he can put samples of his fractions into a VPC instrument, or identify a product spectroscopically, the experiment will provide, at least to some degree, a motivation that is a function of the problem he is working on. The approval or disapproval of the instructor will become comparatively unimportant in stimulating incentive. Designing such experiments is difficult, but not impossible. Students usually enjoy unknowns. I encourage the use of unknowns and laboratory examinations at frequent intervals and with the emphasis on recognizing and solving a problem, rather than on the grade the student may secure.

What about staff incentive? Especially in the large universities, knocking oneself out for an undergraduate laboratory is, well, it's not very smart, it's not an activity that is particularly rewarded. One of these curricular statements I mentioned earlier commented on the fact that it had become common practice for junior staff members to teach the laboratory and for more senior people to teach the lecture sections, and that this had led to a lamentable lack of correspondence between the two. The implication is quite clear: the lecture is important and the laboratory isn't; it can be entrusted to the younger staff. It is more distasteful, time consuming, and problematic. If you muff a lecture, so what? If you really fail in the lab, students can be hurt. There are other ways in which this prejudice against teaching labs comes up. One instance concerned a young staff member who was burdened with a gigantically heavy teaching load one semester. When he talked with the appropriate more senior colleague about the situation, he received the assurance that his very heavy teaching load would be balanced by having only the beginning organic laboratory course to teach the following term. The lab course was used as a sop. The implication was the laboratory course wasn't important, and could be taught so that it would be a very light load. Obviously there will not be good undergraduate laboratories unless the staff members involved and their colleagues really think good lab courses are important.

How difficult is it to change and develop a new course? It's very hard, for there is so much inertia to be overcome. You're all familiar with George Hammond's quote about our conservatism: "Chemists as a group have become highly conservative, an attitude that is inappropriate in any activity designed to pursue new knowledge." It is especially true, I think, for innovations in the laboratory that require money for new equipment and a change for the storeroom man who has been doing things one way for twenty years. And a change in the content of laboratory courses, or a change in which courses are to be required of chemistry majors, may upset the status quo in a department. These are very real arguments for doing nothing, for doing things the way they've always been done.

Hammond has said that deletion of outdated material would be made easier if all existing elementary courses were erased as a starter. The opposite position, defending the current practices and course contents, stresses the potential hazards of change: "One does not burn down one's house in anticipation of a better one."

Whenever we talk about course revision, course innovation, etc., a number of people talk about ideas. What should be done with content, structure, timing? And we have a number of people talking about developments that would require ten faculty-man years, major problems of resources, transitional development through pilot projects, possible funding from outside sources, visiting staff and graduate assistants to work out the new experiments, and establishing workable "operating mechanisms." "Operating mechanisms" is often a euphemism for getting all the people who should be teaching to teach the undergraduate laboratory courses. Course revision is too often looked on as an enterprise or some sort of boondoggle to be done by outside experts or inside operators, an enterprise that shouldn't interfere with the really important things chemistry professors may do with their time and energies.

Why is there so much inertia? People feel very strongly about the way they teach their courses and their own visions of what constitutes basic material. One suggested explanation for this has been offered: "Basic concepts are a very highly personalized matter, usually closely related to the first things that gave a man intellectual satisfaction in his own educational experience. Teachers hate to trim their courses, not because they are building monuments to themselves but because they have packed the courses with ideas which are truly indispensable to themselves." If you're going to revise your course you may have to give up something truly indispensable to you.

An architect specializing in church architecture, while lamenting on the difficulties of dealing with church boards observed, "It's funny, but every member of a church board has strong opinions about how a new church structure should look. When you pursue these opinions it turns out that the new building must be just like the church he went to as a boy." I think similar problems are real barriers to any innovations in our own courses. If you are using the text which you used when you were taking organic chemistry in college, or if you're using experiments that were really exciting to you when you were taking organic lab five or ten or more years ago, maybe this point should be very seriously and honestly considered. Is your favorite experiment, the one that survives term after term, the best possible experiment, or is it one that has a very special meaning for you?

I would like to inject here parenthetically a comment on some of the new trends and curricular changes that are being evolved. You know that several universities, including Illinois, UCLA, MIT, and Cal Tech, are considering or experimenting with non-divisionalized core laboratory curriculums. Let me give you a short sketch of what will evolve, or what I think will evolve, at Illinois. Following freshman chemistry there will be a three-semester core curriculum in laboratory practice required of all chemistry majors. The first semester will be devoted to structure and synthesis. It will involve synthetic manipulations, characterization of products using spectroscopic and chemical means, and some quantitative analysis. The second semester will be concerned with dynamics, structure, and physical methods. Here both classical wet methods and more modern instrumental methods will be employed to measure kinetics of reaction, equilibrium constants, etc. Finally, the third semester will be on chemical fundamentals. It will be a fairly sophisticated physical and instrumental chemical laboratory.

In closing, let me come back to my emphasis on the importance of the staff as opposed to the set of experiments being used through a quote from Fromm. "There is as much intellectual intimacy in our teaching-learning relationships as there is emotional intimacy in a husband-wife relationship." Teaching is a very serious business. Learning is a serious business from the student's point of view. If we treat it as static, in a matter-of-fact way, we can't expect much in terms of fruitful results. We need to generate quite a new level of commitment on the part of staff, a commitment to make our undergraduate laboratory courses what we know they should be.

As I walked past the YMCA on campus this week, I noticed on their outside bulletin board a quote from Dietrich Bonhoeffer to the effect that a man's life is an extension of what he truly believes. I think that can be applied here. The courses we teach are an extension of what we truly believe. If we really believe that the experimental approach is fundamental in chemical education and chemistry; if we believe that the dynamic evolution through constant revision of laboratory materials is worth the price that has to be paid; if we're willing to teach hard; if we're willing to make it possible for the students to have the time and the freedom and the materials they need in the laboratory to teach themselves something, without forever butting into their learning experience; if we are truly convinced that we should aim for quality in the undergraduate laboratories, rather than toward completion of some orthodox set of experiments sanctioned by long usage and perhaps by the American Chemical Society requirements for accrediting undergraduate programs; if we really believe these things, I think we can have remarkably better laboratories, better laboratory experience for our students, and better chemists in the immediate future.

DEMONSTRATION EXPERIMENTS FOR THE MODERN GENERAL CHEMISTRY COURSE

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Although I didn't teach chemistry thirty years ago, I am forced by logic to the conclusion that the General Chemistry Laboratory was a more meaningful experience to the student then than it is now. When I am looking for ideas I pick up a laboratory manual, or a book of lecture demonstrations, or talk with our elderly lecture demonstration assistant, and find that the suggestions are definitely not related to the course I am teaching in 1967; they must be related to the course of some previous period. The laboratories must have reinforced and illustrated the concepts of the course for which they were designed; otherwise why go to the trouble? It is very difficult to design a laboratory to provide the same quality of reinforcement for the lecture material today.

In the freshman course we are now teaching kinetics, thermodynamics, solid state structural chemistry of crystals, kinetic theory of gases--all very advanced concepts which are difficult to illustrate in the laboratory. In my opinion some of us are now in the period or approaching the period where traditional individual student type of experimentation in the General Chemistry Laboratory is obsolete. The high schools are already teaching all of the fundamental laboratory skills and techniques which used to be an important part of the General Chemistry Laboratory. To go beyond the technique-oriented experiments, we need more complicated experimental setups, too advanced in cost to warrant involving a large number of students in them.

I feel that there are three important facets of General Chemistry Laboratory work, reflecting different purposes of the laboratory experience. These are: reinforcement of lecture material, teaching experimental technique, and involving the student in the really exciting part of science--discovery. The boundary condition which I will adopt in my discussion to follow is that the important purpose of our laboratory is to reinforce lecture material. I feel that except for the serious chemistry student, the high schools are already doing an adequate job of teaching chemical technique. Discovery, involving students in research and project work, is another story which I will try not to consider today.

One answer to the problem of our need for elaborate experimental equipment to reinforce complicated concepts is the ersatz experiment. Let a computer simulate an experiment and have the student, at a console, control the experiment. The Commission on College Physics (CCP) has done a good deal of work along these lines ("The Computer in Physics Instruction," published by the Commission on College Physics). With this concept in instruction, the student could do complicated experiments to illustrate complicated ideas--and no chance of breaking glassware. Perhaps the day of the ersatz experiment is coming and we will be able to argue its merit then.

For now we need experiments that we can do to reinforce the material being taught in today's lectures; we need to make the elaborate concepts come alive for our students. It isn't enough to say that the correlation of lecture and laboratory material is difficult, so we won't worry whether or not they are correlated. We must make new efforts in designing more appropriate experimental work; if we don't the students will not appreciate the subject matter being taught.

Consider, for example, teaching of solid state structural chemistry. Is it sufficient for the student to read about X-ray diffraction and crystal structures without becoming involved in experimental work with them? Obviously we can't put X-ray diffraction apparatus into every freshman chemistry laboratory, but Meiners of Rensselaer Polytechnic Institute has invented a Bragg diffraction apparatus, using 3 cm wavelength microwaves instead of 10^{-8} cm wavelength X-rays, and a crystal lattice of steel ballbearings, which a student can take apart and examine, instead of a real crystal. A freshman can do a crystal structure analysis in the laboratory, using this device and the subject of determining crystal structure by diffraction experiments comes alive for him in the process. This type of experiment, coupled with building crystal structure from styrofoam balls, such as we are doing in the laboratories at WPI, can be a real help in reinforcing the matter of the lectures.

Consider thermodynamics with all of its complicated concepts: there are certainly many experiments being done by students in today's laboratories on measurement of thermodynamic quantities; but what about illustrating the basic thermodynamic concepts? -- for example, reversible and irreversible work? Here is a handout which we give our students for a demonstration experiment which we have adapted from Eberhardt's work designed to show the irreversible, reversible work concept. By raising weights in the earth's gravitational field, the system does work on these surroundings (weights), and the amount of work that is done depends on the irreversibility of the manner in which the weights are removed from the elevator. We have added a device to measure the heat produced by nonuseful work being done on the surroundings. With this modification one can obtain an energy balance in accordance with the First Law of thermodynamics.

The subject of statistical mechanics is certainly not an easy one for the students to grasp; after all, a few years ago statistical mechanics was graduate-level course material. Now students, through CBA and Chem Study, are being introduced to statistical thermodynamics in the high school chemistry courses! Sussman of Tufts University has been interested in the problem of making statistical thermodynamics come alive for the student (M. V. Sussman, American Journal of Physics, 1143-46 (1966).) He states in one of his recent papers, "Demonstration devices for statistical thermodynamics are rare." They aren't really as rare as he implies because there have been several described in the Journal of Chemical Education but he has developed a very clever device for showing the Boltzmann distribution.

Another device illustrating statistical thermodynamics concepts (R.C. Plumb, J. Chem. Ed., 41, 254-6 (1964))uses a single plastic sphere, an air jet to provide variable kinetic energy and temperature, a potential energy difference between two states of the system, and a movable barrier to provide variable probability of states or variable entropy per molecule in those states. The student keeps track of the frequency with which the particle lands in either of the two states by dropping a counter into either one of the two beakers. A student playing with this device can soon discover that the effectiveness of entropy as a driving force increases with increasing temperature, that the systems seek a state of maximum entropy, and that at a low temperature systems seek a state of minimum potential energy.

One of the most fundamental concepts of general chemistry is phase equilibrium and its interpretation in terms of the statistical mechanical and kinetic behavior of molecules. Here is a device which I have devised to make these concepts come alive for the student. (R.C. Plumb, J. Chem. Ed., 43, 648-51 (1966)). The behavior of molecules is simulated by motion of glass spheres on a horizontal surface containing a depression. The depression simulates the potential energy difference between a liquid and a gas. We can heat up the liquid and occasionally we see a molecule evaporate and condense; as we increase the temperature, the number of molecules in the gas phase increases and the vapor pressure increases. We can see the irreversible approach to equilibrium when we introduce a sudden change in temperature. Actually, the behavior of this system quantitatively simulates a liquid-gas equilibrium. The results follow the Clausius Clapeyron equation.

The device is useful in teaching the kinetic theory of gases. The model simulates the two dimensional Boltzmannequation quite quantitatively. The model has many other uses including illustrating concepts of the solid state; for example, one can see vacancy and vacancy migration, dislocations and dislocation movement, grain boundaries, annealing of solids, and one can simulate the glassy state. With careful observation one can observe the Einstein motion of atoms in solids.

Similarly, the device is useful in discussing the liquid state, where one sees the short-range order of the liquid state, rapid diffusion of the molecules in liquids, and even the motion of clusters in atoms, a concept which is at the frontiers of research in the theory of liquids.

In conclusion I would like to restate my position. I believe that laboratory experimental work should be highly correlated with concepts being discussed in the classroom portion of this course. It is difficult to find experiments which illustrate the basic concepts, experiments which show exactly what the teacher wants to show, but such experiments can be developed and are being developed.

It's great fun for the teacher, a real pleasure to him, to devise something new and radically different which brings a gleam of understanding to the student's eye. Let's have more imaginative innovation and make the general chemistry laboratory experience really meaningful!

COMPUTER SIMULATION OF LABORATORY INSTRUCTION

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The object of formal laboratory instruction on all levels may be conveniently divided into two areas; the student is expected to (a) become familiar with and appreciate certain manipulative skills, and (b) acquire a degree of maturity in the manipulation of experimental results and the strategy of designing experiments. Because of the increased number of students, the rising degree of sophistication of experiments, the lack of suitable equipment, and the lack of sufficient time, it is becoming more difficult to provide adequate instruction using classical methods.

Computer-based techniques can be successfully used to individualize certain aspects of laboratory instruction. Generally, the modern high-speed computer is considered to be a device used primarily in the solution of complex numerical problems or for processing large quantities of data in standard ways. However, it has been possible to take advantage of the rapid retrieval capabilities of a computer and, using special languages, to develop a system that can conduct a Socratic dialogue with a student as well as to permit him to use the computer in a normal way. In essence, the system permits an instructor to place his thoughts on a given subject in the computer's memory and provides a method for the student to explore those ideas at his own pace. Once the ideas are captured, they are available to all students at their own convenience.

Computer-based techniques can be used to simulate laboratory experiments in several ways. Experiments can be simulated that make more efficient use of time. Often, experiments which are basically repetitive with respect to technique are performed to provide the student with individualized results. Common examples of this situation are the classical qualitative analysis and experiments involving titrations. Computer-based methods can provide a student with practice in manipulating experimental results <u>after</u> he has been exposed to the techniques in the laboratory; the student could be driven to make all the decisions he would normally make in conducting the experiment, collect his results, and come to the appropriate conclusions in less time than if he had performed the experiment in the laboratory. The saving of time could be used to either give the student more practice or have him exposed to a greater variety of experiments in the laboratory.

Computer-based techniques can also be used to extend laboratory instruction in certain areas. For example, it is possible to extend the qualitative analysis scheme to include many more chemical substances than appear in the classical scheme or to permit a student to develop his own scheme, if one exists, for a given combination of ions. Thus, students could be exposed to problems that could normally be investigated only in very well equipped laboratories.

It is also possible to extend the student's experience in handling experimental results by simulating experiments that might (i) involve apparatus too complex for beginning students to manipulate (e.g., atomic and X-ray spectroscopy), (ii) consume a disproportionate amount of time if performed properly in their entirety (e.g., a kinetics experiment), or (iii) involve equipment too expensive to supply for a large number of students.

Computer-based techniques, if properly applied, can be used to individualize instruction directly, as described above, as well as indirectly, by providing more time for the instructor who can be freed from record keeping and grading chores.

AN ANALYTICAL INTRODUCTION TO ORGANIC CHEMISTRY

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> "It is a very fine thing for our students to learn to think. It is, perhaps, even more profitable for them to first learn something to think about." - James Cason

Most organic chemists agree that they "learned" more real chemistry in their "organic qual." course than in any other course in their program. The basic knowledge of nomenclature, use of the chemical literature, common reactions of functional groups, and relationship between structure and properties is inherent to the successful completion of such a course and, in modern programs, spectroscopic and other instrumental principles are included. Typical courses do not, in general, depend on a sophisticated background of physical chemistry or even on a detailed knowledge of reaction mechanisms or stereochemistry.

Several years ago, it seemed to me that the content of an analytical organic course could serve as an excellent introduction to modern organic chemistry by providing the factual background and the feeling for the experimental foundation on which discussions of mechanisms, etc. could be built. At the same time, the analytical approach to laboratory could provide a means for heightening student interest in and enjoyment of this introductory material. Consequently, a course in the analysis of monofunctional organic compounds was devised as an experimental program at Montana State University in Bozeman and was offered to students on an optional basis in the spring quarter of their freshman year. The initial enrollment in 1964 was 93 and by spring of 1966 the enrollment had exceeded the capacity of the 360 seat auditorium so that a second section had to be opened. The lecture and laboratory materials for this course have now been used and revised through experience of nearly 2000 students. Of the students proceeding from this course into the regular organic sequence by 1966, more than 60% attained A or B grades, as compared to the normal A, B rate of 30%.

The lecture program consisted of 22 lectures, including the topics:

The Nature of Organic Compounds and Functional Groups
Relation of Structure and Physical Properties
Isomerism
Nomenclature
Use of the Literature
Analytical Reactions of Monofunctional Compounds
Spectroscopic Analysis
Chromatography
Introduction to Stereochemistry

A minimum of formal lecture time was devoted to "traditional" presentation of "memory" material. Instead, programmed instruction was provided for Functional Group Recognition, Nomenclature, and Analytical Reactions.

Comparative exams showed that students achieved a significantly better grasp of these topics than did students in a conventional organic course.

The laboratory was designed for nine 3-hour laboratory periods. Obviously it was necessary to drastically restrict the number and types of unknowns used as compared to a standard analytical organic course. Students were given four unknowns. One of these was inorganic and had to be identified as such and eliminated before work could begin on the other three. The remaining three were pure single compounds selected from a published list of 175 possibilities. With one group of students an attempt was made to use a mixture of two compounds separable by extraction, but inadequate laboratory ventilation and the lack of fume hoods made this impractical. The general laboratory approach included:

- Determination of the Organic Nature of the Unknown
- Determination of the Melting or Boiling Range and (for liquids) the Refractive Index
- Determination of the Solubility and pH of the Unknown Solution
- Tests for Functional Groups
- Preparation of Derivatives
- Literature Search (At least one primary literature reference was required for support of the student's analysis.)
- Interpretation of Spectra (Practice spectra were given and each student could obtain the UV, NMR, and IR Spectra of any one of his unknowns. Since there were far too many students for available instruments, mimeographed spectra were used.)

Special features of the laboratory included:

- Videotaped or filmed directions for such laboratory techniques as melting range determination, etc.
- Videotaped or filmed demonstrations of use of spectroscopic instruments.
- Access to a special undergraduate reading room stocked with numerous reference materials, including films of sample spectra.
- The requirement of student literature searches and maintenance of research-type notebooks.
- The option of an extra unknown not in the published list to be identified by chromatographic techniques in addition to other methods.

Students completing this course were mainly non-science majors so that most either terminated their program at the end of the course or proceeded into a one quarter course in Natural Products (previously described in J. Chem. Ed., 42, 492, Sept. 1965), sometimes followed by short biochemistry and/or quantitative analysis courses. As has been noted, those few students who continued with a conventional organic course did quite well.

It would appear that an analytical introduction to organic chemistry could usefully be incorporated into the early part of a chemistry major program.

SAFETY IN THE LABORATORY

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Moscow, Idaho

To lay the foundation for our discussion of new approaches to laboratory instruction, I'll say a few words about safety in the laboratory, an essential ingredient of any good laboratory program.

Why me? Anyone can tell I'm not a genuine safety expert: I'm not wearing safety glasses, nor safety shoes, nor a hard hat. You may wonder what are my qualifications for speaking on safety in the laboratory. First, I do have a sense of mission which stems from gratefulness that I escaped serious injury from bad practices in my own student days. I'm pleased indeed that I wound up with as many fingers, hands, and eyes as I started with, more as a result of luck than sound practice. Also, I do have a feeling of urgency to encourage an active reduction in laboratory hazards for the current generation of students. This has led to my service on the ACS Safety Committee and committees of the Campus Safety Association.

Also, I have historical appreciation of safety programs, since I have personally witnessed the rise of industrial safety programs and now am watching the growth of safety consciousness in academic institutions.

a) During summer work in a sawmill 40 years ago, I saw, several times each year, men lose fingers and hands; I witnessed a filer lose an eye to a splinter of flying steel; and a friend seriously injured by a practical joker with a high pressure air hose.

b) There have been marked improvements in safety practices in that same sawmill in later years. Guards are now installed on saws and moving machinery; there is eye protection in the shop, enforced rules against horse play, and active safety interest both on the part of management and union.

c) Sharp reductions have been made in all types of industrial accidents over these same years. Accident rates have declined as shown by the following figures for lost-time injuries: in 1926, 32 million man hours; in 1966, 7 million man hours; and we have much more complete reporting now, which makes the latter figure a more certain measure of progress.

d) As a chemist I take pride in the fact that good chemical companies have a rate of only 3 lost-time accidents per million man hours worked. The chemist fathers of our students are now safer at their jobs than in their homes. Also, men who work for companies with good safety programs are safer in their homes than are the general public. There is a real carry-over of safety consciousness from the job to home, despite the lack of safety supervision after working hours.

e) It was my good fortune that my first professional job was with a safety first company - duPont.

1) duPont enforced an eye protection rule when other companies said this couldn't be done (I was able happily to carry this practice into laboratories of two other companies).
2) Smoking was restricted to approved areas.
3) Protective guards were maintained on all machinery.
4) Safety cans were supplied for flammable solvents and there was protection against static sparks when filling cans with solvent.
5) Routine checking on good exhausts was practiced.
6) No one was permitted to work in the laboratory alone.

f) As safety consciousness grew in industry, people who didn't take safety seriously suffered for bad practices. (I recall one chemist who lost his job because of distilling too large a quantity of flammable liquid in a glass flask.)

But accidents still seem to happen despite our best efforts. When an accident in duPont affected some people close to me, I became impressed with the fact that the duPont safety program was motivated economically - not paternalistically. Accidents cost the company money both for facilities and for personnel.

The rise of safety consciousness in academic institutions now probably has a corresponding economic motivation. In many states it is now possible to sue academic institutions for failure to take proper care of young people entrusted to them. Also, as school teachers have become more prosperous, they have become more likely targets for suit. (This is known as the principle of the deep pocket in claims jargon, i.e., sue those who can pay off when judgments are rendered against them!)

No large number of accidents happen in schools each year, but major dislocations can occur. We all know of disabling accidents and of fires which have crippled chemistry programs in our own or other institutions over the years. Colleges do have a long way to go in achieving the low accident record of a good industrial firm, but they have a real stake in improving their record. An article by Schmitz and Davies in the Journal of Chemical Education for August, 1967 on liability cases, emphasized the fact that: you must not only teach and maintain safe practices in the laboratory, but after an accident takes place you must be able to prove that you did teach safe practices.

Not just to reduce legal liability but also to build safety consciousness overall, we do ask students at the University of Idaho to sign a statement similar to the one attached to this paper, giving one to the instructor and keeping one copy in the notebook. And we do urge our instructors to enforce these practices, since it is almost worse to have the knowledge of good practice, but neglect it, than to live in blissful ignorance.

Actually, any instructor who tries to argue, after an accident, that he wasn't conscious of the need for the wearing of impact-resistant glasses in the laboratory will have a tough time in court these days when half of our states have enacted laws requiring that eye protection be routinely worn in school laboratories and shops.

But I don't want to imply that there is a completely simple answer to the safety glass problem. Dr. Carl Stevens and I sat in on the ACS Safety Committee's session in Chicago to draw up a recommendation for Society endorsement of safety glasses in school laboratories. Unfortunately it is difficult to define just what kind of eye protection should be adopted. In many states the new laws are interpreted to mean goggles, and these have now been adopted at Washington State University as the standard for all laboratories; but many teachers in California object to these because they fog over in humid laboratories. At Idaho, plastic visors which pass the specifications of the American Standards Association for strength and also protect against direct splashes are considered safe for general use; goggles are required only in more hazardous situations.

It is my personal conclusion that eye protection, protection against solvent fires, and safeguards against electrical shocks are the critical points in school laboratories. Students are more apt to know that H_2S, mercury vapor, and certain chlorinated or aromatic solvents are toxic than to know about explosive mixtures of air and solvent or that 110 volt (or 50 volt) electrical circuits can be lethal. (Fibrillation of the heart, which may be induced by low voltage currents, is just as deadly as a massive shock and may be even less susceptible to first aid treatments.) They also don't know that they are potential victims of an accident across the bench, which means that wearing eye protection is essential at all times, not just when they personally are performing hazardous experiments.

Also, it is my impression that many students and teachers are not yet aware that unconsciousness may come from a breath or two of an oxygen-free atmosphere with quick death following in a couple of minutes; or of the explosive hazards met when a conventional household refrigerator is pressed into service for chemical storage.

In particular I believe that we should urge the formation of a broadly based safety committee in every department. We also should urge outside inspection of college facilities at regular intervals by experts in fire protection. In addition, we should counsel against the use of perchloric acid or perchlorates in undergraduate laboratories. (Urge caution in graduate laboratories, too, if perchloric acid is in use!) We should eliminate experiments from introductory courses which have recognizable hazards of appreciable dimensions. The reagents in our undergraduate laboratories should be limited to those in immediate use.

What safety references can be recommended to a college faculty?

a) A number of inexpensive references are available:
   1) Upjohn's "Safety in the Laboratory" (free).
   2) duPont's "Condensed Laboratory Handbook" (single copies free, low cost in large quantities).
   3) "Laboratory Design Considerations for Safety" of the Campus Safety Association ($1.50) has good guidelines on safety in facilities, i.e., hoods, solvent handling, etc. I personally recommend membership in CSA, which too few faculty members join (it is now largely made up of college safety men, but faculty membership is increasing). The CSA puts out a useful monthly safety letter which costs only $2.00 per year and can be obtained through the Campus Publishers, 711 N. University, Ann Arbor, Mich.
   4) Alpha Chi Sigma: Safety Practices in the Freshman Laboratory.
   5) "Safety in the School Laboratory" Bulletin #15 of Science Bulletins Education Center, Columbus, Ohio 43216 (free).
   6) Safety manuals put out by chemistry departments in colleges, e.g., University of Illinois at Chicago, undergraduate division (20¢).
   7) Safety Manual of a university, e.g., University of Kentucky's "Safety Program and Standards for Safety" (general reference for all campus use; many institutions have developed such manuals and will provide them on request).

8) "Safety in the Chemistry Laboratory", reprint of columns edited by Norman Steere in J. Chem. Ed., $3.00.

9) Fawcett and Wood, "Safety and Accident Prevention in Chemical Operations", John Wiley (1965).

10) Norman Steere, "Handbook of Safety" Chemical Rubber Publishing Company, (1967).

What to do after an accident has occurred?

1) What not to do first: don't practice medicine without a license! Send minor cuts, burns, etc., to your student health center, but do accompany the student and provide transportation if there is a prospect that the accident may be more than minor.

2) Learn first aid practices for retarding the flow of blood from arterial cuts and for artificial respiration. A faculty member must be ready to give aid of this kind when it is needed. (Arterial blood flow must be stopped within one minute and artificial respiration is essential within a couple of minutes!)

3) Call for medical help <u>promptly</u> if disaster should strike.

UNIVERSITY OF IDAHO CHEMISTRY DEPARTMENT

General Laboratory Instructions

1. Avoid waste of gas, water (both tap and distilled), filter paper, and materials of any kind.
2. Use only your own reagents and return reagent bottles promptly to their proper places. (Do not return excess reagents to supply bottles.)
3. Dispose of solids by placing them in waste jars, unless they are readily water soluble.
4. Use the lead trough in the center of the desk for the disposal of water only. Dispose of small quantities of nonaqueous liquids by pouring them into the sinks. If such liquids are corrosive or flammable, flush them down with plenty of water. Larger quantities of flammable solvents should be placed in the metal containers provided for this purpose. Substantial quantities (more than 10 ml.) of such solvents must not be poured into the drains since they constitute an explosion hazard.

   If acids or alkalis are spilled on the desk or floor, wash the surface at once with plenty of water; then wash the desk with sufficient boric acid solution in the case of spilled alkalis and sodium bicarbonate solution in the case of spilled acids so as to neutralize the acids or alkalis that have penetrated into the wood; then wash the desk once more with plenty of water.
5. When leaving the laboratory make certain that your gas and water are turned off and that your desk is clean and neat.
6. Maintain an orderly arrangement of the apparatus and materials in your desk. The desk drawers and cupboards are inspected periodically and rated on the basis of neatness and cleanliness.
7. Use only the balance assigned to you.

Special Safety Rules

1. Wear approved eye protection in the laboratory continuously. This means eye covering which will protect both against impact and splashes. (If you should get a chemical in your eye, wash with flowing water from sink or fountain for 15-20 minutes.)
2. Perform no unauthorized experiments.
3. In case of fire or accident, call the instructor at once. (Note location of fire extinguisher and safety shower now so that you can use it if needed. Wet towels are very efficient for smothering small fires.)
4. You must go to the Infirmary for treatment of cuts, burns, or inhalation of fumes. (Your instructor will arrange for transportation if needed.)
5. Do not taste anything in the laboratory. (This applies to food as well as chemicals. Do not use the laboratory as an eating place, and do not eat or drink from laboratory glassware.)

6. Exercise great care in noting the odor of fumes and avoid breathing fumes of any kind.

7. Do not use mouth suction in filling pipettes with chemical reagents. (Use a suction bulb.)

8. Don't force rubber stoppers onto glass tubing. (Protect your hands with a towel when inserting tubing into stoppers.)

9. Confine long hair when in the laboratory. (Also, a laboratory apron is essential when you are wearing easily combustible clothing. Such an apron affords desirable protection on all occasions.)

10. Never work in the laboratory alone.

I have read the laboratory rules and will observe them in my chemistry course.

Signature

Date

(Return one signed copy to instructor).

WHAT SHALL WE TEACH NON-SCIENCE MAJORS?

Edward C. Fuller

Beloit College
Beloit, Wisconsin

"....An informed citizen should be conversant with the larger principles of science, the dynamic potential of scientific research, the main contemporary currents of scientific effort and their relationship to social forces. With such an understanding, an intelligent citizen can make intelligent judgments between good and bad policy on scientific and technical matters. Without it, he can hardly participate fully in a scientific democracy."

These words of Glenn T. Seaborg, Chairman of the U.S. Atomic Energy Commission, cannot be improved upon as a succinct statement of what science for the non-scientist is all about. The teacher who undertakes the formidable but exciting and rewarding task of teaching science to the student whose chief interest lies in some other field will quite properly have his own personal interpretation of what research can do for man and how it is likely to affect our lives. A consultant can be of little use to him here. But "the larger principles" serve as a common denominator of understanding when contemplating the rapidly shifting interplay of dynamic research and technology in our society. It is with these principles that we shall be concerned in this brief paper.

When we plan a course we must ask and answer three basic questions:
(1) What background in science will most of our students have?
(2) What do we want them to accomplish in the one or two semesters we shall have together?
(3) What principles will serve most effectively as the vehicle for these accomplishments?

As a brief summary of "the larger principles" I would suggest the following:

1. All substances are composed ultimately of tiny particles (atoms, molecules, or ions) in rapid motion.
2. The heat content of a substance is proportional to the energy of motion of these ultimate particles; heat changes solids to liquids and liquids to gases by increasing the energy of motion of the ultimate particles.
3. All matter is made up of different combinations of the atoms of some hundred or so elements.
4. Atoms of all elements are composed of protons and neutrons packed in a tiny nucleus surrounded by a cloud of electrons; atoms are mostly empty space.
5. The atoms of different elements differ in the number of protons and neutrons contained in the atomic nucleus and in the number and arrangement of electrons in the cloud.
6. Atoms of elements with similar chemical and physical properties have similar distributions of electrons in the cloud.
7. The masses of atoms are known so that the relative masses of the substances taking part in a given chemical reaction are known.

8. Energy is always either produced or consumed when a chemical reaction takes place; the amount of energy involved is always the same for the same masses of substances reacting in a given way.
9. Energy is the capacity for doing work; work is measured in terms of a force acting through a distance.
10. In all but "atomic energy" reactions the total mass of materials entering into a reaction exactly equals the total mass of the products formed, within experimental error.
11. In all but "atomic energy" reactions there is no loss of energy when one form of it is transformed into another.
12. Matter is an extremely concentrated form of energy, and conversions of one into the other can be made by "atomic energy" reactions; in these conversions, the total of <u>mass-and-energy</u> before the reaction is equal to the total of <u>mass-and-energy</u> after the reaction.
13. All living things are composed of one or more cells which contain a substance called protoplasm.
14. Foods ingested by living organisms are utilized through chemical and physical processes in the organism both to build tissues and to produce the energy necessary to maintain life.
15. Several different classes of food, serving different purposes, are required for the adequate nutrition of man.
16. Living things can arise only from other living things of the same kind; all life tends to reproduce its own kind.
17. The creatures of today have descended by gradual changes from different and usually simpler creatures of the past.
18. The rocks in the crust of the earth contain a record of how the earth and life on it have changed in the past.
19. Past changes in the earth's surface and the living forms inhabiting it are adequately explained by processes now in operation.
20. The conception of the world one builds from his sensory perceptions does not correlate completely with the physical world which produces the stimuli perceived by his senses.

When one looks at this list, it is obvious that he must first decide whether he wishes to teach a course cooperatively with a colleague in another department or limit himself to those principles which are most typically chemical. From about a thousand replies to questionnaires sent to a total of sixteen hundred institutions of higher education, it appears that about 40% of the courses in science for nonscience students in this country are multidisciplinary, that is, include material from two or more departmental disciplines - astronomy, biology, chemistry, geology, mathematics, and physics. Courses in "physical science" are taught in about two-thirds of the two-year colleges. In four-year colleges this combination of disciplines in courses for nonscience students outnumbers all others, but courses including biology are quite frequently encountered. Of the courses involving only two disciplines, chemistry-physics far outnumbers all other combinations.

To lab or not to lab - that is the question that plagues every science teacher. In this writer's opinion, a science course without a lab is like a ship without a rudder - better than no ship, but not much! The laboratory-rudder is needed to give direction and control to the course of the ship - or the ship of the course, whichever you prefer. However, in all fairness it must be pointed out that about 40% of the multidisciplinary courses in science reported in answer to the questionnaire are being taught without benefit of laboratory - and another 4% with only one hour of lab per week. A few such courses entail four or more laboratory hours per week. Most of the other 55% have two or three hours of lab per week. A third of the multidisciplinary courses run for one semester and another third for two. The remaining ones involve various other lengths of time.

The new teaching aids such as films, film loops, video tapes, and remote stations for asking questions of a computer and getting answers promptly will undoubtedly be of great help in relieving both the student and the teacher of much of the drudgery which has bedeviled laboratory work in many introductory courses. The stimulus toward the use of such aids has been provided by the AC3 Committee on Teaching Aids under the chairmanship of W. T. Lippincott. We need to do more experiments in which students gather data and use them immediately to draw some important conclusions about some basic principle in science. The Committee on Teaching of the Division of Chemical Education in the American Chemical Society is stirring up new brews of laboratory experience under the leadership of H. A. Neidig at Lebanon Valley College. The many inexpensive paperbacks dealing with special topics in chemistry and other sciences can be used liberally for spicing up the student's interest in broad and sometimes abstract principles. The "Case Histories" being published by the AC3 Committee on Science for the Non-Science Major under the chairmanship of Robbin C. Anderson will be useful to any teacher planning a course of this type.

Anyone who is ready to roll up his sleeves and plunge into the heady activity of mixing up new combinations of scientific experience for the non-scientist to indulge in will find plenty of help from his colleagues engaged in the same enterprise.

CHEMISTRY FOR NON-SCIENCE COLLEGE STUDENTS

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It seems that I have been talking about this problem since I began to teach in college in 1941. When I arrived at Antioch, I found myself in a situation where there was concern about the wholly educated person. It was a new idea to me then, that some intellectually oriented non-scientists really wanted to know about science and that they even considered it respectable to know about it. In the college it was required that one-third of the general education of the student,which consisted of about one-half of his effort in obtaining a degree, was devoted to the study of science. On becoming aware, I was soon converted to the idea that this problem was just as important as that of turning out well trained chemists.

Now, after twenty-five years, I find myself still talking about the problem. I wish that I could say that now I can offer a solution. Instead I will describe some of our efforts and indicate where we think the problem now stands.

The first indication of real concern on a general level came in the late 1940's when the atomic bomb brought home to the non-scientist that the existence of the world depended on understanding how such a weapon could be developed and how it would affect the political nature of the world.

Combined courses called Physical Science, Life Science,and Earth Science were tried and met with varying degrees of success. In a survey of these programs made in 1955 it was concluded that the success of these depends on the devotion and commitment of the teacher to the idea. Where they were tried and assigned to people not having the commitment (usually to the younger members of the department) they were failures.

The Sputnik was the next disturbing influence. A great deal of money and time has been spent in the last ten years on improving secondary science education and in general it has been successful. The students coming to college are better prepared for science than ever before. It is interesting to note, however, that the improvement in preparation has not produced an increased interest in science as a career. Even though enrollments have gone up the number of people interested in science as a career has remained constant or even dropped a little.

Many have attempted to analyze this situation, and all sorts of reasons have been given. Too much work, the poor image of the scientist, the lack of discipline in present education, poor pay of scientists and many others. I believe that while the young person now has been so saturated with the idea that science can do anything, the romance that is coupled with working in the frontier of things has gone from science and is now centered in working with people and delving into the mysticism of the fine arts. Even those few really interested in science now are attracted to biology and biochemistry, rather than the physical sciences.

The fact that fewer of the total population are now concerned with the scientific profession, makes it more imperative that we reach those having these other concerns with a basic understanding of science.

I have come to the conclusion that there are two major facets to the problem. One of these is mechanical and the other is content. The former involves the question of "how do people learn?" and the second, "what should the non-scientist learn?"

At the AC3 Conference on Chemistry for Non-Science Majors held in Dallas, Texas, April 15 and 16, 1966, I reported on the organization of a new experimental program at Antioch College. The case history presented there has since been published in the AC3 Newsletter VII, January, 1967, and is available in more detail on request to AC3. This program has been in operation for four student quarters, and the second group of students are just completing the program. I will review here the main points of the program and then proceed to give you what we think we have learned from it.

The original program offered in 1965-66 developed by taking the science area approach. All individual science courses were discarded and a series of thirty presentations from all of the departments were offered. Eleven independent studies programs and six special seminars completed the studies. Skills programs in basic mathematics, physics and chemistry laboratory, and graphics were also available to the student. Short seminars and discussion group meetings accompanied each of the thirty presentations.

The student and his preceptor worked out a program which was designed to fit the goals of the student and the background already exhibited through a physical science placement exam taken during the first week on campus. The whole first year program could be waived by a sufficiently high score on an achievement examination. As a consequence, most of the students who came with a commitment to science study waived the special program. The second year of the total college program has remained unchanged.

The general goals for the program were:

1. To encourage the student to assume more responsibility for his program and for his education.
2. To give the student a chance to explore his own ability to learn by independent study.
3. To provide leeway for adjustment to the demands of a college program.
4. To prepare him for entrance into second level courses in general education and in his field.
5. To help him select his major field by allowing him to sample several departmental offerings in the first year rather than tying him down to one, or at a maximum two.

In order to do adequate evaluation of such a program, an office of educational research was set up two years before the program was initiated. A group of students from all areas were selected during that time to act as a control group for the new program. As similar a group as was possible to select was assembled from the students participating in the new program. The first preliminary report on the success in attainment of these goals was issued by the testing office in November. These are the indications:

1. A larger number of the experimental group felt that they were now ready to assume more responsibility for their education. Almost one-third, how-

ever, felt that the college really should have done this for them.

2. As was expected, a much larger number of the experimental group found that independent study was an adequate way to obtain an education but that it was more work.

3. A sizeable decrease in drop-outs was experienced but this is tempered by two things: the draft situation among the men and the fact that each student was assured of being in good standing at the end of the experimental year. However, if he did not perform adequately in any area, he had to complete the work as an elective before he could graduate from college or before he could enter the second level courses. Table I shows how my preceptoral group of thirteen students completed the first level work. This group was typical of the fourteen other groups.

TABLE I
PRECEPTORAL GROUP

Preceptoral Team -- Instructor, upperclass male, upperclass female.

S.S.=Social Sciences -- Non graded courses received S or U. P.S.-Physical Sciences.

H=Humanities -- Graded courses received, A,B,C,D,I or F. F.Y.P.=First Year Program.

Grade point average (G.P.A.) usual 4 points = 1 hr. of A credit.

I was assigned thirteen students: 7 men, 6 women from two halls which were entirely first year halls except for 4 upperclass preceptoral fellows. The table below lists them in order of their academic promise as derived from C.E.E.B. scores. Thirty credits toward graduation were given for first year program work.

Number	Sex	V CEEB	M CEEB	Work completed First year	Work completed 2nd level
1.	M	725	683	P.S. Area. FYP completed 1/2 Humanities 0 SS	Carried 16 hrs. 5 U 5 I 5 D+ G.P.A.1.0
2.	M	703	518	FYP completed all areas 30 credits	Carried 15 hrs. 5 A 10S G.P.A. 4.0
3.	F	690	774	Completed FYP 36 credits +10 by exam	Carried 16 hrs. 6 S 10B G.P.A. 3.0
4.	F	683	788	Completed FYP 36 credits + 10 by exam	Carried 18 hrs. 18 A G.P.A. 4.0
5.	F	657	492	Completed FYP 36 credits + 5 Adv. Placement	Carried 15 hrs. 10 A 5 D+ G.P.A. 3.0

6.	F	648	617	Completed FYP 36 credits	Carried 16 hrs. 10 B 5 C 1 S G.P.A.2.66
7.	M	632	735	Completed P.S. 1/2 Humanities 1/2 SS 30 credits + 10 by exam	Carried 11 hrs. 5 I 6 S G.P.A. 0
8.	F	617	592	Completed Hum 1/2 SS 1/2 P.S. 30 credits + 5 by exam	Carried 11 hrs. 5 A 6 S G.P.A. 4.0
9.	M	625	606	Completed FYP in Mexico Hum. 1/2SS No P.S. 30 credits	Carried 10-1/2hrs. 8 A 2.5 B G.P.A. 3.7
10.	F	612	592	Completed Hum area 1/2 P.S. 1/2 SS 30 credits	Carried 13 hrs. 10 C 2.0 3 S G.P.A. 2.0
11.	M	592	534	Completed Hum. 1/2 P.S. 1/2 SS 30 credits	Carried 16 hrs. 10 C 6 U G.P.A. 2.0
12.	M	546	615	Completed FYP 30 credits	Carried 16 hrs. B 10 C 5 S I G.P.A. 2.66
13.	M	294	324	Completed Hum. in FYP No P.S. No SS 30 credits	Carried 11 hrs. 5 B (lit.) 6 S G.P.A. 3.0

7	Physics	Physics
8	Undecided	Undecided
9	Social Work	Languages
10	Undecided	Languages
11	Undecided	Undecided
12	Geology	Anthropology
13	Social Work	Social Work

In spite of the rather successful results of the overall college program, the program in the physical science area was much less satisfactory. It was not that the students did not complete their science requirement in the first year, but their selection of work from the general program was quite a shock to the physics and chemistry departments. Nearly all of the students selected Biology, Earth Science, and Engineering subjects as a means of fulfilling their general education requirements and only a few less than 10% chose to become involved in chemistry, physics, and mathematics. None changed from other areas to science.

In view of this development and a survey of student and faculty opinion,a modified program was offered to the 1966-67 group of students. Instead of chemistry and physics being spread over the whole first year, sequential seminar type offerings were given which were contained in one period of school. Major presentations were distributed throughout the period. This modified plan is presented in Table III.

TABLE III

PHYSICAL SCIENCE PRESENTATIONS OFFERED IN A SEQUENTIAL PATTERN DURING ONE PERIOD: SUMMER 1966

Subject	Department Responsible for Offering
1. Study of the Earth I: Basic Concepts in Historical Development: Time & History	Geology
2. Structure of Matter: Qualitative and Historical Development of the Kinetic Molecular Theory	Chemistry
3. Galileo - Historical Development	Physics
4. Ways of Knowing in Science and Engineering	Engineering & Philosophy
5. Energy: A Semiquantitative Approach	Physics
6. Physiological Chemistry: A Discussion of the Present Status	Chemistry
7. Newton: A Historical Approach	Physics
8. Study of the Earth II; Composition & Process	Geology
9. Physics "Circus" - A Demonstration	Physics

Table III, continued

Sequential Seminars

Title	Meetings per Week	Description
Physics A	5	For B.S. Student Choice
Calculus A	5	For B.S. Student Choice
Mathematics I, II, III, IV, V	3	M I Sets M I Geometry M III Functions M IV Relations M V Nature of Modern Algebra
Copernican Revolution	3	For General Education (Discovery Approach)
Structure of Matter	1	For General Education
Introduction to Chemistry	1	For General Education and preparation for advanced chemistry

Laboratories in Physics and Chemistry

The results of this change have not yet been evaluated but more than four times as many students were involved in the physics and chemistry portions of the program. The change clearly indicates a tendency to go to a more courselike program.

A second group of students are now involved with a somewhat different program which attempts to emphasize the more successful portions of both of the first two trials. Table IV is an outline of the latest program.

TABLE IV

PHYSICAL SCIENCE PRESENTATIONS OFFERED IN A SEQUENTIAL PATTERN DURING ONE PERIOD: FALL 1966

Subject	Department Responsible for Offering
1. The Earth Model: Problems and Implications	Geology
2. Atomic Structure: Historical and Semi-Quantitative Approach	Chemistry
3. Liquids: Condensed Gases or Molten Solids?	Chemistry
4. The Properties of Water	Chemistry
5. What Makes Blood Red?	Chemistry
6. Firecrackers, Rockets, and Nuclear Reactions	Chemistry

Table IV, continued

Sequential Seminars

Title	Meetings per Week	Description
Physics A	5	For B.S. Student Choice
Calculus A	5	For B.S. Student Choice
Mathematics	3	Several Sections
1. Set Theory: Language in Crisis		4 weeks
2. The Axiomatic Method: Generalizing Truth		3 weeks
3. Topics in Foundations of Mathematics		3 weeks
Descriptive Chemistry	2	A combination of Qualitative and quantitative approach. Group divided into General Education and Preparatory Interests
Physical Science	1	Divided into sections Task force approach
1. From Atomos to Atom: Historical 18th and 19th Century		4 weeks section
2. Birth of a New Physics: Galilean-Keplerian-Newtonian Achievement		4 weeks section
3. Energy: The Physicists Concept The Current Social Problem		4 weeks section

A SERIES OF SHORT SEMINARS BASED ON THE FIRST PRESENTATION "THE EARTH MODEL."

	Title	Meetings per Week	Description
1.	The Origin of Planet Earth	2	Earth Models - 2 weeks
2.	Formation of the Elements	1	Theories - 3 weeks
3.	Visitors from Outer Space	2	Meteorites - 3 weeks
4.	Crystals: An Introduction	2	Crystal Structure - 3 weeks
5.	Composition of the Earth	2	Processes - 3 weeks
6.	The Earth Model	2	Continuation of Presentation - 2 weeks
7.	The Origin of Continents	2	Continuation of Earth Model - 2 weeks

Physics and Chemistry Laboratories are used.

This modified program has not been evaluated yet but, again, an increase in the number of students involved in the physics and chemistry portions was noted. The number in Earth Sciences has remained the same. Offerings in biology are being deferred to the second period. These are very similar to those in the original program.

The preliminary conclusions drawn from experience this far are:

1. A sequential approach to chemistry is more successful and preferred by both teacher and student.

2. Independent study plus seminar and discussion periods is quite usable in chemistry.

3. There has been no demand to return to the lecture-quiz section method by either students or teachers.

4. A full evaluation must wait until next summer or fall.

I would like to add a word of caution to those experimenting with new ways of doing things in chemical education or for that matter any type of education. To reorganize and redo a program takes a tremendous amount of time. The original program was set up by obtaining money from the Esso Corporation that paid for time freed from other work to develop new approaches. In order to continue the experimentation, Antioch College has received a grant of $400,000 from the Sloan Foundation which will allow nine teacher quarters per year to be freed for program development each year for the next five years.

The problem of laboratory work in this experimental program has been approached by new methods also. The laboratory work has been made available on a continuous basis by using the carrel-type of permanent set-up which is open to student use during the afternoon, six days per week, and three evenings. This set-up is quite similar to that proposed by Postlethwaite at Purdue University and used in teaching botany.

The laboratory table tops have been divided into carrels in which all of the equipment necessary for the experiment is available. An instruction notebook goes with each carrel. Where techniques are new, a short film, both loop and projector type, is available. An assistant or an instructor is present at all times. Each student keeps a notebook and completes a question list which he submits to the instructor for evaluation.

OPENING THE DOORS TO CHEMISTRY FOR ALL STUDENTS: INTRODUCTORY CHEMISTRY FOR TWO-YEAR COLLEGES

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Because the type of institution tends to determine the characteristics of its chemistry program we should consider first what is meant by a two-year college. These institutions are the public community colleges, public junior colleges, private junior colleges, two-year technical institutes and two-year centers of university systems. The public institutions are often characterized as open-door, comprehensive, community colleges. The concept of opening the doors to chemistry for all the students is a consequence of the open-door, comprehensive, community college philosophy.

The "open door" means entry into the college is generally unrestricted. It means that many courses and many curricula must be available. Some courses will be within the range of a student's interest and within the purview of his abilities. Some will be outside his interests and some beyond his ability. The student need not choose what lies outside his interest. He should not be allowed to choose that which clearly lies beyond his ability. Unfortunately, many two-year college administrators and faculty do not realize that the open-door college philosophy does not require every curriculum and course to be open-door. It does require a variety of curricula to match the potentials of a variety of students.

"Comprehensive" means a commitment to a multiplicity of educational functions or purposes. Six functions are generally listed: 1) education for transfer, or the lower-division parallel function; 2) education for occupational competence, or the career training function; 3) education for living, or the general education function; 4) counselling and guidance; 5) community service, and 6) education for overcoming deficiencies, or the remedial or salvage function.

The "community" concept arises because the colleges may be wholly or partially governed by local authorities, they may receive considerable financial support from local sources, they may be tuition-free, or relatively low-cost, compared to other higher educational institutions. Furthermore, they generally respond quickly to the educational needs of their communities, and by the extended day scheduling of classes, they educate and train all segments of the community, from 16 years to 80.

The development of chemistry programs for two-year colleges must be viewed in terms of the open-door, comprehensive, community philosophy and the six functions mentioned earlier. To fulfill the education for transfer function, a college must provide a well-rounded or complete lower-division college program for persons who desire to continue their education in an academic or professional discipline such as chemistry, physics, biology, engineering, or dentistry. Many students cannot qualify for the university or the state college upon high school graduation, but are potentially capable of obtaining a baccalaureate degree and often a doctorate. In California the university system accepts only the top 12-1/2 percent of the high school graduates and the state college system, the top 35 percent. In Florida, which has only a university system, these institutions accept only the top 40 percent. The two-year college must provide an opportunity for the unqualified or ineligible students to demonstrate their capacity to maintain, over an extended period, an acceptable standard of scholarship in subjects of collegiate level, so that they can enter the four-year institutions as fully qualified juniors. Reports from the universities indicate many "ineligibles" transfer, graduate, and continue to graduate degrees. El Camino College, in its twenty years, can identify many such students who have received Ph.D. degrees, some in chemistry, and others who have earned professional degrees in fields such as medicine and dentistry. Two-year colleges also enroll many students eligible to enter the four-year college direct from high school but who, for various reasons, elect to attend the two-year college and then transfer.

If a two-year college is to maintain college level standards in college level courses it must be concerned about and maintain the integrity of its transfer courses and program. Therefore, for students not qualified to embark upon a college level course or program, the college must provide remedial programs. They may be high school equivalent courses for students who possess insufficient skill or competence to master college level work.

There are three implications of these considerations for the chemistry programs of two-year colleges. First, the college must offer a general chemistry course equivalent to that of the corresponding university and state colleges. Second, it must offer a second-year chemistry program equivalent to that of these institutions. (I purposely used the term equivalent rather than identical or parallel.) The third implication is that the college must provide a means of developing a student's level of performance and understanding so he can enter the general chemistry course with a reasonable chance of success.

To fulfill the function of education for occupational competence the college must prepare its students to enter gainful employment upon completion of a two-year course of study and with a reasonable chance of succeeding and advancing. There is currently much interest in and concern about chemical technicians, who are generally classified as being semi-professionals. They represent one part of a continuous spectrum of scientific and technical jobs for which the two-year college must train and educate students.

This spectrum has four broad bands. The first band includes craftsmen or skilled tradesmen; second, highly skilled or industrial technicians; third, semi-professionals or engineering and scientific research technicians; and fourth, professional engineers and scientists. The band boundaries are diffuse rather than discrete. The bands are characterized, as one moves from the craftsman to the professional, by increased complexity and intellectual content of the job demands. Two-year colleges must develop programs which will train each group of students what they are required to do on the job and educate them in what they are required to know to perform effectively in their jobs. The provision for the professional is a part of the transfer function.

The implications for chemistry programs is that the college must provide instructional programs, curricula and courses for the craftsman, the highly skilled, and the semi-professional if it is to fulfill its occupational education function. There must be as great concern about the integrity of these programs as that of the transfer program.

The general education function requires that we provide general liberalizing education for transfer and occupational students. It also requires that we provide educational experiences of a generalized nature for those members of our community who have neither a higher educational degree goal nor an occupational educational goal.

A fifth implication for chemistry programs is that the college must provide part of the general education program in science for the non-science and non-technical students.

The counselling and guidance function is important because we are obliged to provide a multiplicity of programs for a heterogeneous student body. We have to deal with students who come to us and say "I want to be a chemist, or a doctor." This may or may not be a realistic goal.

The sixth implication for the chemistry programs of the two-year colleges is that they must develop a philosophy and program for the placement of students in chemistry courses at the place where the student has the most reasonable chance of succeeding and where he will obtain the education and training in chemistry best suited for his educational goal. The two-year college situation is such that students should not be allowed to enter a college level program when they obviously are not ready and will probably "sink". There is considerable evidence that through counselling, guidance and remedial programs large numbers of students can be salvaged and thereby succeed in swimming the whole distance.

The community service function requires that the two-year college identify all of the educational needs within the local community, be they highly specialized or general, and respond to these needs by providing suitable educational programs.

A seventh implication for the chemistry programs is the need to develop a series of specialized courses or programs related to chemistry such as a nuclear science course, or a water chemistry program, or a science lecture series.

The salvage function and the implications related to providing a remedial program in chemistry have been previously mentioned. Introductory chemistry programs of the two-year colleges have tended to evolve or develop in four general phases.

The first phase starts when a college is new. Older colleges with limited enrollments may remain in this phase for many years. Phase one introductory chemistry consists of a single one-year course, often entitled General Chemistry, and characterized by the complete lack of, or near lack of, mathematical and scientific prerequisites.

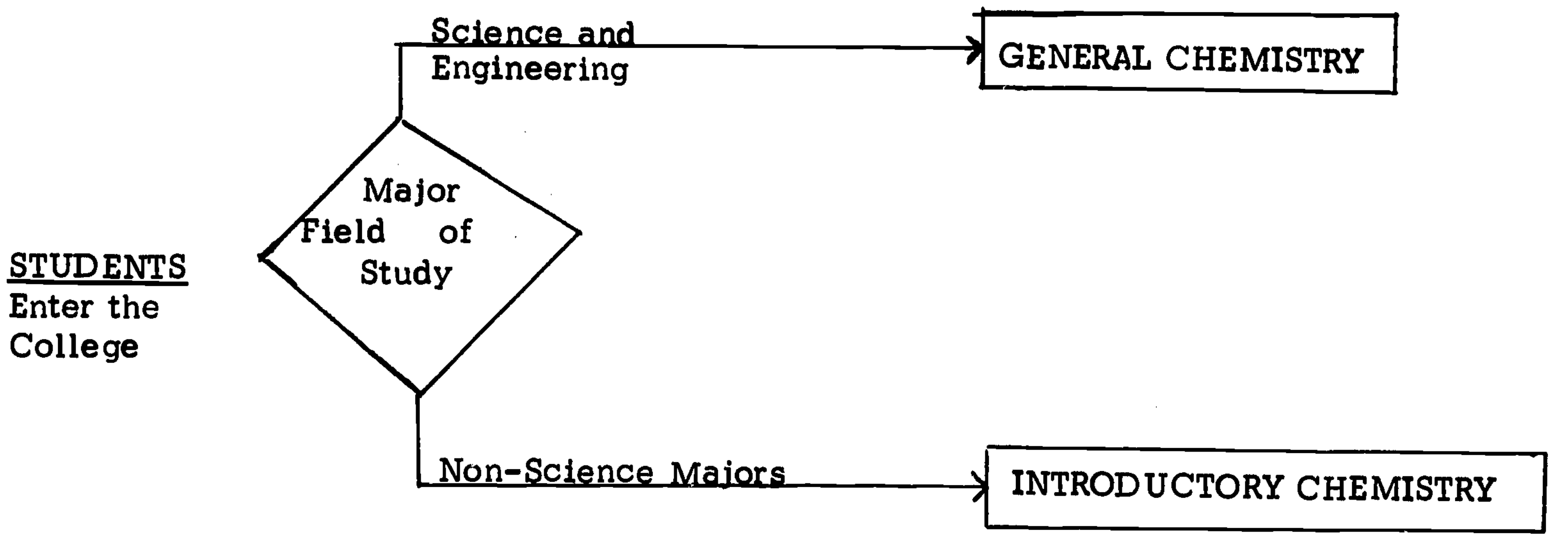
All students who are required to or who elect to take chemistry are enrolled in this course: chemists, chemical engineers, physicists, biologists, engineers, pre-medicals, pre-dentals, nurses, all forms of technicians, and non-science majors. The problems and pressures characteristic of phase one begin to appear immediately. If the course is so taught that students are adequately prepared for advanced work in chemistry and related fields, what happens to the various technicians and non-science majors? The mathematical and scientific backgrounds, abilities, and interests of these several groups of students are extremely diverse. The diversity within each major group is considerable for there may be in the group high school valedictorians, and other high school graduates and adults who have never attended high school but can profit from instruction. The frustrations of dropouts and failure often become so great that the college administrators become concerned. If the faculty reduces the scientific contact and mathematical orientation their transfer students do poorly at the transfer schools.

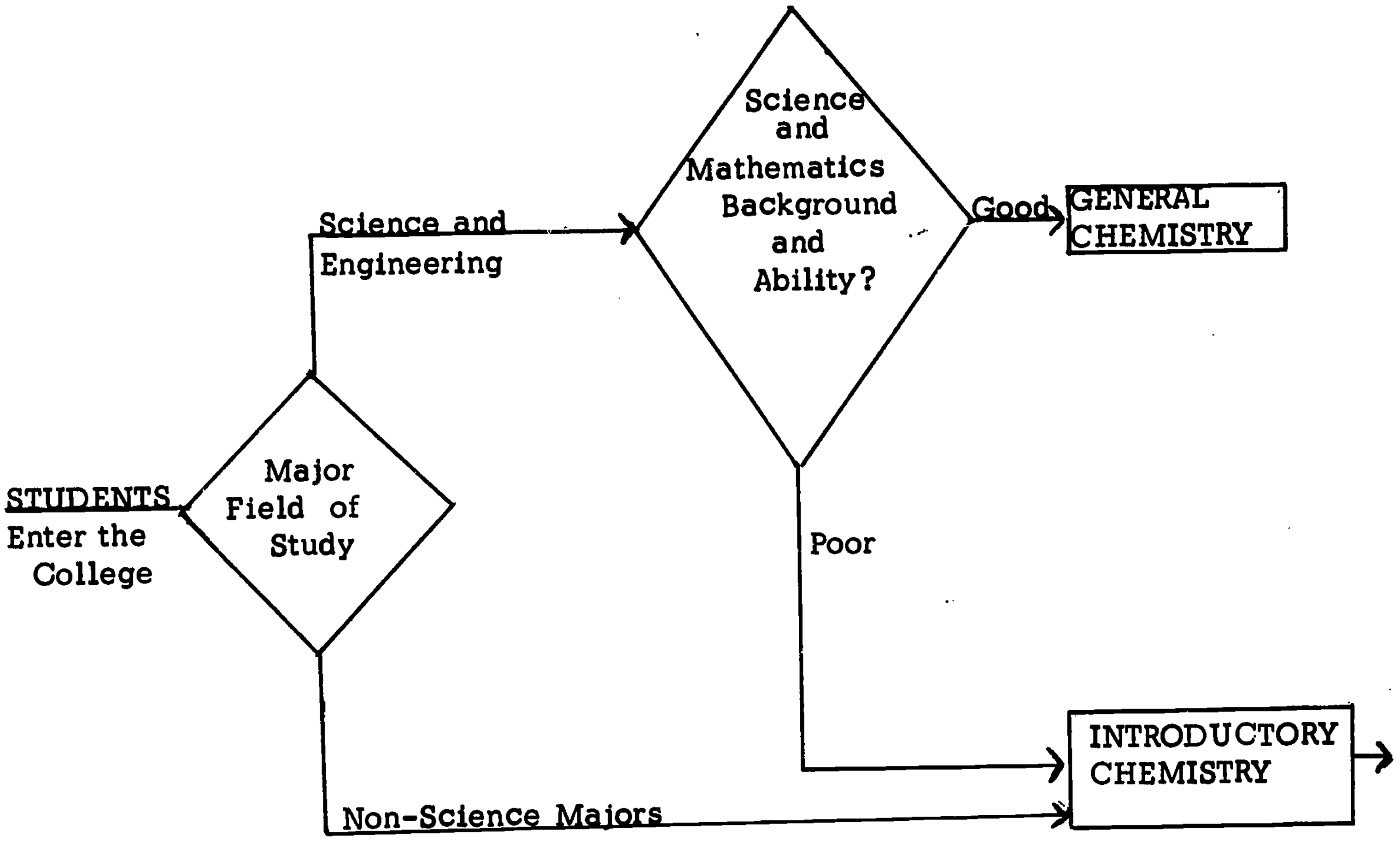
When the pressures from this melting-pot situation become so great and/or the number of students increases significantly the college tends to enter phase two of the development of its chemistry program. Some new colleges start in phase two if they feel initial enrollments will justify such a program.

The second phase is characterized by the introduction of a second introductory chemistry course. Students are divided between these two courses on the basis of their majors or educational goals. One course we will call "general chemistry for science and engineering majors", and the other, "introductory chemistry." Prerequisites in mathematics are generally instituted in general chemistry and some colleges may also add chemistry and/or physics prerequisites. The trend is toward requiring the completion of second year high school algebra or intermediate algebra in college. Some will allow concurrent enrollment, but these are balanced by others who require completion of or concurrent enrollment in trigonometry. There is a definite trend toward requiring high school chemistry and a placement examination before they are allowed to enroll in a chemistry course, to validate the previous chemistry and determine whether the student has a reasonable chance of success in general chemistry.

For introductory chemistry the college may require the completion of the first course in algebra before enrolling although many colleges do not. Students enrolled in introductory chemistry include the non-science majors who elect chemistry to satisfy a general education requirement, students in nursing, home economics, agriculture, physical education, and non-chemical technology curricula. Increasingly, baccalaureate nursing, home economics, and agriculture students and clinical and research oriented technician students are being placed into the general chemistry course. Students who fail to meet the entrance requirements or to pass the placement test for general chemistry are often required to complete this course or one term of it before enrolling in general chemistry.

Figure 1 shows the flow of students into and through a characteristic phase two chemistry program. Note the branching based on educational goals and background or achievement and the two inputs of students for both general chemistry and introductory chemistry. The flow from introductory chemistry into general chemistry represents the preparatory use of the introductory course. Many colleges require that students receive a "C" in the introductory course before proceeding into general chemistry. Others require a "B" since they want entering general chemistry students adequately prepared and don't want to penalize the non-science majors.





Colleges in the second phase have solved one major problem related to the general chemistry course when they regulate entrance into the course, thereby maintaining integrity. This creates a new problem, namely the overriding concern in the introductory course with preparation for the general course. When the faculty realizes that the chemical education needs of the health-related occupational groups, the non-chemical technicians, and the non-science majors group are not being properly serviced, when the preparatory function dominates, they are nearing the third phase.

Phase three is characterized by a course split which splits introductory chemistry into two courses, entitled beginning chemistry, primarily to prepare students for general chemistry, and chemistry for non-science majors, to serve the health-related occupational groups, the non-chemical technicians, and the liberal arts students. Figure 2 shows how students with inadequate preparation move into general chemistry through beginning chemistry. Many schools will not completely cut off entry to general chemistry from the non-science majors course because they don't want to lose the opportunity for a student to become excited about chemistry or some other science once he's had an enthusiastic contact with chemistry. Entrance requirements for general chemistry from the non-science majors course may differ from those from beginning chemistry, generally being higher.

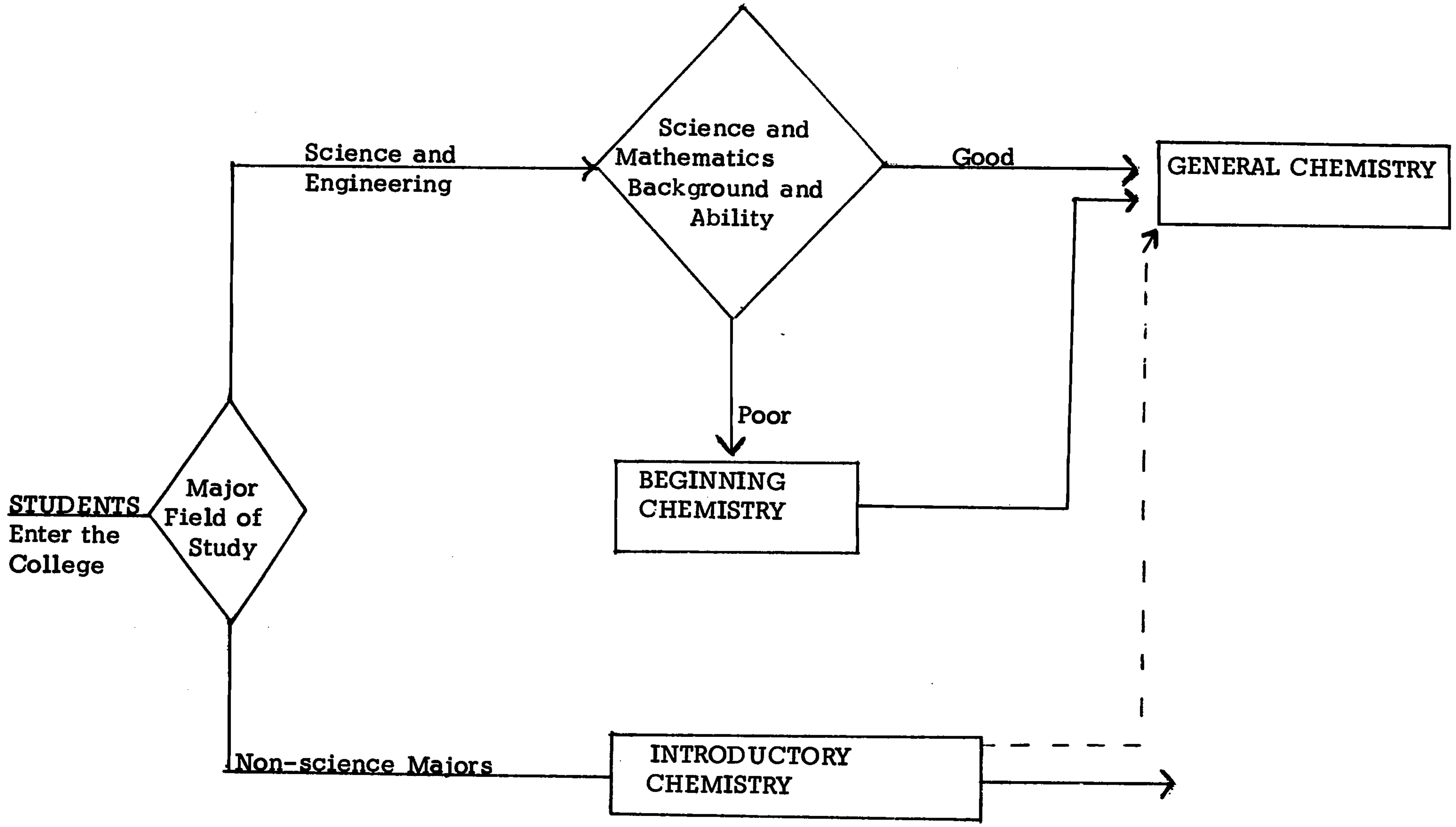


Figure 2 - Phase three program for chemistry in the two-year colleges.

The fourth phase has recently developed in several larger two-year colleges. The idealism of the administration and faculty in many newer institutions creates programs which attempt to be all things to all people. With time this idealism is tempered by a realism which comes only from knocking heads with the students. Phase four is characterized by course splitting which may involve any or all of the three courses in phase three.

In general chemistry some colleges are instituting honors type programs into which they place the cream of their general chemistry students. They continue to maintain the regular level general chemistry for science and engineering majors. Other colleges are reflecting changes in their corresponding four-year colleges by splitting general chemistry into two courses based on student majors. This might mean a general chemistry course for chemistry, physics, mathematics and engineering majors with calculus either pre- or corequisite. The second general chemistry course might be for the biology, geology, pre-medical, pre-dental, etc. majors. Chemical technicians may be included in one or the other of these depending on the level of technician being trained. A third example of general chemistry course splitting is the combination of quantitative analysis and general chemistry into a year course, at the same time retaining the traditional general chemistry course for those who do not need the quantitative analysis.

Course splitting in beginning chemistry appears when colleges realize the spread in the ability of students unprepared for general chemistry is so great that some students need considerably more work than others to bring them up to the level appropriate to enter a college level course. Some colleges have discovered that the general chemistry placement formula will also predict probable success in beginning chemistry in phase three if lower cut-off scores are used for the study. They have designed beginning chemistry program splits based on this information and are able to continue using the same pre-enrollment placement procedure. One college with a beginning chemistry course of four units has added a second course of five units which includes three hours of problems and drill per week for the lesser prepared group. Another college requires that students come in the summer for placement and it differentiates by saying that the students must concurrently enroll in a problem session for the first part of the semester along with general chemistry or beginning chemistry. There are many different examples of splitting at the beginning chemistry level, depending upon the local situation and the combination the faculty and administration can agree upon.

Course splitting in the course for non-science majors results from the differing requirements of the nursing paramedical and the non-chemical technology groups; the needs of these two are much more specific than those of the liberal arts student and the general citizenry. This is also strongly influenced by the differing general education requirements in science of the various corresponding four-year colleges. This course splitting often finds the creation of chemistry courses for occupational groups such as one for nursing and other paramedical curricula and another for non-chemical technicians. On occasion this brings about chemistry courses for individual curricula such as chemistry for nurses, chemistry for cosmetologists, chemistry for fire science, etc. This type of course splitting most often is the result of pressures brought to bear by the college, community, and state or professional licensing authorities for these occupational areas. These persons tend to prescribe the time, content, and orientation of these courses. The health science groups want more organic and biochemistry and engineering related technologies want more solid state material, oxidation-reduction, metallurgy and material science.

Another trend is one which fractionates the curriculum but integrates the disciplines. Some occupational groups in some areas want physics and chemistry but will only allow time for a single course. This is so in some nursing, dental related programs, fire and police science, metals-related technologies, etc.

A faculty and administration may decry and oppose these splitting trends but when they are dealing with state boards that license, specialized accrediting agencies that approve, and vocational educational groups that dictate what must be done for the college to receive various Federal monies, the institution often has little option. Failure of the chemistry faculty to respond to these occupational needs or requests results in the removal of such courses from the chemistry department into the occupational or vocational-technical area where they are taught by non-chemists from the occupational faculty. This poses many problems for a college chemistry program.

Many descriptions of chemistry programs in the two-year colleges and recommendations related to such programs have been published in publications of the Advisory Council on College Chemistry, the Two-Year College Chemistry Conference of the Division of Chemical Education, the Improvement of Instruction Workshops of the California State Department of Education Bureau of Junior Colleges, and the University of Florida-Community College Articulation Conferences in Chemistry. To anyone interested in Introductory Chemistry Courses in Two-Year Colleges and in examples of the developments described earlier, I would recommend they review these publications and reports.

Many colleges would like to make curricular changes in chemistry. Many should do so to be fair to their students. Problems related to faculty time, facilities, space, and budgets force many to stay in their present phase. Four ways of accommodating changes which some colleges have found should be mentioned.

First, the use of concurrent laboratory sections where there is a low enrollment in two or more courses or laboratory sections. Students from two different courses are assigned to the same laboratory at the same time and under the same instructor. This is possible when the administration is willing to allow separate lecture sections for each course. This technique cuts the cost of necessary low enrollment courses.

Second, the analysis of courses to determine similarity in principles, ideas, and depth required. If enough compatibility is found they may group students into large lecture groups for appropriate lecture experiments and presentation of the chemical concepts and principles. Students would also be scheduled into small discussion groups and laboratory sections in which the discussion and experiments would be directly related to their curricular needs.

Third, audio-tutorial instructional systems are being given serious consideration. The possibilities for the development of several somewhat unique packages for self-instruction under the general guidance of a faculty member are great. Postlethwaite has pioneered this in botany at Purdue and Pate and Flitcroft have effectively applied it to chemistry at Simon Fraser University. Heider of Meramec Community College has an Esso Foundation grant to develop such programs in chemistry and the two campuses of Oakland Community College are completely committed to such programs for the whole instructional program. The audio-tutorial approach will allow a college to take care of the differing needs of small groups on an independent basis and has merit. However, an effective program of this type has large initial costs and requires provision for constant revision and updating.

Fourth, the idea of regional cooperation and planning should be explored in the context of more effectively opening the doors of chemistry to all the students. Institutions within 20 or 30 miles of each other might agree that one college would offer the chemistry for nurses and another the chemistry for technicians. Arrangements for coordinated scheduling and transportation would have to be included in planning such cooperation.

In summary we find large numbers of students in the two-year colleges whose goals and abilities are more diverse than one finds in most four-year colleges. Placement procedures are being utilized to screen students and place them in the chemistry program where they have a reasonable chance of success and where their educational needs for chemistry will be most efficiently serviced. Placement of students and design of courses tends to be by majors and therefore somewhat related to abilities and student achievement. There is much concern about the integrity of the program for the colleges desire that their students be able to flow smoothly onto their next immediate educational or occupational goal. There is concern about how a college can serve the chemistry needs of a diverse student body and curriculum in educationally efficient and economically feasible ways. This concern is giving rise to new approaches in scheduling courses, designing courses, and in the utilization of audio-visual materials.

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