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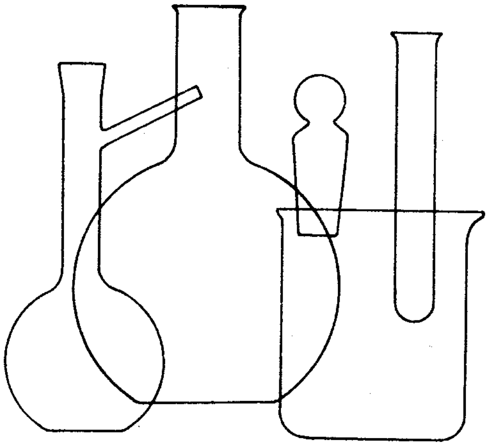

CHEMISTRY IN THE TWO-YEAR COLLEGE

VOLUME XVII 1976

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COMMITTEE ON CHEMISTRY IN THE TWO-YEAR COLLEGE
DIVISION OF CHEMICAL EDUCATION • AMERICAN CHEMICAL SOCIETY

Foreword

The quality of our meetings is directly related to the speakers obtained by the regional chairperson, the organization of meetings by the local arrangement chairperson and the prompt and complete reporting of the papers by the conference editor. All of these people respond to the coordination of the Chairman of COCTYC.

The final meeting while Doug Bauer was chairman was at Kansas City and was a great conference. Kathy Weissman was the Regional Chairperson and assembled a fine group of speakers and workshops. Cecil Hammonds was the local arrangements chairman and through his efforts we met in conjunction with the Midwest Regional ACS and the Missouri and Kansas Academy of Science. Kathy acted as the editor and assembled nearly all papers and promptly submitted them for publication. You might notice we are trying to include pictures made from the slides Leonard Grotz used in his presentation. The editors hope that this will be a technique which will make papers more meaningful.

Curt Dhonau was Chairman of COCTYC for the meeting at Brandywine College. Gus Vlassis was the Program Chairman and acted as the Conference Editor. Gus built the conference around the theme of "Chemistry Futurama" which included fine papers and workshops.

Merwyn Deverell served as the Local Arrangements Chairman and made our stay on the beautiful Brandywine campus most pleasant.

Our great big thanks goes to these people who made the conferences a fertile site for exchange of ideas and made it possible for us to pass it on to you in the form of this journal.

Jay Bardole
Editor

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SOME SPECIAL PROBLEMS IN CHEMICAL EDUCATION

CURRENT CONCEPTS IN CHEMICAL EDUCATION

LEARNING THEORY APPLIED TO CHEMISTRY
More Piaget for Chemists: Things that I Wish I Had Told You

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Purdue University
West Lafayette, Indiana 47907

Presented as a part of a Special Topics Symposium at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City Missouri, October 29, 1976.

In March of 1975 the Journal of Chemical Education published a paper which I wrote entitled "Piaget for Chemists"[2]. In that paper I tried to explain, in terms of a theory of intellectual development developed by Jean Piaget, why many students that we try to teach do not take well to our subject. Since that time I seem to have become the guru of Piagetian theory applied to chemistry; a role that doesn't particularly fit and one that I feel ill prepared to play. What makes me even more uncomfortable is that I have yet to find someone who feels more competent to explain the implications of Piaget's work. I am here then, as a kind of unwilling and uncertain authority, anxious to tell you all that I know but equally anxious to admit abundant ignorance.

I am convinced that Piaget's theory has many implications for the teaching of chemistry and I now know that I am not alone. Since "Piaget for Chemists" appeared, I have received about 200 requests for reprints (I didn't buy any since I was sure nobody in chemistry would really be interested) and I have had about 20 letters and at least a dozen phone calls from chemistry teachers asking for detailed information about how this wise man in Geneva, Jean Piaget, could lead us from our abysmal hell in chemical education to the promised land of enlightened student faces and knowing nods. I have had to tell them all what I must tell you now, I really don't know. I know some things that are not going to get us to the promised land. I know some things that appear to be consistent with Piaget's theory and might work. I even know some things that seem to help. However, I am not able to prescribe some teaching strategy that will lead to certain success and I know of nobody who can. Still, I believe that Piaget's theory provides a frame of reference out of which we might profitably operate in our search for teaching improvements. For that reason, I think that chemistry teachers at all levels should understand what the theory says and what it does not say; what avenues might be worth exploring and what avenues are likely to lead to dead ends.

I will organize what I want to say around some questions put to me in letters, phone calls and private conversations. In that way I hope that I will be speaking to some of the questions that you have.

1. Several people have asked me how they can identify students who are operating at the concrete operational or formal operational level. Isn't there a test that can be administered to students so that the sheep can be separated from the goats? The answer, in my opinion, is no.

Several people have worked very hard to develop a short answer test which can be administered to large groups of students. Others, including a dedicated graduate student at Purdue, are still working to develop such a test and perhaps they will eventually succeed. There have been some partial successes. The test developed in France by Longet[9,10] and translated and used in this country by Sheehan[12] is undoubtedly of some value, but it has limitations as well. The problem is that when you are trying to classify students as concrete operational or formal operational, you are interested in the reasoning that the student uses (or fails to use); you need to crawl into his brain and see how he thinks as he arrives at an answer. You are really not too interested in the final result. Whereas individual interviews such as those used by Piaget and Inhelder in their work do provide some opportunity to see how the student is thinking, quick-scoring, paper and pencil tests provide little opportunity to do this.

Let me illustrate. The Island Problem was described by Karplus several years ago and was adapted by Tom Sills for possible use in the test he is trying to develop at Purdue.

Islands A,B,C, and D are four islands in the ocean. People have been traveling among these islands by boat for many years but recently an airline started in business. Carefully read the following statements about the possible plane trips at present.

The trips between islands may be direct or include stops and plane changes on an island. When a trip is possible, it can be made in either direction between the islands. People can go by plane between islands C and D. People cannot go by plane between islands A and B. People can go by plane between islands B and D. Can people go by plane between islands A and C?

A. No, because no statement was made about a plane connection to island A.

B. No, because if you could fly between islands A and C, then you could fly between islands A and B which is not possible.

C. No, because since you can fly between islands C and B, you could fly between islands A and B which is not possible.

D. Not enough information is given to know.

It can be argued that the logic characteristic of concrete operational thought would lead to choices A and D whereas logic characteristic of formal operational thought would lead to choices B and C. Still, many of you formal operational thinkers arrived at choice A or D. Subtle interpretations given to the word "between" can lead to various interpretations of the problem. Similar difficulties have been encountered with most questions designed to measure hypothetico-deductive logic, one of the characteristics of formal thought.

In addition to the problem of formal students giving what are considered to be concrete answers, concrete operational students may give answers that appear to be characteristic of formal thought. For example, the following question appears to involve proportional reasoning, a characteristic of formal thought.

> If 2 apples cost 20 cents the largest number of apples I can buy with 50 cents is :
> (a) 1 (b) 2 (c) 3 (d) 4 (e) 5

When this item was given to a group of students, most of whom operated at the concrete level, 88% gave the correct answer of 5. Are they using the proportional reasoning characteristic of formal thought? No, they are not. When you interview the students to see how they answered the question, you find that most of them cannot tell you. They are not at all aware of the form of the reasoning employed.

If a student does explain his answer, it often goes something like this:

> "Well, 2 apples cost (correspond to) 20¢, then 1 apple costs (corresponds to) 10¢, and 5 apples cost (correspond to) 50¢."

The reasoning involves seriation and correspondence, the logic of concrete operational thought. If the problem is changed to read, "If 2 apples cost 23¢, how many apples can be bought for 57¢?" most concrete operational students are unable to solve the problem because the seriation and correspondence is less obvious. An exception would be found in cases where the concrete operational student recalls an algorithm for problems of this kind and applies it without reasoning of any kind.

Apart from my reservations about the validity of group tests of intellectual development, I worry about why chemistry teachers want to identify concrete students at the beginning of the term.

Perhaps people want to sort students, placing some in "slow" classes and others in "fast" classes. This may have merit, but certainly one would want to consider factors such as reading ability, existing knowledge of chemical facts, and knowledge of mathematics skills in addition to intellectual development. I suspect that measures such as SAT and the

Toledo Chemistry Exam are just as useful for screening purposes as a test of intellectual development.

Perhaps people want to identify students at the concrete operational level so that they can help them. Good! But do you need a screening test to do this? I am not sure that you do. I really make no attempt to classify students as concrete or formal, but do try to identify instances of concrete operational thought through informal discussion. When I find that students have difficulty with problems involving proportional reasoning, I go to them during lab or some other convenient time and ask them to tell me how they went about solving the problem. I may give them another problem or two and ask them to talk out loud as they try to solve the problem. Knowing the characteristic reasoning that I am looking for, I believe that I soon get a fairly good reading of the student's ability to use proportional reasoning. I emphasize that this gives me a reading on their ability to do proportional reasoning because there are other aspects of formal reasoning that they may use even though they don't use proportional reasoning. The converse, of course, is also true. From the point of view of the classroom teacher, I am not sure that a gross classification of students as formal or concrete is what we need. Rather, we need to know if they are comfortable with hypothetico-deductive reasoning (what we normally call "scientific reasoning"), if they habitually think in terms of all possibilities, if they systematically examine all possibilities, if they see the logical necessity of "all other things being equal," if they use proportional reasoning, and so forth. I believe that I get a satisfactory reading on these separate issues through informal contact in the laboratory, in reading laboratory reports, in reading responses to essay questions, in discussing homework problems with students, and through informal class discussions. I would emphasize, however, that in order to do this, one needs to be familiar with the characteristics of formal and concrete operational thought and give some attention to the reasoning that students seem to be using in striving at their responses rather than just saying, "Look what that stupid kid said! How can he be so dumb!"

2. Let me now move to another point that concerns me. I think that many chemists who have developed a recent interest in Piaget for incorrect or incomplete notions about what is meant by concrete operational thought. For example, I was recently talking to a chemist who seemed to equate concrete operational students with students who do things well with their hands but not with their heads. This represents a gross misunderstanding of the idea. Piaget is talking about intellectual development, not psychomotor development. A concrete operational student may or may not be good with his hands. The distinction is in the reasoning that the student uses and their ability to go beyond actual experience

and reason in terms of what has not been experienced.

This latter point was illustrated rather nicely by a comment made by Jane Copes in describing some questions that she uses to see how students are thinking. (1) I do not recall the whole story but it involves a turtle that can fly a certain distance in one time and a rabbit that can fly a different distance in another time; students being asked to tell which flys faster or, if they cannot solve the problem, to explain why. Some students respond that the problem cannot be solved because turtles and rabbits cannot fly. Such a response represents a rather profound inability to divorce oneself from experience and operate in the realm of possibility. Most college students that I work with seem to be beyond this point but it does illustrate the problem.

In discussing an experiment in which students add zinc to a fixed amount of hydrochloric acid and collect the zinc chloride produced, concrete operational students may have difficulty in seeing what would happen if they had added more and more zinc to the fixed amount of HCl or added more and more HCl to a fixed amount of ainc. They need to see it happen -- or at least see the results obtained when other students in the class do the experiment under these hypothesized conditions. Formal operational students more easily divorce themselves from the world of "what I actually saw happen" and operate in the world of "if I did this, what effect would it have on what I saw happen."

I have already mentioned that the logic commonly used by concrete operational students is one of seriation and correspondence. I can think of no better way to illustrate this than with an anecdote from a class that I taught a few years ago. In that class we were doing an experiment on linear expansion as a function of temperature. The apparatus had a rod laying on a needle with a cardboard disk attached. As the rod expanded, it rolled the needle and caused the cardboard disk to rotate. A rotation of 360° would correspond to a linear expansion of the rod equivalent to twice the circumference of the needle. Students had no difficulty in seeing this. In the experiment, typical expansion caused a rotation of 5° and the problem was to find the change in length of the rod. Many students proceeded as follows:

If 360° corresponds to .20 cm (twice the circumference of the needle)
then 180° corresponds to .10 cm
90° corresponds to .05 cm
45° corresponds to .025 cm
22.5° corresponds to .0125 cm
11.25° corresponds to .00625 cm
5.625° corresponds to .003125 cm

so the rod expanded a little less than .003125 cm. I would say about .003 cm.

Here the student obtained a *series* of *corresponding* values by successive division by 2 and arrived at an answer that was perfectly satisfactory to them. The answer that they got was close enough. Indeed, I expect that in virtually any everyday application of proportional reasoning, this procedure *would* provide an answer that is close enough. It isn't close enough for science, however, and the strategy is certainly not as universally applicable as the proportional one that we would use to arrive at the answer of 2.8 x 10^{-3} cm.

Now to make another point. A formal operational student *might* solve this problem in exactly the same way; particularly if the experience is entirely new to the student.* There are two reasons for this; one is that we tend to use reasoning that we have used successfully in the past and the other is that we always need to describe and order experience (concrete reasoning) before we explain experience (formal reasoning).

To illustrate, consider the basketball player who has just learned to shoot left-handed crip shots. In the beginning it is awkward and uncomfortable. He can do it but it is easier to shoot right-handed. He will often revert to shooting right-handed crip shots when a left-handed shot is more appropriate. In similar fashion, when a student begins to use formal reasoning, it is awkward. Under stress, the student is likely to revert to concrete reasoning which the student has practiced repeatedly, even in cases where formal reasoning is more appropriate.

When the student is plowing unfamiliar ground, as students were in the linear expansion experiment that I described, it is always necessary to describe and order experience before explaining it or manipulating the information obtained from that experience in a formal way. The seriation and correspondence strategy that I described earlier may be used by a student to get a clear idea of how the expansion of the rod is related to the rotation of the carboard disk. It may even be a necessary step before the student can use the proportional reasoning that we would use to solve the problem.

The difference, then, between the formal student and the concrete student is that after describing and ordering the experience using concrete operational thought, the formal student will be able to understand the strategy for solving the problem which employs proportional reasoning when it is pointed out. He will probably adopt this formal strategy for solving similar problems because of its obvious advantages. The concrete operational student will *not* see the proportional reasoning inherent in the formal strategy and will either avoid using it because it doesn't make sense or will memorize the algorithm which the instructor *insists* that he learn and apply (or misapply) the algorithm *blindly*.

* For further discussion on this point see Piaget[11]

I have already said that formal operational students see the logical necessity of "all other things being equal"; i.e., they control variables in an experiment. Concrete operational students generally do not do this. Some people seem to be confused about what this means in practice. Let me see if I can clarify, using more anecdotes.

This past summer I taught a class for elementary school teachers in which they were asked to design and carry out a simple experiment. One of the students -- one that I have reason to believe was formal operational but rather ignorant about science -- decided to investigate the question of why hot water freezes faster than cold water. (It really does, you know, if conditions are wrong.) He placed 500 ml of tap water in one plastic container and 500 ml of boiling water in an identical container and placed them in the freezing compartment of the refrigerator, going back periodically to see when the water froze. He found that the hot water did freeze sooner than the cold water. He also observed that the level of the water in the container of "hot" water was lower than the level in the container of "cold" water, but really didn't know what to make of the observation. Eventually, through considerable discussion and reading, it became obvious to the student that he had not controlled some variables. Does this mean that he was not operating at the formal operational level? I don't think so. He saw the logical necessity of "all other things being equal" and did control all variables he knew were important, but he was ignorant of the fact that the density of water is a function of temperature, that evaporation results in a considerable loss of heat, and several other salient facts. Once he was aware of these variables, he knew that he had to control them and proceeded to do so. Even though he was capable of formal thought, he did not originally design a controlled experiment. Experienced scientists are just as guilty and for the same reasons.

In contrast, another student -- one that I believe operated at the concrete level -- decided to investigate a burning candle. He placed a candle under a jar and measured the time that it burned. He then relit the candle and placed it under jars of different sizes, again measuring the time the candle burned. Important variables were apparently controled and the student seemed to be conscious of the need to use the same candle, place the jar over the candle in the same way, and so forth. Then does the fact that the student controlled variables indicate that he was using formal operational thought? Not necessarily. Concrete operational students are likely to control variables if the number of variables to be controlled are few (say one or two) and if previous experience has produced evidence that the variable matters. However, they are likely to focus on <u>one</u> variable that they believe will have an effect while they ignore other variables <u>that they believe will have an effect</u>. This student, for example, indicated in our conversations that he thought that the height of the candle might affect the time that it burned and that the kind of wick in the candle might matter and that the thickness of the candle could be important. He then proceeded to test the possibility that the length of the candle was an important variable by observing the burning of a short candle and a long candle. But it happened that the short candle that was available was a fat one used in a warmer for a tea pot and the long candle that was available was a birthday candle. As he focused attention on the variable of interest, he ignored other variables that he knew could be important. The logical necessity of "all other things being equal" was really not apparent in any meaningful way. I believe that further evidence of this student's failure to use formal reasoning was evident in his conclusion that "the candle burns longer in the large jar than in the small jar because there is more oxygen in the large jar." The propensity of students to give inferences as conclusions is, in my judgment, due to their inability to examine alternative explanations. Based on their past experience (in this case, something the student had been told) they arrive at answers that seem plausible and conclude that this must be the answer. Once such students arrive at such explanations - often by considering only part of the data - they are reluctant to abandon them and consider other possibilities. They have a solution that is consistent with what they know. It constitutes a kind of reality which they are reluctant to abandon for an exploration of the unreal world of possibilities. Even when someone suggests other possibilities, they are likely to respond as this student responded repeatedly, "But it is because the candle burns up the oxygen that it goes out. I don't see the point of your saying that I didn't observe that oxygen was being consumed in my experiment."

3. Earlier I mentioned that a student who is capable of using formal operational thought may not do so. I would like to elaborate on this in discussing a third point where I think there is confusion.

Some people seem to believe that once a student has reached the stage of formal operational thought that there is no problem in using abstract discussions of new ideas without concrete experiences such as demonstrations, illustrations, diagrams, and laboratory experiments. Physical chemists are notoriously bad at this. They go merrily on their way explaining thermodynamics, equilibrium, and chemical bonding with complex equations and ideal systems that exist only in one's imagination. Since advanced chemistry students are almost certain to be capable of formal thought, they really see no problem with this. There is.

Piaget argues that everyone reverts to concrete operational or preoperational thought whenever they encounter a new area. Before one can reason with hypotheses and deductions based on experience, there must be a sound descriptive base which has been put in order. All of us have seen evidence of this need for concrete referents in order to provide meaning to formal, abstract discussions. How many times have you listened to someone explain a new idea, been confused, and asked, "Can you give me an example?" After you see the application of the idea in one or two concrete instances, you are able to proceed to theoretical discussions but you need the concrete experience before the theory takes on meaning.

I believe that you will agree that Linda Fowler's video tapes have helped you understand what is meant by concrete and formal operational thought; I hope that some of my anecdotes have done the same. I don't think that the video tapes helped me very much. At this point, I am sufficiently conversant with Piaget's ideas that I can usually operate without the concrete experience but this was not so in the beginning. I must constantly remind myself of that fact when I am talking to people about Piaget or I end up talking about meaningless abstractions. We are guilty of doing the same thing when we teach chemistry students. Because we are at the point that the concrete experience is superfluous, we tend to forget that it was not always so and in our rush to "cover the material", we omit the very kind of experiences that can make our subject meaningful to beginning students.

I have taken two courses in chemical thermodynamics during my education. I made suitable grades in both but I did it my memorizing a lot of meaningless equations and algorithms which I applied blindly to a large number of problems without ever seeing any relationship between these problems and real chemical systems. Although all of my physical chemistry colleagues seem to disagree, I don't think that this was necessary. I believe that, had they taken the time and energy to develop some suitable demonstrations or showed films of actual thermodynamic experiments and developed their idealized models in that context, I might have understood what they were trying to tell me. As it is, I still don't understand all that I know about thermodynamics!

Let me make one additional point about the value of using concrete operational reasoning and concrete referents in developing new ideas. The point is that, by doing so, we may be able to get concrete operational students to believe that a formal procedure is correct even though they do not understand why it is correct. This, in itself, gives more meaning to what we try to teach.

Do any of you have students who do not really know what we mean by area or volume? I do and think that I know why. It is because area and volume are generally taught as formal algorithms, assuming that the student already understands what the algorithm produces and why. Students in math class are taught that the area of a rectangle is length times width and that the answer is in square units. Now I contend that it is not immediately obvious that multiplying one length by another length will tell you the number of squares that are required to cover a surface. In fact, it is not even obvious that when one writes 100 ft^2 as the area of a floor that the meaning is that it would take 100 squares measuring 1 foot on a side to cover the surface of the floor. Some students never see this. In the class that I taught this summer for elementary teachers -- students like those that many of you have in your classes -- 3 out of 4 thought that when they used the formula A = LxW, to get area they were finding out something about the distance around the surface. I think that this class was atypical since I have not observed that much confusion in other classes but the problem certainly exists.

Area can be taught in a purely concrete manner. Using graph paper or square tiles that students can lay on a surface, the concept can be presented as the number of squares that are needed to cover the surface. Students can count the tiles or squares on the graph paper to see how many squares are required. They can then be shown that the counting can be done through a shorthand procedure summarized by the formula, A = LxW. They can rearrange the tiles into different rectangular shapes and see that the formula always works. Even if they are unable to see why the formula produces the same result as counting, they can come to believe that it does. They can then accept the formula as a useful algorithm -- which is all that it is -- and know what the product actually represents. Similar arguments pertain to the concept of volume.

Let me give another example that is closer to the hearts of chemists. In discussing equilibrium calculations you are faced with the problem of determining the concentration of various species in a 0.1 M solution of acetic acid or other weak electrolyte. The typical procedure goes something like this:

> Let x represent the amount of electrolyte that dissociates. Then the concentration of undissociated molecules will be 0.1 - x and we can write the following expression:
>
> $$k = \frac{x^2}{0.1 - x}$$

We can then solve the expression for x if we know the value for k (and we always do or we wouldn't be working the problem). So far we have only applied an algorithm that has been memorized and there is no difficulty but at this point we want to take a shortcut. (Chemists are notoriously lazy and avoid all unnecessary effort). We say something like, "Since x will be small compared to 0.1, we can ignore it and solve the equation for x by taking the square root." Can any beginning student see why this is true? I contend that it is not obvious and that it cannot be made obvious to any student who does not have a high degree of mathematical sophistication and who does not operate comfortably at the formal operational level.

There is concrete strategy that can be used to convince the student that the approximation is ligitimate in most cases and even lead the student to predict when he had better not rely on the approximation. What I do is have students do a series of calculations in class. (With pocket calculators, it can be done rather quickly.) One group of students does the calculation using the quadratic formula while another group does the same calculation using the suggested approximation. They get the same result. We then repeat the process using initial concentrations of .01 M, .001 M, and so forth. They then see that the approximation is rather good until the initial concentration approaches the value of the equilibrium constant. Students do not see <u>why</u> the approximation works using this procedure but they <u>do</u> gain faith that it is ligitimate and are confident in using it. I am sure that there are other areas in which such concrete strategies could be used to provide students with more confidence and understanding of what we are trying to teach. As teachers, we should be looking for places to use such strategies.

Now let me turn to a discussion of illustrations and analogies. Most teachers are convinced that illustrations help students at the concrete level understand difficult concepts and they do. However, it is easy to confuse illustrations with analogies and I am not convinced that analogies are particularly helpful to concrete operational students even though I believe that they <u>are</u> helpful to formal operational students. My contention, essentially, is that analogies require formal thought.

What do I mean by illustrations and analogies? Well, if you say that a base will turn phenolphthalene pink and add the phenolphthalene to solutions containing a base to show this, you are providing an illustration. You might also illustrate that adding an acid can restore the colorless solution. The CHEM Study film on Molecular Spectroscopy provides a beautiful illustration of constructive and destructive interference when some oscillating energy source interacts with molecular models connected by loose springs. It is clear from the film that at certain frequencies, the physical model absorbs vibrational energy. As the frequency of the energy source increases, the vibration of the model ceases until some other natural mode of vibration for the model is reached, at which point the model again vibrates. It is a beautiful illustration of the principle that energy from some oscillating source will be absorbed by a physical system when the frequency of oscillation of the source is the same as the natural frequency of vibration of the physical system.

At this point, the illustration observed in the CHEM Study film turns into an <u>analogy</u> because the whole point of the illustration is to provide a physical analogue of molecules interacting with light. The purpose of the film is to "explain" why certain molecules absorb light at one frequency while other molecules absorb light at another frequency; i.e., to explain the principle of molecular spectroscopy. I am convinced that this analogy -- i.e., the use of a physical system to model the hypothesized behavior of molecules interacting with light -- is very helpful to students who are at formal operational level. They see the form of the logic used in explaining the behavior of the physical system and they can apply this same logical form to the imaginary world of molecules. Not so, I believe, for concrete operational students. They see that the energy is absorbed by the models in the physical system all right, but they are unable to abstract from that illustration the form of the logic inherent in it and then apply that same logic to some imaginary system far beyond their experience.

What I have just said about the spectroscopy analogy being lost on students who are at the concrete operational level is pure speculation. I believe it to be the case, but I haven't really explored that hypothesis with students. I have used other analogies, however, and I am convinced from those experiences that the analogies have very limited value in teaching concrete operational students.

Let us look at a simple problem involving the mole concept. The problem is this: "One mole of sodium weighs 23 grams. How many moles are there in 126 grams?" The problem involves proportional reasoning of a simple sort but it causes problems for many students. In working with students who have difficulty with such problems, I often use an analogy such as this: "One dozen eggs cost 60 cents. How many dozen can you buy for $6.00?" Most students can do this one. I then ask the same question but change the numbers so that it cannot be solved intuitively: e.g., "How many dozen eggs can you buy for $4.50?" This will stump some students and we then go back to the first problem to see if the student can figure out the form of the logic that he used intuitively. If he can't, I try to show him what it is and we then apply it to the next problem. When the student is confident of the procedure for the egg problems, we return to the mole problem. The form of the logic is identical. The wording is as nearly identical as possible. It is clearly an analogous mathematical problem; at least the analogy is clear to me. It is seldom clear to these students. If the analogy helps, it is not obvious during the discussion.

The most elaborate analogy that I have used is one in which I use nuts and bolts to represent atoms. I get the actual weights of the nuts and bolts, give them symbols; Hx for hex nut, Sq for square nuts, Bo for short bolts, and Bl for long bolt. We get a relative weight scale for these nut-and-bolt "atoms" and show that the relative weight of that "element" expressed in any mass unit (I use kilograms) will contain the same number of "atoms". Eventually we go into the laboratory, the students make nut and bolt molecules, note the formula, weigh the amount of each "element" in the compound, divide that weight by the relative weight of the atom, and proceed to find the empirical formula. They are surprised to find that it is the same as the formula of the compound that they originally made. I then give the student an envelope containing some unknown number of nut-and-bolt molecules of unknown formula. The student is given the mass of one of the "elements" in the compound, weighs the envelope and subtracts to get the mass of the other "element", and proceeds to calculate the empirical formula of this unknown nut and bolt compound. He then has permission to open the envelope to check his answer. The following week we do an experiment to find the empirical formula of zinc chloride. The procedures followed in the two experiments are analogous from a logical point of view. Most of the students in the remedial course that I am teaching see no relation between the two experiments. Why? Although I am not sure, conversations with students during the course of these activities give me a clue. We work quite a bit with the nuts and bolts, using them to represent atoms and molecules. However, many students seem unable to view them as atoms and molecules. To them, they are nuts and bolts; no more, no less. The difficulty that these students seem to have in using physical models as representations of some microscopic particle probably explains their difficulty in seeing the relationship between the two experiments. To them, apparently, one experiment is about nuts and bolts; the other experiment is about chemicals.

4. This leads me to my fourth point. Some people seem to believe that so long as we illustrate concepts such as atom or molecule with concrete objects, the concepts will become clear to students. This just doesn't seem to be the case. The models that we use are, in effect, analogies. So long as the student's thought processes are tied very closely to concrete experience he is likely to see the models that we use as just that, models. What we want him to do is imagine the atoms and molecules which the models are intended to represent. I would certainly not want to suggest that models are of no value. I actually think that they are of considerable value. The more the better, but I am not convinced that students develop the concepts that we are trying to get them to see. Rather, I am inclined to think that to them, the model <u>is</u> the atom or the molecule.

5. The last point that I would like to discuss is something for which I may be to blame. In the article on "Piaget for Chemists," I suggested that there may be some s students at the concrete operational level who should be left there; that the effort required to get them to operate at the formal level may be more than we or they are willing to expend and that the chemical facts that they need to know may be such that they could be taught at the concrete level.

Since writing "Piaget for Chemists" I have talked to several teachers -- mostly high school teachers -- who have reasoned that since 50% or more of their students are likely to operate at the concrete operational level, they should design their course so that there is no need for formal operational thought. After all, it isn't fair to ask students to do something that they are not capable of doing.

Even though I do believe that there may be circumstances in which one should design the course to minimize the need for formal thought, this reasoning frightens me. It seems to me to be a little like a basketball coach noting that his new team members aren't very good at dribbling or passing and deciding that he should design his training program so that there is never any need for the players to dribble or pass. In that way they can all be successful and happy. Unfortunately, basketball really isn't basketball without passing and dribbling and science really isn't science if we never use abstractions, never think in terms of possibilities, never recognize the logical necessity of "all other things being equal", never learn to use proportional reasoning, and all of the other logical processes associated with formal thought.

I have little faith that a person will learn to dribble or pass if he is never asked to dribble or pass; likewise, I see little reason to believe that a person will develop the logic associated with formal operational thought if he is never asked to use that logic. Still, one would not begin to teach a person to dribble or pass with some complex drill involving these skills put together in some intricate pattern. One simply must get the feel of the ball first; toss it from hand to hand, bounce it a few times, bounce it from one hand to another, and so forth. It will take time and it will take practice and it will take encouragement. It seems to me that this applies to any development of a complex set of skills. It may, in addition, require maturation.

Few two year olds seem able to dribble even after much practice. Few students below the age of 12 seem able to use formal thought even after much practice. It seems to me that, rather than try to eliminate the need for formal thought, we need to design our curricula so that there are many opportunities for students to use formal thought. These opportunities should be interspersed with a lot of concrete experience and the concrete experience should support those activities that require formal thought. We should design the curriculum so that we return frequently to the same kind of formal operational thought in new contexts and we should constantly encourage the student's faltering efforts.

I don't think that we know how to do what I am suggesting. We need a great deal of research on this question in order to learn the mix of formal and concrete activities to be included in courses. We need research to tell us strategies that will help students develop the skills inherent in formal operational thought, just as the coach needs to know drills that help players develop dribbling and passing skill. We need to know more about the number of students who will be able, in a reasonable length of time, to develop those skills only to the level needed for "avocational activities".

Piaget's theory postulates that intellectual development occurs through a process of "self-regulation" which requires concrete experience, social interaction, and maturation. Based on these ideas contained in the theory, it is possible to hypothesize some teaching strategies that seem likely to help students develop formal thought. Some of these hypotheses are being advanced and tested.

A paper by Lawson and Wollman[8] describes homework problems that might be used to promote self-regulation. To my knowledge there has been no empirical test to show that the strategy actually works but it appears that it should.

Arnold Aarons has developed a physical science course for elementary teachers that we have used at Purdue and our experience provides hints that the strategies used in that course help some students develop formal thought.

Lawson and others[4,7] have tested a strategy to teach students to control variables and has been working on a strategy to develop proportional reasoning[6] and, again, the results are somewhat promising.

I have reason to believe that some of the activities that I use in my remedial course at Purdue are beginning to be effective.

We have a long way to go before we will know how to teach chemistry so that it is understandable to all students. Piaget's theory provides a framework for understanding the difficulties that some students have with our subject and I believe that all science teachers should be aware of that theory. If it does not eventually show us how to lead students to the promised land of understanding, it can at least guide us to give comfort to those in the hell of ignorance, confusion and frustration.

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The Comprehension of Chemical Concepts and its Relationship to the Development of Cognition as Defined by Piaget

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We have all seen students that have experienced difficulty in understanding chemistry concepts. Jean Piaget, the Swiss psychologist, has formulated a theory of cognitive development that seems to explain some of the problems that students encounter in studying chemistry. His theory helps to explain WHY many students have trouble learning chemistry concepts.

There may be a relationship between cognitive development and the ability to conceptualize chemistry. Gagné explains cognition as a hierarchy with eight types of human learning (Gagné, 1970). Bruner describes perceptual and conceptual modes of categorization (Lefrancois, 1972). Cognition is also classified using Bloom's taxonomy of the cognitive domain (Bloom, 1956). Piaget explains the stages of his intellectual development model as the emergence of new structures at certain age levels (Renner, Stafford, Ragan, 1973). All these theories describe essentially the same development. The Piagetian theory is used here because its method of measurement uses physical science principles as the basis of the diagnostic tasks. The Piagetian tasks, therefore, relate well to understanding in chemistry. This paper will explain Piaget's theory of cognitive development and why the application of this theory to chemistry teaching will help insure greater success for your students.

Overview of Piaget's Theory

According to Piaget, individuals advance through four levels of cognitive development in a hierarchial manner. These stages are the sensori-motor, preoperational, concrete operational and formal operational. All levels are inferred by observing and analyzing the responses of the child to a task or problem. The division of one's cognitive development into main stages is based on the character of the actions that link the subject to the surrounding world. Each stage is identified by the appearance of groups or transformations of thought processes called cognitive constants. Cognitive constants include concepts such as object permanence (even though an object isn't actually seen, it still exists) and conservation. One premise of Piaget's theory is the hierarchial development from one stage to another. Most individuals undergo intellectual development and advance from one stage to another. It takes some people longer than others to go through the developmental sequence, but no stages can be skipped.

Stages of Cognitive Development

The first stage of Piaget's theory of cognitive development is characterized by the coordination of perceptual and motor functions and the ability to form a generalized behavior for dealing with external objects. Pretending behavior is apparent during this stage. The Sensori-motor stage covers the period from birth to about two years.

The second stage includes learning a spoken language which is a specific manifestation of representing the external world by symbols. Reactions are intuitive and, therefore, there is little reasoning by implication. The child is simple-goal directed which is shown by trial and error. There is no operational reversibility in thought and action. Children who are functioning at this level of development have problems in expressing the order of events, explaining relationships like cause and effect, understanding numbers and their relations and understanding and remembering rules.

If a child at this stage is shown a 100 ml graduated cylinder and a 100 ml beaker both filled to the 100 ml mark with water, he will insist that the graduate holds more water. This individual cannot be convinced of the conservation of volume concept even if he sees the water being poured from one container to the other. If the child is shown a pencil held vertically on a table and then allowed to fall, this child would not be able to order pictures of the positions of the falling pencil. According to Piaget, the preoperational stage is usually found in children from about 2 1/2 to about 7 or 8 years.

The third stage represents a more flexible and comprehensive system of thought. It is characterized by the ability to reverse concepts and perform elementary logical operations. Concrete operational cognition means that the child can think in a logically coherent manner about objects that DO exist and have real properties. He can think about actions that are possible with these real objects. He can organize experiences into a consistent whole and make rational sense of this experience. He can make classifications and arrangements and is able to conserve and reverse operations on the classifications. He can perform some mental operations when asked verbal questions or when manipulating objects. The actual presence of objects is preferable for clarification but is not a required condition. Performance at the concrete operational stage of cognitive development limits the student to solving tangible problems. He must deal with each problem in isolation. His operations are not coordinated. He cannot integrate solutions with general theories. He can solve problems of a given type as long as he has a definite example to follow, but he cannot think beyond this example. Analogies have little meaning and are often confusing. If a student at this stage is shown the two containers, beaker and graduate, with 100 ml of water, he may or may not be able to conceive that the volumes are equal. But, if he were to have the concrete experience of seeing the liquid being poured from one container to the other, he would understand that the volumes are equal. He can reconstruct the falling pencil situation. This concrete operational stage is usually found from the ages of 7 or 8 to about 11 or 12 years.

According to Piaget's theory of cognitive development, the highest stage is the one which uses formal operations. There is an easy reversal of direction between reality and possibility. At this stage of mental development, an adequate notion of experimentation emerges. An event can be conceived of from different perspectives simultaneously. The formal operational stage can be characterized by scientific reasoning, hypothesis formation and testing, and reflects a true understanding of causation. The individual can use combinatorial thought, solve complex verbal problems, conceive of hypothetical problems and apply proportional logic. They are able to measure and utilize quantities that are not observed directly such as heat of reaction and make derivations of rules or laws from general principles. They can utilize analogous thought. Mental models make sense.

An individual who has developed to the formal stage of operations can conceive of the two containers and the volume of liquid in the graduate and beaker mentally and is sure that the volumes are equal. The falling pencil sequence is manifested as a cause and effect situation. In essense, once the formal operational stage has been reached, "...the content of a problem has at last been subordinated to the form of the relations within it." (Phillips, 1969, p. 104) According to Piaget, the formal operational stage is attained at about 12 to 15 years of age. However, the sample Piaget used in his investigations was small, from an elite socioeconomic background and were European. It is unwarrented to expect this sample to be generalizable to other populations.

Functionally, both concrete and formal operational stages employ logical operations. The major difference is the larger range of application of logical operations with formal thought. No individual makes the transition from one stage to another as a clean break. Capacities for performing formal operations develop one by one, rather than all at once. It is not unusual to find a person using some concrete and some formal operations within a short time span. It should be expected that the transitional individual, when under stress or in a new situation, will revert to earlier ideas and behaviors. This may be because one has had more experience in the stage of concrete operations.

Piagetian Tasks

The criteria used to distinguish the levels of cognition are based on Piagetian tasks (Inhelder and Piaget, 1958). Piaget used questions that require an explanation in order to study the way children think, By noting consistent patterns in the thinking, Piaget has categorized the four levels of cognitive development. The validation criterian used by Inhelder and Piaget (1958) are based on 75% of the subjects of a given age answering a question in a specific manner. This criterian has been used in most of the studies using the Piagetian tasks (McKinnon and Renner, 1971).

The Piagetian tasks on chemical combinations is a simple one and helps to clarify some differences in the abilities of the concrete operational thinker and the formal operational thinker. We must realize that these are generalizations and tend to oversimplify the cognitive operations. Five containers labeled A through E each containing a colorless liquid are given to the individual. He is also shown a sixth container with a yellow liquid and told that the proper combination of A through E will produce the yellow color.

Students at both the concrete and formal operational levels will start out systematically combining two liquids at a time. When nothing happens, the student at the concrete stage either gives up, combines all five at once or randomly combines liquids. Students at the formal operational stage will systematically test all possible combinations of one, two and three liquids until he reaches the one that works: A x C x E. There is also a major difference in the explanation of the appearance of the yellow color. The student at the concrete operational stage states that the color was within one of the original liquids. The student at the formal developmental stage realizes that the color was produced as a result of the proper combinations of liquids forming a new substance. Be aware that other factors such as motivation and experience can modify reactions and responses.

Implications

The Piagetian tasks have been used to identify populations operating at different levels. In the United States, there is mounting evidence that the advancement from concrete to formal operational may occur later than is indicated by Piaget's studies. See Table 1 below.

Study	Sample	Level of Cognition		
		Concrete	Transitional	Forma
McKinnon and Renner 1971	131 college freshman	50	25	25
Tomlinson - Keasey 1972	89 females ages 11-54	49		51
Renner and Stafford 1972	290 high school students	66	17	14
	44 law students	22		88
Lengel and Buell 1972	20 S's grade 7	55		45
	20 S's grade 9	20		40
	20 S's grade 12	15		85
Chiappetta 1974	15 K-8 female teachers	53		47
Griffiths 1973	Community College freshmen	73		27
	University freshmen	66		34
Herron 1975	143 College freshmen	25	25	50
Lawson and Renner 1975	134 high school biology, chem. and physics students	65	30	5

If the majority of students operate at the concrete level of cognitive development, this should have meaningful implications for chemistry teachers. Chemistry is usually taught in a manner appropriate for students at the level of formal operations. Chemistry syllabi must be scrutinized to isolate and modify teaching techniques that will allow the student at the level of concrete operations (at least 50% of your class) to gain understanding and a measure of success in the chemistry classroom.

The subject of chemistry is composed of many concepts - most of which require abstract reasoning. Students who are not capable of abstract reasoning have problems measuring and understanding quantities that are not observed directly such as density and heats of reaction, using ratio and proportion to solve problems not of a "type" which has been memorized, making derivations of rules or laws from general principles such as the law of conservation of mass, and explaining change in temperature in terms of collision theory. Since it has been shown that many students function at the concrete operational level of cognitive development, the system is forcing failure on students by demanding they master concepts which require formal cognitive development. If topics that require formal operations are taught to students who operate at the concrete level of thought, basically there is little or no learning occurring, or the learning that does occur is inaccurate.

Conclusion

According to Piaget, an individual learns by a process which first integrates new perceptual matter or stimulus events into existing patterns of behavior called assimilation. If the stimulus doesn't fit, he either creates a new cognitive structure or modifies an existing cognitive structure called accommodation. Piaget suggests that an increase in accommodation, assimilation responses will facilitate the student in advancing to a level of higher cognitive operations and cites two methods that can be used in the classroom:

(1) manipulation or doing something with the empirical world

(2) peer group interaction which results in active discussion or debate and allows for reflection upon implications and explanations.

You utilize the first method when you use concrete examples such as demonstrations, films and laboratory exercises in your classes. These are necessary for those students at the concrete operational stage and helpful to ANY student when he is introduced to a new concept.

The second method which permits active participation can be utilized in small groups such as problem solving sessions. If there is a time available for students to work together and discuss problems and laboratory experiments, there are more and varied experiences to help the students in accommodating and ultimately using the new cognitive structures.

Reflect on what has been said about Piaget's theory and problems and questions your students encounter. Do you find any correlations?

Appendix A

The liquids used in the Chemical Combinations Task were:

A 1 N H_2SO_4 B H_2O C H_2O_2 C 0.1 M $K_2S_2O_3$ E 0.1 M KI

Combining A, C, and E_2produced I_2 with some colorless IO^-. The addition of $S_2O_3^{-2}$ causes the I_2 to form I^-.

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Some Thoughts on the Psychology of Chemical Education

W. Robert Kenzie

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A conscious Psychological perspective is necessary if the teacher is to avoid unconsciously imposing his own personal psychology on his students. For the teacher of college chemistry, a variety of options are available, of which two are considered here. One psychological option is to adopt the approach of educational technology, which views the learner as predictably responsive. Then training can be systematically designed, tested for reliability and efficiency, and instituted under relatively controlled conditions. The behavioral objectives of the training program can be disclosed to the student, who can also be informed of what the instruction will consist of, and advised of his ongoing progress. Detailed preplanning allows all concerned to be kept aware of just where things stand. Here, the underlying psychology is positivistic. Its application is typified in the use of instructional hierarchies, which can in principle be extended even to high-level skills such as the planning of laboratory experiments. (Kenzie, 1969).

Another option for the teacher is to attempt to engage the intrinsic motivation of the student, on the assumption that somewhere in the subject matter there exist topics and problems in which every student can become involved as an autonomous inquirer. Then what is needed is a battery of stimulating situations (such as the puzzling laboratory phenomena provided in Jay A. Young's manual, Practice in Thinking) and a teaching methodology that facilitates individual learning but does not direct it (Kenzie, 1973). In this type of program the course of learning cannot be predicted nor can the specific learning outcomes be specified in advance, although generally speaking the student is expected to become more self-directed, and the quality of learning, in comparison to predesigned instruction, is thought to be more"liberal" and more solidly based in personal experience. In such student-directed programs, problems of evaluation are more complex and more subtle.

Actually, neither of these extreme psychological positions is likely to be chosen by most college chemistry teachers. Yet, elements of both positions are commonly encountered. On the one hand, elements or aspects of predesigned instruction are a feature of most technical programs. The teacher of such programs needs to be aware of the psychological assumptions associated with instructional design (whether these are stated in text resources or not). On the other hand, many college chemistry programs include problems for the student that do not have "correct" solutions in a mathematical or authoritative sense, problems that the student is expected to grapple with and find his own way through. Student experience in creating one's own structure is likely to lead to cognitive development of a more thoroughgoing kind than that created by predesigned instruction. The process of attempting to invent scientific knowledge (on some small scale) may thus provide the student with an opportunity for understanding scientific knowledge as human invention.

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SOME SPECIAL PROBLEMS IN CHEMICAL EDUCATION
Chemical Technology for the Undergraduate — A First Step

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two-Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

The Department of Chemistry at the University of Wyoming is in the process of developing a new curriculum for its majors. As originally conceived, this program would include only those individuals who are designated as majors in chemical technology. In actual practice, however, at least in the first year, all individuals who have declared themselves as chemistry majors, be it in the traditional ACS program or the Chemical Technology program, are enrolled in common chemistry courses. While this program includes those aspects which are unique as well as those which have been included in both traditional and experimental chemistry curricula before, the overall concept is different than that one usually expects from a chemistry curriculum. In order to see how these differences have arisen, it is important for us to review the criteria whihc were set forth at the inception of the program. The criteria were numerous. First, the program was designed for a student planning to enter an applied area of the chemical profession, initially with a B.S. degree. It was also felt that it was essential to provide the necessary preparation for that student who chose to go on to graduate work. Second, chemical principles plus application were to be emphasized in the laboratory. A technique once learned was not intended to be dropped until a distant future date, but was intended to be repeated again and again, both in that laboratory and in subsequent laboratories. Above all it was essential that the laboratories should stand by themselves and not merely be an ancillary part of a lecture course. Three, where possible, use of standard methods, industrial methods, and real samples were to be emphasized. Four, it was felt that input and exposure to the chemical industry and other areas of applied chemistry was a necessity. Five, the incorporation of an industrial co-op program was felt to be important. Six, the student should gain a solid core of experience in the first two years with emphasis on analysis and instrumentation. Considerable flexibility was to be retained in the last two years. The reason for the emphasis in the first two years was to provide a basic background for the students in order to allow them to advance to more complex problems in the upper two years. In addition, such a structure would provide the student with the opportunity to develop a saleable skill within the first two years. Seven, it was further felt that students should have marketable skills at any point of our program. You will see later, when we discuss the freshmen chemistry laboratory, that there is a heavy emphasis on us of instrumentation. Consequently, it was felt that with an ea ly emphasis on instrumentation the student, should he or she have to leave school even at the end of the first year, would be in a position to compete favorably in the market for a technician's position. Eight, some emphasis on related areas of engineering, economics, and management was felt to be necessary. Nine, professionalism was to be emphasized throughout the program.

From this has developed the current program. We have a new professional program which is parallel to the existing program with some course overlap. The program meets the minimum ACS recommendations. All our labs are taught by experienced faculty with considerable emphasis being put upon the laboratories being taught by faculty who are currently actively engaged in chemical research. Depending upon the semester, seven to nine faculty members are involved.

As an added attraction, through cooperation with the community colleges in the state we have managed to put together a program which is transferable after two years. This does not mean that in every case the community college program is identical to the University of Wyoming program. Obviously there are differences in facilities, instrumentation, and number of faculty available. But, the same chemical principles are emphasized and the concept of the utilization of instrumentation is emphasized, providing the optimum situation for transferability.

Finally, a summer co-op program is indeed in the process of being constructed, and we have a flexible program in the upper two years.

I will emphasize the form of the program in the first year since this is where my primary involvement occurs. However, initially, I feel that it is essential to describe all four years of the program in order to provide you with an overview. The curriculum for the freshman year is shown in Table I. You will note that at this early stage it includes many aspects that one would find in a traditional college curriculum. Chemistry 303F, labeled Principles of Chemistry, is a course which is duplicated in many universities over the country. It includes the typical content that would be found in any course designed for chemistry majors and consists of one three-hour laboratory plus three hours of lecture. The laboratory in the first semester reflects the principles described in a lecture. The laboratory in the first semester reflects the principles described in a lecture. In the second semester the laboratory emphasizes qualitative analysis. The offering, 305M, is a new course constructed strictly for the program in chemical technology, but does, as I indicated earlier, include all chemistry majors. This course is entitled Basic Laboratory Techniques in the fall, and in the second semester, Chemical Analysis I - Instrumental Methods of Analysis. It consists of one three-hour laboratory per week in the fall semester and one three-hour laboratory combined with a one-hour lecture in the spring semester.

Table I
B.S. in Chemistry and Chemical Technology
Department of Chemistry, University of Wyoming

FRESHMAN YEAR

Fall Semester	Credit Hrs.	Spring Semester	Credit Hrs.
Chem. 303F Principles of Chem.	4	Chem. 303G Chem. of the Ele. (Qual. Analy.)	4
Chem. 305M Basic Lab. Tech.	1	Chem 305M Chem. Analy I (Intro. to Instru. Meth. of Analy.)	2
Chem.591M (elec.) Glassblowing I	1	Computer Sci. 499 Computer Program. for Chem.	2
Math. 311F or 303D Calculus or Alg.	4 or 5	Eng. 301G Fresh. Eng.	3
Eng. 301F Fresh. Eng.	3	Math 311G or 317D[a] Calculus	4 or 5
Pol. Science 305D Gov't. of the US and Wyo.	3		1/2
P.E.	1/2		
	16 1/2-17 1/2		15 1/2-16 1/2

[a] 311FG will be recommended to those with the proper background. Students with a deficiency in algebra will take the 303D-317D sequence.

There are two possible mathematics options, Mathematics311F or 303D. We have decided to retain a flexible requirement for mathematics depending upon the preparation and the goals of the student. If the student's preparation is poor, he will take the algebra course. If his preparation is adequate, he will take the calculus course. As you will note from the Table, the usual offerings of English, political science, and P.E. are retained here. In the second semester a course in computer science is initiated. This course is presently taught by our computer science department and is based around the Fortran language.

Table II describes the program in the second year.

Table II

SOPHOMORE YEAR

Fall Semester	Credit Hrs.	Spring Semester	Credit Hrs.
Chem. 530F Organic Chem I	3	Chem. 530G Org. Chem II	3
Chem 533M Chem Synthesis I	2	Chem. 533M Chem. Synthesis II	3
Chem 524M Chem Analy. II (Quantitative Analy.)	4	Chem. 592M Chem. Analy. III (Problems in applied chem. analysis)	1 - 2
Physics 303F or 321D General Physics or College Physics	4 or 3	Physics 303G or 322D Adv. Gen. Physics. or Ad. Col. Phys.	4 or 3
Math. 511D or Elective Multivariable Calculus	4 - 3	Chem. 591M (elec.) Glassblowing II	1
Chem. 503D Computer Programming for Chemists	2	Industrial Ed. 408D Graphics	2
		Elective (humanities, fine arts or soc. sci.	3
	17 - 18		

Summer Industrial Apprentice Co-op

Here we begin our organic chemistry offerings, Chem 530F and 530G. These are again courses which are typical of those one finds in traditional programs. All majors take these courses. Chemical Synthesis, 533M, is a course which was constructed principally for our program in Chemistry and Chemical Technology, and is unique in that it emphasizes applied organic experiments. Typical of the types of things that are done in this laboratory in the first semester are the isolation and purification of insecticide, isomerization of hexane, hydrogenation of peanut oil, and preparation of a dye. In the second semester of 533M these types of experiments are continued and expanded. Chemistry 524M, Chemical Analysis II, and 529, Chemical Analysis III, are directed to continuing the students' training in quantitative analysis, and then applying those techniques to problems in applied chemical analysis.

At the sophomore level, physics is introduced. And as you can see again we have two levels of physics, physics for those who are mathematically well prepared, and that physics which is for those who are not so well prepared. Computer Programming for Chemists, Chemistry 503D, is placed in the curriculum at this level. This course is designed to introduce the student to both the time sharing and the batch processing aspects of the computer. They are expected to apply the Fortran language to problems which are of direct importance to the chemist. In the second semester, glassblowing is continued and the first of our program related external courses, Industrial Education 408D - Graphics is introduced.

Table III gives you an idea of our program in the junior year.

Table III

JUNIOR YEAR

Fall Semester	Credit Hrs.	Spring Semester	Credit Hrs.
Chem. 652F or 650D Physical Chem. I	3	Chem. 652G or Elec. Phys. Chem. II	3
Chem 624D Chem. Analy. IV (Optical and Elec. methods of analy.)	5	Chem. 626D Chem. Analy.V (Separation Techniques)	3
Chem. 781M (elective) Chem. Syn. III (Advanced syn. methods)	2	Biochem. 625M Biochem. Techniques	2
Elec. Eng. 600F Electronics I	3	Elec. Engr. 600G Electronics II	3
Elective (program related)	0-2	Chem. 600M Seminar	1
Chem. 670D Biol.Chem.	3	Elective (program related)	3
		Elective (humanities, fine arts or soc. sci.)	3
	16-18		18

Summer Industrial Apprentice Co-op

Physical chemistry is introduced again at two levels; 652FG - the more mathematical of the two and 650D - for the individual with perhaps the poorer preparation. Chemistry 624D and 626D are courses in chemical analysis. Chemistry 624D includes various optical and electrical methods of analysis, while 626 emphasizes modern separation techniques. Chemistry 781 is a course in advanced synthetic methods and can be varied to meet the needs of the students. This current semester it is a polymer preparation and characterization course. Also in the fall semester a course in electronics is included and the student is introduced to biological chemistry. In the spring semester biochemistry is continued as is the education in electronics. The spring semester also includes a student seminar, since we maintain a strong conviction that practice in communication is necessary.

Table IV describes our senior year of the program, which as you can see contains many elective hours.

Table IV

SENIOR YEAR

Fall Semester	Credit Hrs.	Spring Semester	Credit Hrs.
Chem 781M Chem. Practice I (Industrial synthesis)	3	Chem. 792M Chem. Practice II (Industrial prob.)	3
Chem. 600M Seminar	1	Biochem. 702D Radiotracer Techniques	3
Electives (program rel.)	4 - 8	Chem. 600M Seminar	1
Electives (Hum., fine arts or social science)	6	Electives (pro. rel.)	4 - 8
		Elec. (Hum. fine arts, or soc. sci.	3
	14 - 15		14 - 15

In the fall semester Chemistry 781 now emphasizes industrial syntheses. This course gives the student an opportunity to attempt, at least on a laboratory size scale or even a pilot plant size scale, industrial syntheses. The seminar program is continued while in the spring semester a course in Industrial Problems is introduced. This course would address itself to problems such as cost analysis and problems that one runs into in scaling up a reaction from the bench to the pilot plant to the production line. It will be also designed to give the students some idea of what the chemical engineer does in the plant.

We introduce radiotracer techniques in the spring semester and continue the student seminar program.

Now to turn our attention back to the freshman course in the Chemical Technology Program - Chemistry 305M. As I indicated earlier, this course was designed to emphasize the use of instrumentation. As it turns out, we attempt to use the most sophisticated instruments in the department in order to familiarize the students with complex instrumentation. In some cases an experiment could be just as easily done with much simpler instruments, and in certain cases could probably be done more efficiently. At upper levels of the program an attempt is made to indicate to the student that the instrument suitable for the measurement is the one to be used and that it is not necessary for every physical measurement to utilize an ultrasophisticated instrument. However, there is a barrier which many students face when it comes to the initial handling of complex instrumentation. Consequently, we feel that, since we have the more sophisticated equipment available, it is in the student's best interest that he be allowed to use this equipment at a very early stage.

Table V

CHEMISTRY 305M - BASIC LABORATORY TECHNIQUES

1. Elementary Physical Properties
   Color, fluorescence, microscopy, solubility, density of liquids by pycnometry, density of solids by flotation and displacement.
2. Chemical Purity
   Fractional crystallization, drying (use of Abderhalden apparatus), % recovery, melting points (use of Thiele tubes, hot stage, Thomas-Hoover apparatus).
3. Separation Techniques: TLC
   Separation of two dyes, use of precoated plates
4. Separation Techniques: TLC
   Preparation of TLC plates, separation of dansylated amino acids, detection by fluorescence.
5. Separation Techniques: Column Chromatography
   Column packing, choice of column material and solvents, separation of same two dyes as in 3, use of spectrophotometer (Cary 14) for quantitative determinations.

6. Introduction to Nuclear Magnetic Resonance
Principles and practice, use of Varian EM-300 in analyzing various knowns, use of Sadtler Index, application of symmetry to nmr, use of Varian HA-100.
7. Introduction to Infrared Spectroscopy
Preparation of mulls, pellets and use of solution cells, care of salt plates, interpretation of IR spectra and application to the determination of structure.
8. Acetylation of Ferrocene
Chemical reaction, use of TLC to determine number of products, purification by column chromatography, introduction to molecular weight determination by vapor pressure osmometry, use of IR, NMR, UV-Visible, and molecular weight to characterize products.
9. Introduction to Mass Spectroscopy
Elementary aspects of mass spectroscopy, use in qualitative and quantitative analysis. Mass spectra of knowns.
10. Identification of Unknowns
Identify simple and complex unknowns using physical methods employed above.

The first experiment, entitled Elementary Physical Properties, is an experiment which is included in an effort to familiarize the student both with the laboratory and with some of the physical properties and materials. The student is introduced to the concept of color - what causes it, fluorescence - what causes it, and that one may utilize a microscope to gain information about crystal shape. Some idea of solubility and why things are soluble in a given solvent and others are not is introduced, and a standard density experiment, the kind found in many chemical curricula is included. The second experiment again is of the more traditional variety except that slightly more sophisticated apparatus is used than one would find in the average freshman laboratory. We have constructed and use drying pistols of the type found in any research laboratory. For melting points, we use not only Thiele tubes, but hot stages and a Thomas-Hoover melting point apparatus. Experiment 3 now begins to emphasize techniques which are not normally seen in a freshman laboratory. Here we introduce the concept of separation techniques, with particular emphasis on, for this experiment, thin layer chromatography. The students separate two dyes using precoated plates. They are given three different types of precoated plates to use - alumina, silica, and cellulose, and are asked to determine which of these plates provides the best separations.

The use of thin layer chromatography is continued in the fourth experiment where the student must prepare a thin layer plate and separate a group of amino acids which have a fluorescence as a detection technique. It also provides them with an opportunity of seeing and actually participating in the preparation of thin layer plates in the event that some time in the future they are required to prepare a plate from a material for which precoates plates are not commercially available. In Experiment 5 we continue with a study of separation techniques introducing column chromatography. In the experiment we cover the concept of column packing, choice of column material and solvents, why certain solvents are chosen, and why certain column materials are preferable given a certain set of compounds which we wish to separate. The students then use a packed column to separate the same two dyes as they encountered in Experiment 3. In Experiment 5 the student is also introduced to the use of the Cary 14 spectrophotometer, and is required to carry out quantitative determinations of the components in the starting material and must use spectrophotometry to determine the percent recovery of the two dyes in the final product.

In Experiment 6 we introduce the concept of nuclear magnetic resonance. A formal introduction is accomplished both through the use of audio-visual aids and faculty lectures. The principles of both the NMR Spectrometer and the nuclear magnetic resonance phenomenon itself is discussed, simple preparation is discussed, and the analysis of NMR spectra is covered in detail. The students are introduced to the use of the Varian EM-300 spectrometer and are required to analyze various knowns using it. He or she is made aware of the Sadtler Index and how it may be utilized. An application of symmetry to NMR problems is emphasized. The student is encouraged to familiarize himself with our Varian HA-100 spectrophotometer, and although at this stage they do not use the machine themselves, they are encouraged to have spectra run on this machine so that they may compare the spectra from the 100 MHz instrument with the 30MHz EM-300. (I might note here, in order to avoid confusion, that one "experiment" may cover several laboratory periods.)

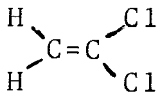
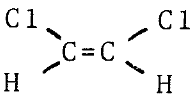
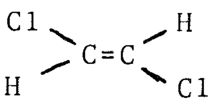
In Experiment 7 the student is introduced to the principles and practice of infrared spectroscopy. After the fundamental principles of vibrational spectra are discussed (in a qualitative way) and the instrumentation demonstrated, the preparation and care of salt plates is discussed and demonstrated. The student is then required to polish his own set of plates. He is then required to learn to prepare proper mulls and pellets using a variety of known samples. The student is also introduced to the use of solution cells. A comparison of the advantages and drawbacks of each type of sampling technique is clearly illustrated in the laboratory. After experimentation with "known" materials is completed, the student is required to identify the functional groups for a series of unknown compounds.

Experiment 8, the Acetylation of Ferrocene, is an experiment used in many organic laboratory courses. We have, however, expanded upon it in order to require the student to utilize the various techniques which he has learned in the previous seven experiments. The chemical reaction is run, then thin layer chromatography is used both to determine the number of products that are present and to determine the number of products that are present and to determine which substrate and which combination of solvents would be best utilized for column chromatography. After separation of the products by column chromatrography, the infrared spectra of the products are recorded and the spectra assigned. Following this the student is required to determine the molecular weight of each compound by vapor pressure osmometry as well as by freezing point depression. This is followed by the recording of the NMR spectra and the investigation of the UV-Visible spectra of both the unpurified reaction product and the pure components.

In our ninth experiment we introduce mass spectroscopy. This is probably the least well-covered technique in our program because of the complexity in the utilization of the technique. The elementary aspects of mass spectroscopy are discussed. Its use in both qualitative and quantitative analysis is covered in some detail. The student obtains the mass spectra of a series of knowns. Here again in the lecture portion of this experiment some audio-visual aids are used.

In Experiment 10 the student is supplied with a series of both simple and complex unknowns. The simple ones are taken first so the student can obtain some background in analyzing an unknown using the techniques that he has learned, and then he is introduced to unknowns which are of quite a complex nature, again being expected to produce the structure of the compound. Although this might seem to be too great a challenge for the student, in actual fact it has worked very well. The students, on their own by this time, are able to sit down and analyze virtually any of the unknowns which are given to them.

By the completion of the second semester the students have gained considerable skill in identifying chemical compounds from their infrared and NMR spectra. An indication of how well developed this ability has become in one year's time can be gained by looking at the final examination given in the spring of 1976. This examination consisted of four questions. The first of these questions was:

> "The compound $C_2H_2Cl_2$ can have three different configurations:
>
> 
>
>
> 
>
>
> 
>
>
> Given the NMR and the IR spectra below, determine which group are the spectra of which compound. Explain your rational."

Both the IR and NMR spectra from the Sadtler Indices were given **for** the 1,1 and the 1,2-trans compounds, but only the IR spectrum was given for the 1,2-cis compound.

In question two the student was again given an infrared and an NMR spectrum and asked:

> "Given that the chemical formula of the compound represented by the spectra below is $C_5H_{10}O_3$, what is the structure of this compound?"

In the third question the student was required to draw the structure of 2,6-xylenol given only the molecular weight and the IR and NMR spectra. In question four the spectra of the various isomers of bromofluorobenzene were presented and the student was asked to relate the various isomers to the appropriate spectra.

While it is perhaps logical to expect a disasterous result from such an examination, the result was, on the contrary, very gratifying. The top performance out of a class of six was 85% while the low grade was 50%. Certainly under normal circumstances a student who received a grade of 50% would be in serious trouble, however given the nature of the examination all parties were satisfied.

I might note in closing that we have found that our approach to the freshman laboratory has been tremendously stimulating to the student. They feel as though they are learning useful skills rather than being involved in "make work". Indeed, many of the students who have completed 305M end up in their second year serving as research personnel in faculty laboratories. In this role they have been quite successful.

Making Chemistry Visible

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

It is not an infrequent occurance for a typical professor of chemistry to be frustrated after a day of trying to teach some, or any chemistry. It is a more frequent occurrence today as a result of the metamorphosis that has taken place in higher education in the United States in the past twenty years. Twenty years ago, the higher education system was an elitist system which catered only to the academically gifted. Note that I did not say the intellectually gifted. Other would-be students were dismissed as being too lazy or too stupid to benefit from higher education. Then, the frenzied desire for growth led to more spaces in the colleges than there were qualified students. To fill the spaces, the colleges and universities have eliminated the last vestiges of elitism that were considered by social theorists to be antithetical to education in a democracy. The well adjusted professor of 1976 has learned to accept the academic heterogeneity of his students and characterizes the tail end of the distribution as a neglected challenge to his ability and integrity as an educator.

As we all know, accepting the challenge and winning the battle are two distinct entities. Our knowledge of the learning process is so meager that we do not have the slightest idea whether failure in the academic environment is the result of the lack of ability of the student, or the lack of ability of the teacher, or even the net result of the entire regulated and regimented process. We professors of chemistry, much in need of bread and board, must view this challenge to our way of life as being capable of solution through improved and imaginative new techniques of teaching. By this I do not mean to send the poor disenchanted students off to converse with inane machines, but the development of techniques that get to the sources of their difficulties. I can pretty much guarantee you that the taxpayers are not going to provide funds for one teacher and one log per student, a la Mark Hopkins, nor will they continue to allow us to lay all the blame on their sons and daughters.

There are four reasons why Johnny and Joanie cannot do chemistry. Reason one, nothing up in the bone box, is certainly true in a few cases, but cannot account for the students that fail chemistry, but do very well in their other studies. Reason two, does not have the prerequisites in mathematics, English, and logic is true in many cases, but when we provide the prerequisites we salvage only a few of the students. Reason three, cannot be motivated, is certainly true in a lot of cases, but we all know that there are a number of highly motivated but highly unsuccessful students. This brings us to reason four, that the material is beyond the cognitive level of the student. While this reason may be something of a tautology, it does offer our only clue to solving our problems. Piagetian studies seem to tell us that only one-third of the population ever advances to the formal operational level. The obvious question to ask is if this is a characteristic of the population, or the result of our educational system? To maintain our jobs we have to believe that this is the result of our failures as teachers. Certainly we would not propose cutting college enrollments to one-third of their value.

It has been suggested by Ausubel that meaningful learning takes place if incoming information can be connected in a meaningful and non-arbitrary manner to the particular cognitive structure of the individual learner. The cognitive structure is the arrangement of concepts, facts, principles, and rules related to the particular subject matter in the individual learner's head. It is an ideational or conceptual framework to which relevant substantive ideas and information can be associated and retained. According to Piaget's studies, concepts in new subject matter have to be demonstrated by concrete empirical facts. All of what is really chemistry, however, is formal logical operations and abstract conceptualization. The only way that we are going to make the abstract imaginary world of chemistry concrete is to make models to represent and to simulate our concepts and our submicroscopic world. It is easy to see why chemistry has relied so much on models and modeling and why an even greater emphasis has to be placed on modeling to match chemical concepts to the cognitive structures of today's students. The use of imaginative modeling is a way to get chemistry across to the students at the concrete operational level without turning off the students that have already crossed over to the formal operational level.

Under the pseudonym of "Crazed Lennie", I have been engaged for the past three years in the process of trying to make chemistry visible; to effect a transmutation of our abstract ideas into concrete models. By the time I retire I hope to have a model for everything I teach in general chemistry. I will now explain some of my favorite models, but I want to remind you that they are just models and are not the real thing. The full appreciation and understanding of chemical concepts requires a stepwise educational process, and conceptual maturity can be prevented by preoccupation with an insufficiently refined model.

The basic construct of the world of make believe that we call chemistry is the atom. Figure I shows a cross-sectional slice of an atom. This model does three things. First, it shows our fuzzy quantum mechanical atom and that there is no definite outer boundary to the atom. Each white dot is one 1250th of the probability of finding the electron. Second, with a radius of one meter and a nucleus of one-tenth millimeter, the model gives the relative sizes of atoms and nuclei. The flip side of the model, shown in Figure II shows the contrast with the Bohr atom with its fixed orbits and its radii that increase with n squared.

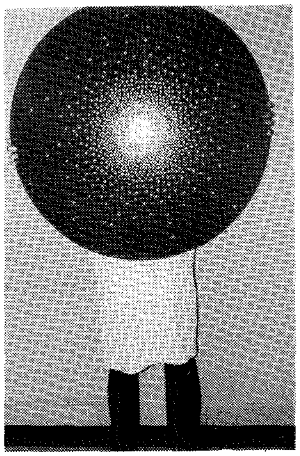

Figure I

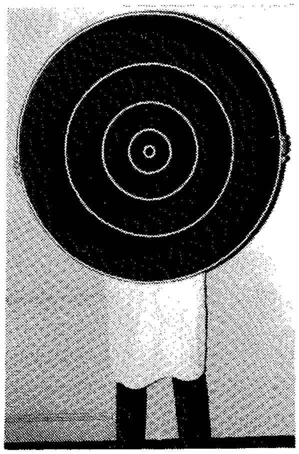

Figure II

One of the pecularities of atoms is their tendency to stick to each other. This may be illustrated by imbedding. A one time, as shown in Figure III, we attributed the bonding of atoms to hooks, but now we have replaced them with fuzzy hooks; if you squint the hooks will become fuzzy. Atoms differ in their masses. Figure IV shows that by assigning a value to the mass of one kind of atom, we can by weighing, arrive at the masses of other atoms.

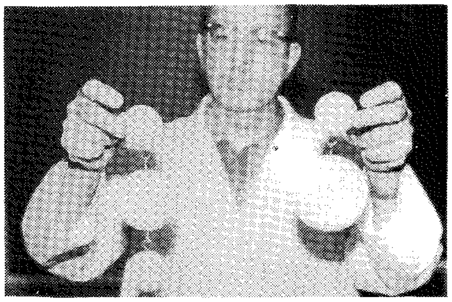

Figure III

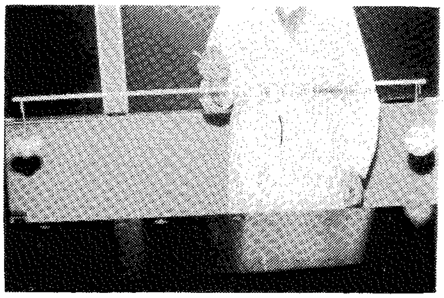

Figure IV

When atoms have only one hook, the molecules will always have a constant composition, but when an atom has more than one hook, it can form compounds with a given other element in more than one atomic ratio. If chemical reactions involve only the making and breaking of hook couplings, then there should be no change of mass in chemical reactions.

A concept of some considerable difficulty to beginning students is that of the equivalent weight. Because of this problem, someone has recently suggested that we abandon this concept. However, I think that this is a situation where my chemistry "by hook or crook" can make a real contribution. The equivalent weight can be defined as the mass of a substance that is required to provide Avogadro's number of hooks. For atoms, two factors are involved, the mass of the atom and the number of hooks per atom. Dividing the mass per atom by the number of hooks per atom will give the mass per hook. Multiplying by Avogadro's number will give the mass per Avogadro's number of hooks. Figure V shows the contribution of mass to equivalent weight and Figure VI the contribution of the number of hooks per atom to the equivalent weight. These are shown on the next page.

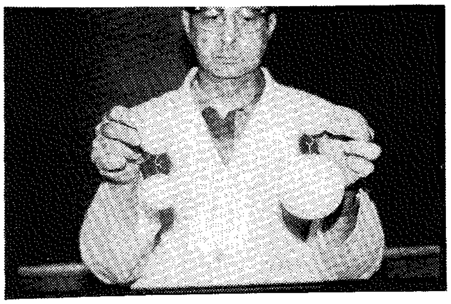

Figure V

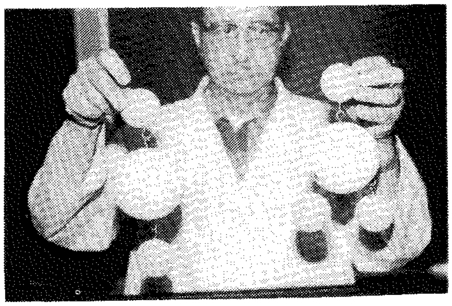

Figure VI

A second major ingredient of our world of make-believe is motion. A molecule undergoing translational motion can be illustrated by throwing balls into the air. Figure VII shows the vibrational motion of a pair of atoms that are bonded together in a molecule. The three components of the rotational motion of a non-linear molecule are modeled in Figures VIII, IX, and X.

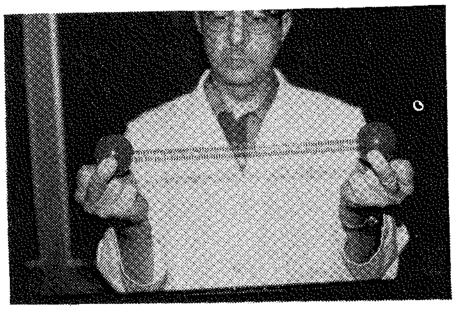

Figure VII

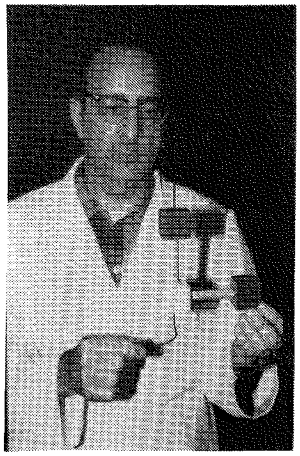

Figure VIII

Figure IX

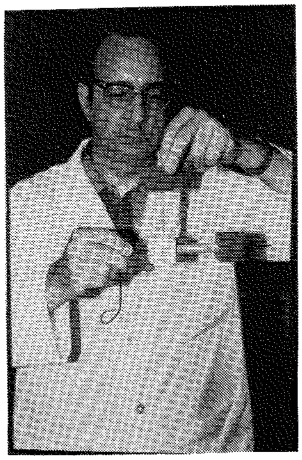

Figure X

The motions of molecules result from the transfer of energy or momentum from other molecules. Figure XI shows that the motion of a little red atom can be increased by being struck by another molecule, that is by the transfer of heat, or as shown in Figure XII by being struck by a baseball bat, that is by the transfer of work.

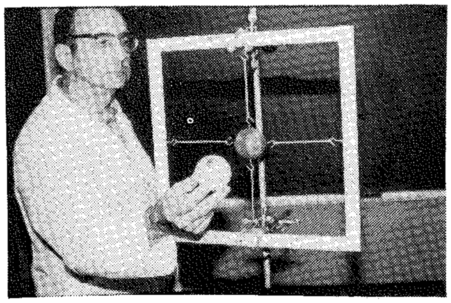

Figure XI

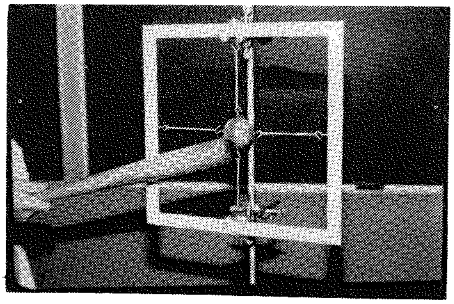

Figure XII

Different substances differ in the amount of energy required to take them to a given temperature. If we define temperature as the intensity of motions of molecules, then Figure XIII shows a way to explain different heat capacities. If the bottom atom is activated as shown while holding the center atom, the intensity of the vibrational motion of the atom is greater than when the center atom is simultaneously released. The greater number of bonds involved in the latter case requires a greater amount of energy to cause them all to vibrate at some specified degree of intensity.

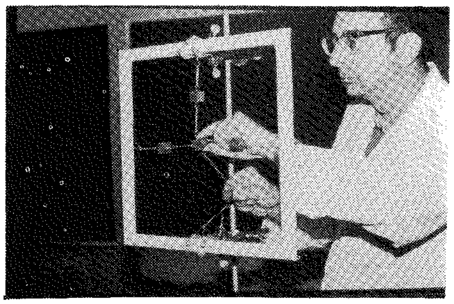

Figure XIII

Figure XIV shows a water analog model to discuss heat, temperature, and heat capacity. Heat can be compared to the water volume, temperature to the water height, and heat capacity to the volume of water required per unit height. In two of the cases the heat capacity is a constant independent of height and in the other two cases it is a function of height.

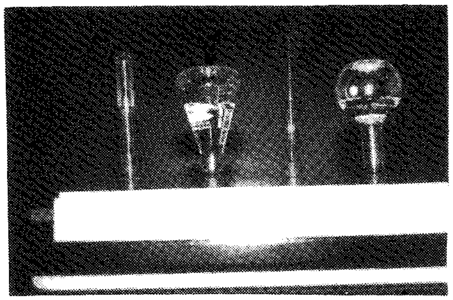

Figure XIV

When molecules have a lot of motion they will occupy all the space in a container and give matter that we refer to as the gaseous physical state. When the motions of molecules are reduced, portions of the molecules can attract each other and they can stick together to form the liquid and solid physical states as shown in Figure XV. Molecules that roll about each other, that is, are not stuck in one spot, give the liquid state simulated in the beaker. When the molecules are stuck in one spot, matter has a fixed shape independent of the container and we have the solid physical state. The two models shown are the models of hexagonal close packing and of cubic close packing of identical spheres.

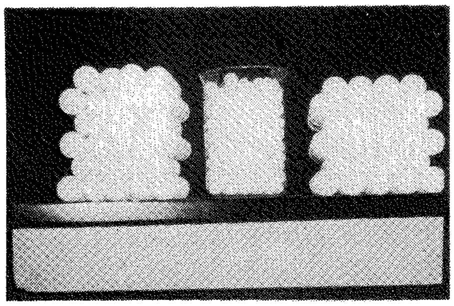

Figure XV

Equilibrium, both with respect to its establishment and with respect to its circumvention, is a major concern of general chemistry courses. Figure XVI shows the L.C. Grotz static equilibrium demonstrator. The balance of forces results in no motion. When the rubber band is cut, thereby destroying the balance, the wooden duck goes a-flying. Please note that a good deal of chemistry is concerned with the destruction of balanced forces.

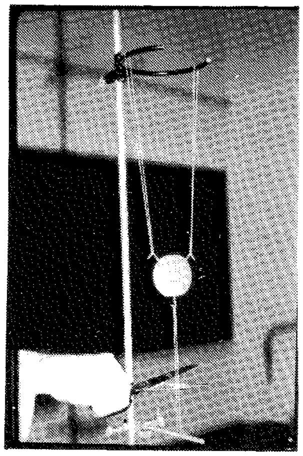

Figure XVI

Figure XVII shows the L.C. Grotz dynamic equilibrium demonstrator. When the rate of the water flow into the tube equals the rate of flow out of the tube, the volume of water in the tube becomes constant. The equilibrium volume of water can be shifted up or down by increasing or decreasing the forward or reverse rates.

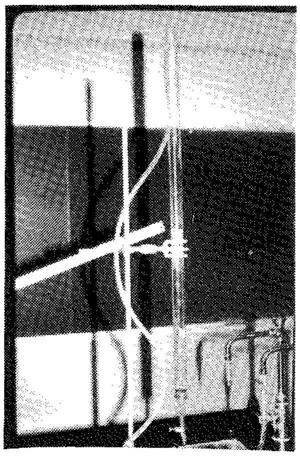

Figure XVII

Like a chemical reaction, an increase in the forward rate results in a concomitant increase in the reverse rate in the establishment of the new position of equilibrium.

A reaction that goes only a small extent can be shifted to completion by the chemical or the physical removal of a product of the reaction. A water analog of this principle is shown in Figure XVIII.

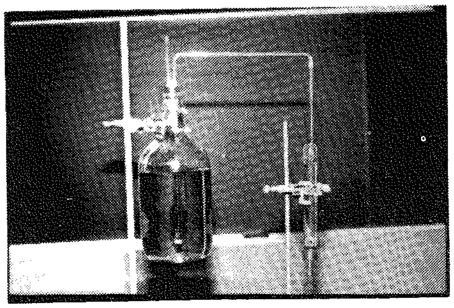

Figure XVIII

After drawing off some water on the product side, the reaction shifts to replace the removed water. The continued removal of product will convert all of the reactant to product. The chemical removal of a product to shift an equilibrium is called the coupling of reactions. A reaction that goes to completion is used to drive an incomplete reaction. Dolls do not spontaneously jump up into the air. But when a fat doll jumps on the other side of the teeter-tooter, as in Figure XIV, that overriding spontaneous process drives the nonspontaneous process.

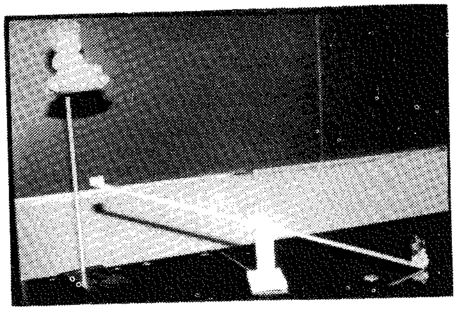

Figure XIV

Figure XX shows a model for the quantization of the energy levels in systems of atomic dimensions. I do not know of anyone who can raise his potential energy by an amount equal to the spaces between the steps of a ladder. However, Figure XXI shows that when the spacings between the energy levels become too small to detect, the quantum mechanical treatment goes over to the classical treatment. This is known as the Law of the plank and has nothing to do with Planck's Law. When your feet are big enough to cover the holes in the plank, then you can raise your potential energy by any amount.

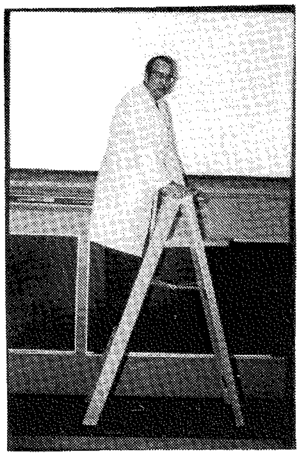

Figure XX

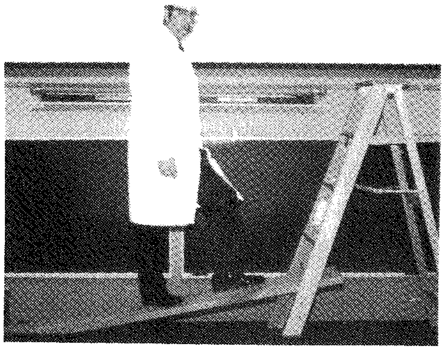

Figure XXI

A pair of inflated balloons can be used as a model to explain how stabilized emulsion droplets can coalesce and become large enough to settle out under the influence of gravity. A sufficiently large impact will distend and rupture the film and allow coalescence to occur.

Figure XXII shows a set of models for discussing the effect of volume on the entropy or disorder of a system. The greater the number of volume slots, the greater is the number of possible ways of arranging the system.

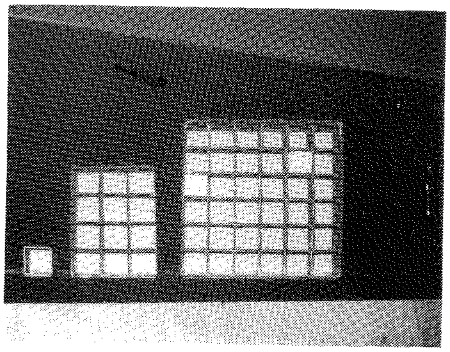

Figure XXII

Figure XXIII is a model to discuss the effect of energy on the entropy or disorder of a system. The wires represent equally spaced energy levels. This figure shows one of the 42 ways that the system can have 10 units of energy and Figure XXIV shows another of the 42 ways.

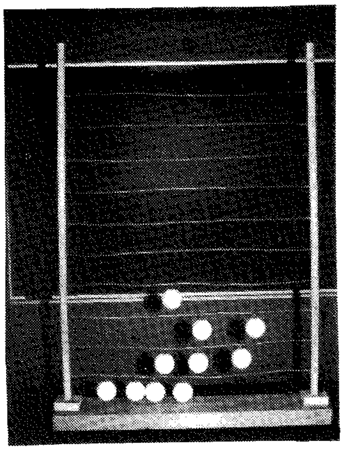

Figure XXIII

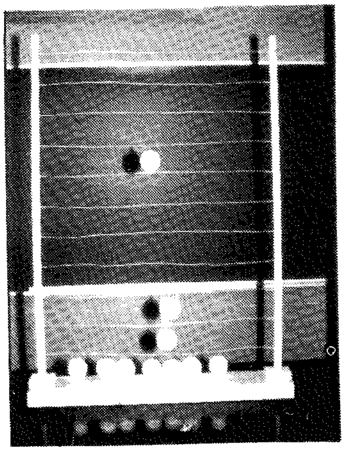

Figure XXIV

Figure XXV shows a model of a three dimensional reaction coordinate-energy diagram that is useful for discussing the energy of activation for reactions, exothermic and endothermic reactions, and kinetic and thermodynamic instability. This figure shows a system that is kinetically unstable; the ball on the right shows a system that is thermodynamically unstable but kinetically stable; and the ball on the left shows a system that is both kinetically and thermodynamically stable.

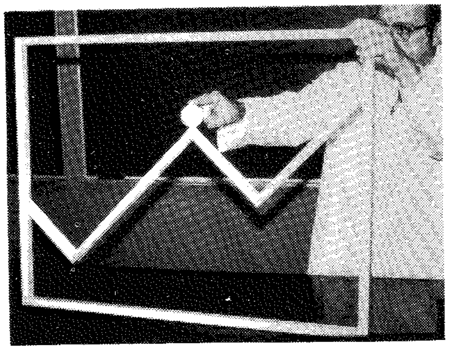

Figure XXV

Figure XXVI is a picture of models designed to show the two types of monomers that can lead to polymers by condensation polymerization. In the one case the single monomer unit has both hooks and eyes. In the other case there are two monomer units; one has a pair of hooks and the other a pair of eyes.

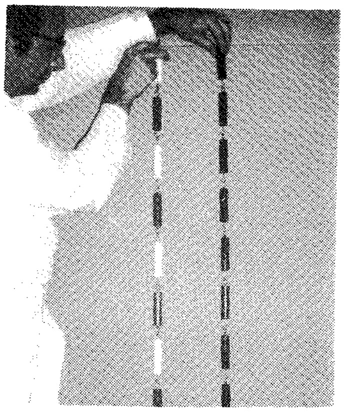

Figure XXVI

The following set of nine figures show various models of coordination complexes. Wooden spheres are too expensive and polystyrene spheres are too fragile so wooden cubes were used to construct the models. Never having seen an atom, I do not know for sure that they are spherical in shape. The first of these, Figure XXVII shows the cis and trans forms of the planar square complex, MA_2B_2. Figure XXVIII shows the two isomers of the trigonal bipyramid complex, MA_4B.

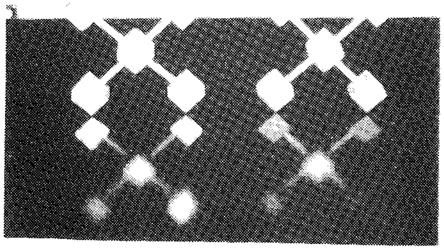

Figure XXVII

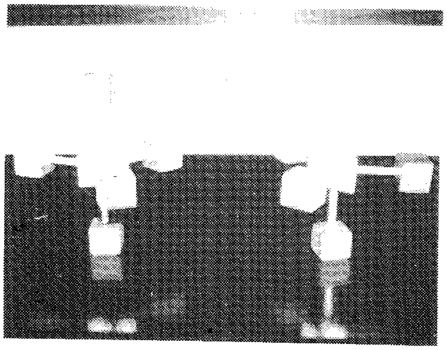

Figure XXVIII

The three isomers of the planar square complex, MABCD, and the two isomers of the tetrahedral complex, MABCD may shown. Also the three isomers of the trigonal bipyramid complex, MA_3B_2 may also be constructed.

Figure XXIX shows the two isomers of the octahedral complex, MA_2B_4. The two isomers of the octahedral complex, MA_3B_3 may be constructed. Figure XXX shows the cis and trans forms of the octahedral complex, MA_2B_2, where A is a bidentate ligand. You may illustrate the two mirror images of the cis isomer that was shown in Figure 30.

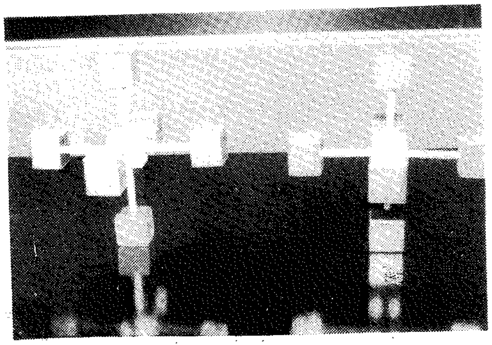

Figure XXIX

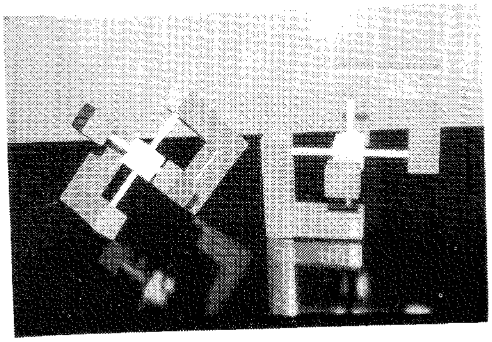

Figure XXX

A standard device for the demonstration of explosive limits is useful. After igniting the gas on top of a can, the gas line is pulled out of the can. In a couple of minutes the flame disappears, and in one to three more minutes an explosive mixture forms in the can and blows the friction lid off of the can. I always get a kick out of this demonstration as the time required for the explosion is sometimes quite unpredictable.

There are many many challenges remaining in the modeling business. For example, a concept that everyone talks about, but which nobody does anything about is the perpetual motion machine.

Letting It Happen in Chemistry

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

The traditional sixteen week one semester survey of chemistry for allied health students covers nowadays in sequence topics in general chemistry, followed by topics in organic chemistry, followed by topics in biochemistry. This sequence includes a great deal of material and includes many topics. The number of topics treated in the one semester allied health chemistry course approaches the number of topics covered in the more mathematical two semester sequence of general chemistry!

From the sixty hour overview of three major divisions of chemistry it is imperative that the student will glean sufficient mastery of chemistry so that she or he not only does well in the final exam, but also achieves high scores in the national league for nursing test, and eventually passes the state board examinations. Hopefully she or he enters the job world still convinced that chemistry is useful and interesting to anyone active in the health care professions.

How have we been trying to make this happen? In 1945 Joseph Routh published what was called in those days Fundamentals of Inorganic, an Biological Chemistry. In this new book Routh states his objective as early entry into and emphasis upon biochemistry to enhance the usefulness of the course to the nurse and to get a favorable response to the course by the student. Routh therefore limits the inorganic chemistry, but at the same time calls attention to applications of chemical science to the living organism and to nursing care, and emphasizes especially the biochemistry which "is more closely allied to the practical chemistry of medicine and of nursing". Routh says in the preface he has found the response of the student to the biochemistry has "always been more favorable".

The chemical formulas in texts back in 1945 were relatively simple, reflecting the descriptive nature of the biochemistry in the texts. The numerous illustrations in the book are photographs of people with various nutritional or hormonal deficiences.

Rather significantly, the book is dedicated to a person who is not named -- "my wife, the nurse whose ideas and experience made this book possible"!

For a quarter century the trend continued to attempt to enhance the long range usefulness of the chemistry course to the nurse while also engaging the interest of the student by adding organic chemistry and especially biochemistry to the general chemistry of the course. The 1971 edition of Routh, Eyman, Burton has broad coverage, includes many applications, and the theme now very apparent is "The Molecular Basis of Life". The inorganic section has doubled in size, the organic section is expanded by seven chapters, there are chapters added in the biochemistry section of the book. Notice chapter twenty-three "Nucleic Acids", the following chapter "Biochemistry of the Cell and High Energy Compounds", and the final chapter "The Biochemistry of Drugs"! These chapters reflect the collosal advances in biochemistry and molecular biology which took place during the 1950's and 1960's. Also reflecting the new knowledge note that in this 1971 text the compound niacin is shown incorporated into the coenzymes NAD and NADP.

Interestingly enough, in this edition three persons are named in the acknowledgements, -- they are Dorothy Routh, Joy Eyman, and Marge Burton. However, they are commended for their "constant assurance, patience, and generous assistance in typing of the manuscript.". In this edition thanks for ideas and experience go the graduate students and colleagues of the authors.

The Holum text, which we have been using, shows in the 1975 edition the same trends of organizational sequence, amount of text, and also the same kinds of acknowledgements as we see in the later Routh texts. We also see included in the texts increased amounts of equations, more complex organic molecules, and more examples of the directional effect of a change in one equilibrium system upon other equilibria in the cell and in the entire organism.

To summarize the last quarter century of teaching of chemistry for allied health students, the trend to include significant amounts of very descriptive biochemistry was new and well received. With advances in the young fledgling field of biochemistry came the molecular concepts and schemes of today. With the new knowledge came a doubling of the text size to accommodate the need to transmit information about the molecular basis of life. The input concerning what should be included in a text for allied health students came increasingly from the chemist.

Today many college related curricula leading to a baccalaureate degree in a health field include two semesters or three quarters of chemistry, and in this way accommodate to the breadth and depth of the new molecular science. However, we are also experiencing increased numbers of one year to three year curricula for which some brief instruction in chemistry is (or should be) required. The phasing out of the one semester or one quarter course in "biochemistry" does not seem likely in the near future.

Today in chemistry courses for allied health students we try to impart at the molecular level some sense of wonder and appreciation for the chemical marvels in the living person. With some of our students we see this accomplished. For others of our students, however, our pressure packed classroom agenda of fundamentals of inorganic, organic, and biochemistry in sixteen weeks may cause more trepidation than appreciation. Theodore Jones writes[1] concerning the very significant challenge facing the instructor in chemistry for nursing: "first many beginning students are unaware of the full extent of the scientific basis to their future scientific work, and hence come to see chemistry and other basic science requirements as being of little relevance to them and as serving primarily to eliminate weaker students from the nursing program. This attitude may lead to considerable resentment of these required courses which in turn makes it more difficult for the student to beenfit from these courses to the extent that should be possible. Secondly many Schools of Nursing, for reasons of efficiency schedule all of their basic science courses in the Freshman year, leaving all clinical experience for the Sophomore and later years. The result of this is to increase the student's sense of unrelatedness of chemistry and nursing and to make it more difficult for the student to maintain a sense of motivation. For the professor it becomes more difficult to show the application of chemistry to nursing in a significant and meaningful way."

This established mind set among students and graduates may be augmented by the heavy classroom agenda of selected segments from courses organized for other clientele. Therefore, in spite of the instructor's efforts, the student's involvement with chemistry may not be perceived by them as a satisfactory experience.

As I see it, the one semester chemistry course for allied health students should be set into a new framework. There should take place a sifting and winnowing process and a streamlining and integrating of the course. There should include persons teaching chemistry to allied health students, biochemists, clinical nursing instructors, dental hygiene educators, the nurse and the hygienist who are serving the public as part of a health care delivery staff, and some of the recent graduates from our curricula.

As a beginning, this is one way in which the traditional sixteen week course for allied health students may be rearranged, streamlined, and integrated. I would view the molecular basis of life without distinguishing whether a compound is organic, organic, or biochemical. I would look at the field of chemistry relevant to the molecular basis of life under five headings. I have been able to implement this program and so far it appears to be workable.

Under atoms and bonds I have considered with my students Bohr models of the atoms, followed by Lewis models of ionic and covalent compounds. The carbon to carbon covalent bond and the study of functional groups using ball and stick models follows.

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[1] J. Chem. Educ., 53, 581 (1976)

Hydrogen bonding between water molecules, behavior of ionic compounds in water, hydrogen bonding and solubility of carbon compounds are the second topic, which includes a small study of concentration expressions, but involves very little calculation.

The third topic, acids and bases includes Arrhenius and Bronsted strong and weak acids and bases. Balance in health and disease is woven into this section with pH, buffers, and hydrolysis. A related section on transport of ions is woven into topic two.

The fourth topic, redox, includes electromotive series of metals, a series illustrating the stepwise oxidation of carbon compounds, the structure and metabolism of foods. A detailed study of enzymes serves to reinforce the ideas of oxidation-reduction and serves as a bridge to topic five, the molecular basis of heredity. In this section we always make time to take a look at the effect of high energy radiation upon the cell to bring us full cycle back to atoms, bonds, and energy, which is what life is about at the cellular level.

The one semester or one quarter chemistry course for nurses ought to be condensed. The suggestions of a multi-discipline group of experts in various fields related to allied health education should be used as a basis for action.

The last quarter century teachers of chemistry have diligently tried to make it happen in allied health science. By some reorganization, reassessment and lots of salesmanship we can make chemistry a joint venture. Perhaps we can then LET IT HAPPEN in chemistry.

The Preparation of Chemistry Students for the Chemical Industry

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

In 1971, Dr. Thomas Cole, Chairman of the Chemistry Department, sent proposals to several chemical companies in which he stated that although the Atlanta University Chemistry Department Masters Program served well in providing our students with the training necessary to continue their studies in doctoral programs or go into teaching, it did not satisfy the needs of all our students. A recent survey had shown that fifty percent of our students obtained jobs in the chemical industry. Atlanta University had traditionally awarded masters degrees in organic, inorganic, physical and biochemistry.

In 1972, Atlanta University initiated the Masters of Science Degree Program in Industrial Chemistry. Although our students were well-prepared, no attempt was made to prepare them for the kinds of jobs which were available at the master's level in the chemical industry. As a result, our graduates were too specialized. They were oriented more toward theoretical, rather than practical, aspects of chemistry. Their lack of awareness of the varied job opportunities and responsibilities resulted in the need for additional training on the job and inaccurate assessments of job opportunities.

It was thought that our curriculum should be tailored to the needs of our students and their potential employers. This did not mean a radical change in our program or compromising our efforts to achieve quality education at the master's level.

A student with a masters degree in industrial chemistry is more attractive to the chemical industry than a comparably trained graduate with a traditional masters degree. Our graduate is still a chemist, but his broad background in core courses, polymer chemistry, industrial organic chemistry, economics, and scale-up principles puts him in a better position to remain a bench chemist, go into research and development, sales and marketing, or into management.

Figure I shows the Master's Degree in Industrial Chemistry curriculum. In the first semester, industrial majors take the same courses as students enrolled in the traditional programs. Instrumental Analysis is a particularly important course for our industrial majors. In that course, they use such instruments as a nuclear magnetic resonance spectrometer, an infrared spectrophotometer, an ultraviolet spectrophotometer, and gas chromatographs. The theory and interpretation of mass spectra, optical rotatory dispersion, circular dicroism, atomic absorption, polarimetry, and electron paramagnetic spectra are also discussed.

In the second semester, in addition to Advanced Organic and Advanced Inorganic core courses, industrial majors take Polymer Chemistry and Industrial Chemistry Seminar. The industrial seminars are presented by industrial scientists and engineers.

In the summer and first semester of the second year, our students spend seven months in the chemical industry as interns. During this time they gain valuable industrial experience as well as possible thesis material.

In the second semester of the second year, industrial majors take "Topics in Industrial Chemistry," "Scale-Up for Chemists," and an elective in Business Administration. "Topics in Industrial Chemistry" is taught by scientists and engineers from the chemical industry. "Scale-Up for Chemists" provides an introduction to the principles of scale-up from the laboratory bench to pilot plant to commercial scale.

MASTER'S DEGREE IN INDUSTRIAL CHEMISTRY CURRICULUM

FIRST YEAR:

First Semester

	Hours
CHM 520 Structure, Energetics, and Dynamics	5
CHM 541 Instrumental Analysis	3
CHM 551 Seminar	1
	9

Second Semester

CHM 605 Organic Polymer Chemistry	3
CHM 501 Advanced Organic Chemistry	3
CHM 531 Advanced Inorganic Chemistry	3
CHM 551 Seminar	1
CHM 561 Industrial Chemistry Seminar	1
	11

Summer

Internship or Research	3

SECOND YEAR

First Semester

Internship or two courses as follows:	
Elective in Chemistry	3
Research	3
Seminar	1
	7

Second Semester

CHM 606 Topics in Industrial Chemistry	3
CHM 607 Scale-up for Chemists	3
Elective in Business Administration	3
CHM 551 Seminar	1
CHM 561 Industrial Chemistry Seminar	1
	11

Summer

Research and Thesis	
	41

Figure I

Figure II below shows the medicinal chemistry option.

MASTER'S DEGREE IN INDUSTRIAL CHEMISTRY CURRICULUM
MEDICINAL INDUSTRIAL CHEMISTRY OPTION

FIRST YEAR:

First Semester	Hours
CHM 520 Structure Energetics, and Dynamics	5
CHM 541 Instrumental Analysis	3
CHM 551 Seminar	1
	9

Second Semester	
CHM 501 Advanced Organic Chemistry I	3
CHM 511 Advanced Biochemistry I	3
CHM 531 Advanced Inorganic Chemistry	3
CHM 551 Seminar	1
CHM 561 Industrial Chemistry Seminar	1
	11

Summer	
Internship or Research	3

SECOND YEAR:

First Semester	
Internship or two courses as follows:	
Elective in Chemistry	3
Research	3
Seminar	1
	7

Second Semester	
CHM 502 Advanced Organic Chemistry II or CHM 512 Advanced Biochemistry II	3
CHM 607 Scale-up for Chemists	3
Elective in Business Administration	3
CHM 551 Seminar	1
CHM 561 Industrial Chemistry Seminar	1
	11
TOTAL	41

Figure II

Figure III shows the Industrial Chemistry Seminar schedule for last year.

INDUSTRIAL CHEMISTRY SEMINAR SERIES

SPEAKER	SUBJECT
Don Larkin, Celanese	Oxidation of Hydrocarbons
Dr. Vincent A. Perciaccante American Cyanamid	Polymers in Industry
Dr. A.J. Rosenthal Celanese	Design of Experiments

Figure III (con'd.)

Buckeye Cellulose	Gas Chromatography of Cellulose Derivatives
Dr. David Pond Tennessee Eastman Company	Cycloaddition Reactions of Carboxyl Compounds Possessing High Energy Content
Dr. Paul Resnick DuPont Company	Fluorocarbon Chemistry
Dr. W.W. Kaeding Mobil Oil Company	The Energy Crisis
Dr. H. Buchert Dow Badische Company	Melt Spun Fibers Technology
Dr. T.R. Beattie Merck Sharp and Dohme	Polymeric Reagents in Organic Synthesis

Figure III

Figure IV shows the "Topics in Industrial Chemistry" roster for last year.

Topics in Industrial Chemistry

SPEAKER	TOPIC
Dr. Malcolm Polk	Industrial Chemistry
Mr. D.A. Young Celanese Company	General Instrumental Characterization of Polymers
Dr. W. Brendley or Dr. V.G. Calder Rohm and Haas Company	Industrial Coatings
Dr. Gerber American Cyanamid Company	New Dying System From Concept to Maturity
Examination	
Mr. W. Huth Sun Oil Company	Planning and Communications
Dr. T.J. Lynch Gulf Oil	Heterogeneous Polymerization
Dr. I. Thomas	Inorganic Polymers
Dr. M. Jaffe Celanese Company	Textile Fiber Technology
Eli Lilly	Pharmaceutical Chemistry
Mr. Herman Leggon	Statistical Analysis of Data
Lab	
Final Exam	

Reference Texts:

Seymour, "Introduction to Polymer Chemistry"
Billmeyer, "Textbook of Polymer Science"
Braun, Cherdron, Kern, "Techniques of Polymer Synthesis and Characterization"
Vollmert, "Polymer Chemistry"
Williams, "Polymer Science and Engineering"
Sandler, "Polymer Syntheses"
Wittbecker, "Macromolecular Syntheses"
Lenz, "Organic Chemistry of Synthetic High Polymers"
Alfrey, "Organic Polymers"

Other colleges and universities are involved in similar efforts. Seminar courses with speakers from industry are being initiated at Winthrop College in South Carolina and at the University of Georgia. Courses dealing with business and management are being initiated at St. Joseph's College in Brooklyn, Lehigh University, Emporia Kansas State College, and the University of Detroit.

Florida Technological University has developed a course in which a limited number of processes and products are studied in depth and from a viewpoint which stresses the development effort which was involved. This four-credit-hour lecture course in industrial chemistry is normally taken in the senior year. Their approach is to review the development from the standpoint of the chemist and to illustrate how the principles acquired in academic courses are utilized in the development.

A new B.S. degree in Chemistry and Chemical Technology was started at the University of Wyoming in 1974. This program involves collaboration with the chemical industry in developing experiments and procedures characteristic of the industry. This program involves industrial consultants who work with the faculty at the University of Wyoming to develop industrially related experiments, discuss standard methods or company analytical methods, discuss industrial problems and their solutions, and offer plant trips, seminars, or short courses on applied chemical topics.

How best can junior colleges benefit from these experiences? I would think that the first step would involve contacting and developing programs with local industrial companies. An attempt should be made to establish an industrial seminar series. If possible, an internship program should be arranged with local companies.

As far as course content is concerned, including polymer chemistry in organic chemistry courses would be useful and the use of the Florida Technological concept in developing an industrial chemistry course or in an organic chemistry course would be helpful. As an example, the oxidation of cumene is used for the manufacture of phenol. This process follows the overall route described in Figure V. The mechanism of the process is thought to involve a free radical intermediate. The resonance stabilization of the free radical intermediate by hyperconjugation and delocalization of the free radical electron into the ring can be discussed. The free radical mechanism for the production of cumene hydroperoxide and the resulting proton addition, followed by loss of water, migration of the phenyl group and formation of phenol and acetone can be described in detail. Additionally it may be pointed out that the reaction was discovered by two German chemists, Hock and Lang, in 1944. After they treated cumene hydroperoxide with dilute sulfuric acid and observed the formation of phenol, chemists at Distillers Company Ltd. in England and Hercules Power in the USA developed processes for the manufacture of phenol based on this reaction.

Oxidation of Cumene - Preparation of Phenol

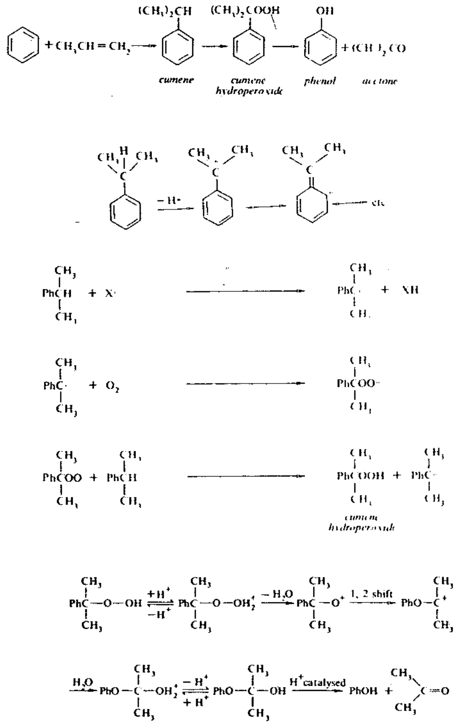

Figure V

One might utilize Figure VI, the Dow Phenol from Toluene process to illustrate chemical principles. In 1845, German chemists showed that when cupric benzoate is heated, phenyl benzoate is formed. Ninety to one hundred years later, other researchers showed that phenol and salicyclic acid are also formed. The Dow Chemical Company, in the 1950's, investigated the feasibility of a process for the manufacture of phenol based on this reaction Liquid-phase free-radical oxidation is utilized for the conversion of toluene to benzoic acid. Next, air and steam are passed into molten benzoic acid containing a catalytic amount of cupric benzoate. Phenol distills out at the temperature of the reaction.

The process development involved an extensive investigation of the chemistry of the second stage. The conversion of cupric benzoate to o-benzoyloxybenzoic acid is the key step. The o-benzoyloxybenzoic acid is hydrolyzed to benzoic acid and salicyclic acid and the salicyclic acid decarboxylates to phenol. The mechanism of the first step is thought to involve ortho addition of the benzoyloxy free radical to the ring. This has been established with isotopically labelled benzoic acid.

Dow Phenol from Toluene Process

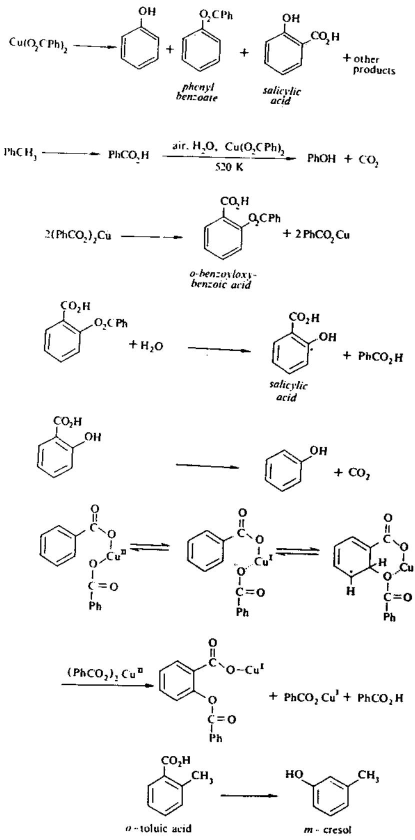

Figure VI

An in-depth analysis of this process for an industrial chemistry course would involve a consideration of engineering principles and economic factors. Perhaps these considerations could best be developed with the aid of industrial consultants. Also, two relatively new books are available which could be used as textbooks for such a course. The books are: "An introduction to Industrial Organic Chemistry" by Wiseman, and "Survey of Modern Industrial Chemistry" by Cook.

The Romance of Polymer Chemistry

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

Polymer chemistry is undoubtedly one of the most fascinating, if not the most fascinating, of the fields of chemistry which can capture the imagination of the beginning student of chemistry, at any level of education. This is because it can tell an exciting story both about mankind's constant striving to unlock the secrets of nature and the final success of the chemist in duplicating and improving upon nature. Further, more the successful synthesis of various polymers represents an accomplishment which is of utmost urgency as it bears on the dwindling supply of earth's resources, and is a very relevant question of daily life. Hence polymer chemistry can easily interest the student right from the start.

The best way to start this topic is probably to draw the student's attention to the unique character of the macromolecule, i.e., it's "giant" size compared to ordinary molecules. This can, for example, be done as indicated in Table I, which gives some idea of their relative size, and also indicates the long-chain character of macromolecules. These data can then be used to explain the fact that macromolecules lead to materials of substantial coherence and strength, even in the amorphous condition, as compared to liquids or weak solids made up of small molecules.

MOLECULES AND MACROMOLECULES

SUBSTANCE	CHEMICAL FORMULA	SIZE OF MOLECULE
Water	H_2O	1×10^{-8} inch
Sugar	$C_{12}H_{22}O_{11}$	3×10^{-8} inch
Cellulose	$(C_6H_{10}O_5)_{2000}$	2×10^{-6} inch
Rubber	$(C_5H_8)_{20,000}$	4×10^{-6} inch

TABLE I

These explanations of the structure of the naturally occurring macromolecules can then be followed by the exciting story of how the chemist has found it possible to create macromolecules from the usual small molecules, thus not only duplicating some of nature's art, but improving upon it by synthesizing polymers of entirely new chemical structure and useful material properties.

This "romantic" story can probably be called "Taming the Macromolecule", and recounts how the chemist, over the past 40-50 years, has gradually succeeded in bringing under control the various polymerization reactions which lead to the synthesis of long-chain macromolecules. It can be told under the following headings, which actually represent the chronological order of these acoomplishments:

1. Control of the average molecular weight
2. Control of the isomeric chain unit structure
3. Control of the distribution of molecular weights

Control of Average Molecular Weight

Under this heading, one can introduce the general nature of the two types of polymerization reactions, i.e., (a) reactive end-group polymerization, and (b) chain growth reactions. These will include such reactions as polycondensations to yield polyesters and polyamides (Nylon), as well as the chain reactions of unsaturated monomers (ethylene, styrene, butadiene) which proceed by the three main mechanisms, i.e., free radical, cationic and anionic. The thrust of these discussions should be on the effect which all of these mechanisms exert on the molecular weight of the final product and on the distribution of molecular weights.

Control of Isomeric Chain Unit Structure

This topic tells the story of the century-old quest of the chemist to duplicate one of nature's "tricks", i.e., its ability to create "stereoregular" macromolecules, such as α or β-glucosides (cellulose or starch), cis-1,4-polyisoprene (natural rubber), etc. The triumphant climax of the story is, of course, the breakthrough of "stereospecific" polymerization, in the mid-1950's, which garnered the Nobel Prize in chemistry for Karl Ziegler and Giulio Natta. This story also then presents an opportunity to demonstrate many of the entirely new stereoregular polymers which have since been synthesized, such as isotactic polypropylene, cis-1,4-polybutadiene, etc.

Control of Molecular Weight Distribution

The most recent victory of the chemist in the battle of control over polymerization comes in the form of designing long-chain molecules of remarkable uniformity of chain length. This has been accomplished by means of the technique of anionic "living" polymerization, i.e., avoiding the termination step in the sequence of chain reactions. By this means, the distribution of molecular weights can be made extremely narrow, corresponding to the well-known Poisson Distribution. This technique also has further ramifications, in that it can be coupled with stereoregular polymerization and with the synthesis of relatively uniform "block copolymers" by sequential addition of monomers. It can also be used for the synthesis of macromolecules having desired reactive groups at the chain ends, which can then be linked rogether in various ways to create interesting new plastics, rubbers and fibers.

The above treatment can well illustrate the story of polymer chemistry in the service of mankind. However, one additional aspect should be borne in mind, which is not really related to the quest for synthetic materials. This relates to the breakthrough in knowledge about the nucleic acids, DNA and RNA, and their mechanism of replication through the double helix structure. Thus the synthesis of proteins turns out to be a "stereospecific" polymerization process leading to long-chain macromolecules, which are the very substance of life and living tissue. A fitting conclusion to the "Romance of Polymer Chemistry".

The question will arise as to where we can find material for this type of presentation. Unfortunately, it is not contained in the usual introductory chemistry texts, which are, regrettably, not aware of these relatively new developments in the chemical world. A recent symposium on "learning Chemistry from the Macromolecule" has been published in the Journal of Chemical Education (Vol. 50, p. 731, November 1973) and could be helpful as a source of such material.

Chemical Evolution as a Framework for Teaching College Chemistry

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Presented as a part of a Symposium on Pedagogical Perspectives in Chemistry at the Fifty-Second, Two Year College Chemistry Conference, Penn Valley Community College, Kansas City, Missouri, October 29, 1976.

The program which I am going to discuss had its genesis in the Flint Hills of southern Kansas. It has stood the test of six years of teaching to some 400 students, but it is still in a rapidly evolving state. Each summer when I would return home to work in the hayfields, friends and relatives would ask me what I was doing in college and wonder if I would ever graduate. My proud reply that I was majoring in chemistry always seemed to elicit one of two replies: What is that? of On, no, I flunked chemistry! The anti-science attitudes which swept our campuses in the late 1960's and the increasingly lower respect shown for science by our politicians during the same period intensified by feeling that something had to be done in order to remove chemistry from the 10 most hated list and restore some of the respect that napalm, orange II, and irrelevant intro courses had lost. But it should be a different kind of respect than the science-can-do-anything awe of the 40's and 50's. What was needed was interest in the material, knowledge of the limits of science, a sound foundation on which to build a career in the discipline of choice, and hopefully enthusiasm to know more.

As I tried to identify the source of these ills and fears of college chemistry, I seemed to always return to the following items:

1. Students expect college to be a substantial change from high school. When they find that the topics covered in college chemistry closely parallel those taught in high school, they frequently develop that, "Oh, I've had this" attitude.

2. Students need a clear view of chemical science as a vital, growing discipline which is worthy of their time to study it. In an effort to "cover" the large number of topics thought to be essential in introductory chemistry, we too often fail to show the humanitarian and technological outreach of chemical science.

3. Upper level students seem to find considerable difficulty in grasping the interdisciplinary nature of science. Can this be the result of too much partitioning of disciplines during the early years of scientific study?

4. With increasing attention given to the impact of science and technology upon our society, all students need to view the nature of scientific controversy as a healthy state of disagreement.

The overhaul of our general chemistry program seemed too formidable a starting place for educational panacea. Consequently, I decided to initiate our Department's first course for non-science majors. This was 1969 and the theme chosen was environmental chemistry. This was so easy that I dug a large hole and jumped in, only to find that there were no ladders out! No textbooks on environmental chemistry existed and what's more, all the non-science student books looked like watered down general chemistry books. In the process of asking myself how I got in such a predicament, I concluded that if the evolution of ideas had gotten me there, why couldn't I get out the same way?

With that self-fulfilling philosophy, I decided that I would use the concept of chemical evolution as the vehicle in which to introduce non-science students to important chemical concepts (chocolate flavored cod-liver oil never worked better!!)

This approach has worked so well that I am now working on--ways to apply it as a theme for general chemistry. What I wish to do today is to outline a method of approaching chemical concepts for the non-major and then extend this to include a framework for general chemistry. The approach which I have taken is to divide the topic into four major areas: Formation of the Universe, Formation of the Earth, Chemical Evolution, and the Machinery of Life.

Formation of the Universe

One can begin this unit by asking questions about the present complexity of our physical, biological and social system compared to even the recent past (that which students have experienced). This naturally raises questions about what happened prior to written history or even geological history. The need for models as an intimate part of scientific study is quickly realized! Since time seems to parallel an increase in diversity and also complexity, it seems rather logical to ask questions about the formation of matter and to then speculate about its changes through the eons.

The primitive mysteries surrounding the beginning, evolution, and conclusion of the universe remain largely unanswered. We do not know why the universe was formed or how it will end. We do not know whether many of the structural details of the universe and events in its history were accidental or inevitable. We do not know why there are living creatures nor if there is some special role or purpose for thinking creatures. And what is more, we do not really know if it is important to find out! To obtain a "scientific" answer to all these questions might require as much as 30 billion years and few have the patience or endurance to await the experimental results. Consequently, we must resort to more speculative answers to these questions.

Astronomers and astrophysicists currently prefer to think that the universe began with a "Big Bang" some 12-13 billion years ago. At this time, a primordial ball of neutrons, protons, and electrons somehow was formed and the nuclear reactions in the resulting "fireball" may have produced the matter and much of the energy which exists in our universe today. This model provides an easy introduction to electrons, protons, and neutrons as important fundamental particles of matter and a way to discuss the forces and interactions between them. Nuclear processes, fusion and later fission, arise as needed concepts in the stellar nucleosynthesis of the elements. Since nuclear processes involve energy changes, this concept immediately surfaces and provides one with an opportunity to examine not only the units and magnitude of nuclear energy but also the various forms in which energy can be found. A problem develops in this area because the quantity of energy produced by nuclear reactions (either in stars or elsewhere) is so enormous that most students do not appreciate the magnitude of these reactions until one makes comparisons of the energy potential in coal vs. uranium or the discussion of nuclear explosives with conventional ones. Stellar nucleosynthesis provides the opportunity to talk about electronic as well as nuclear structure of the atom and provide contrasts between them. With more advanced students one could proceed directly into the quantum model at this point.

The discussion of stellar nucleosynthesis naturally leads one into consideration of the evolutionary nature of stars as their composition and energy changes. Depending upon one's interest in astrophysics, main sequence, red giants, horizontal branch, white drawf and supernova stars can be discussed. I find that many students have heard some of these names and express interest in how they may arise and die. The issue of black holes and/or neutron stars always seems to surface along with the question of continual expansion of the universe (red shift).

The fusion processes which result in nucleosynthesis lead readily to the knowledge frontier in astrophysics. One must confront the problems of heavy element production and fission, radioactivity and half-life, and relative stability of the nuclides are introduced. If desired, the successes and problems of heavy element synthesis in laboratories can be discussed here.

Formation of the Earth

Does the earth actually have an origin? Obviously this is a question with an unprovable answer but it seems unlikely that is infinitely old! One could argue, however, that the age of the material from which the earth and solar system are composed is nearly infinite. In any case, it is likely that the earth formed by aggregation of cosmic material some four to five billion years ago. The scientific arguments leading to this hypothesis rely heavily upon the use of isotopic abundance ratios and the composition of noble gases presently found in the earth's crust. The use of radioacitive isotopes in dating the age of the earth generates the need for a further discussion of nuclear fission and isotopic stability and provides a process to help explain the production of heat in the earth's core.

The discussion of early earth, atmosphere and lithosphere, provides an opportunity to introduce both some properties of gases and chemical reactivity and periodicity. Much of the evidence for earth formation at a relatively cool temperature is based upon the hydrogen:helium ratio of earth compared to the universe. This means that the students should understand the velocity-melecular weight relationship and one could dig into a general discussion of gases at this point.

The study of the structure and composition of the prebiotic solid earth (lithosphere) provides a melting pot for several important concepts from radiochemistry, geochemistry, and chemical periodicity. Questions such as, "Why is the earth's core molten?" can be tackled by discussing the poor thermal conductivity of solids and noting that the heat produced by colliding bodies would not have been readily dissipated. Of course, nuclear fission of radioactive isotopes contained in the aggregating matter would have continued to generate much thermal energy which again would remain trapped in the earth.

The problem of geochemical match-making provides an excellent opportunity to approach chemical reactivity and periodicity. The groundwork laid in basic atomic structure is adequate for developing the periodic table and simple Lewis "dot structures", especially for the ionic-type interactions so characteristic of minerals. Even the covalency concepts needed to "stick" a silicate together can be accommodated without elaborate bonding theory. At this point I usually work in some basic concepts of electronegativity and "hardness" and "softness" of atoms and ions as an aid to helping inexperienced students develop a "feel" for what might have a stickiness for what. Early applications of these concepts to simple binary systems also reduces the fright factor when one becomes concerned about such things as ore composition, solubility, mobility of water pollutants, or the role of heavy metals in the biosphere.

The problems of elemental differentiation leading to mineral, rock, and soil formation seems to hold considerable potential as a vehicle for studying some descriptive chemistry. When one asks why heavy elements are found in the earth's crust rather than settling to the hot center of the earth, the problems of chemical reactivity, stoichiometry, and the importance of limiting quantities of reactants surface immediately. I must admit that I have only begun to tinker with this material as a way to generate student interest in flat out learning some chemical reactions and perhaps even enjoying it at the same time.

As the earth gradually warmed the composition of its atmosphere no doubt changed. A little time spent discussing the chemical nature of the prebiotic atmosphere sets the stage for the next topic of chemical evolution while requiring further exploration of covalent chemical bonding in simple molecules. This is also a good place to briefly examine the absorption of energy by molecules. One could pause here for an indepth study of chemical bonding intermolecular forces, gas phase equilibria, and absorption of energy by molecules including a little spectroscopy. This background could open up an excursion into astrochemistry and a study of what we are learning about the composition of the solar system in our search for life on other planets.

As the earth's surface began to warm, it is likely that small polar, covalent molecules (e.g. water, carbon dioxide) began to vaporize and conventional weathering processes began. During this period, some four billion years ago, the conditions may have been forming to trigger the complex series of events which are needed to postulate that chemical evolution might be critical to the formation of life. The oceans as we now view them are probably too young (only some 100 million years old) to have been involved in the formation of the earliest life. However, the early availability of marshes may have provided the protection from intense solar radiation and the concentration of raw materials which was crucial for the simplest biochemicals to survive. This topic provides a good opportunity to delve into water as a solvent system and to study effects of molecular polarity upon solubility and reactivity. One could proceed directly into homogenous and heterogenous equilibria at this point.

Chemical Evolution and the Origin of Life

An inquiry into the origin of life raises a variety of philosophical "chicken and egg" type questions. For example, how did the first nucleic acids arise when there were no patterns to copy, or how did the first membranes arise to separate individual cells from their environment, or why was phosphorous selected as a major energy storage system when it is fairly scarce in the earth's crust? Current biochemical research is telling us more and more about what is but the "in the beginning" questions are often incompletely asked and the answers less well understood.

History is filled with disabled or discarded theories about the origin of life. An excursion into the rise and fall of some of these ideas can provide useful insight into the nature of scientific investigation, the inertia of "in-vogue" beliefs, and the tender boundary between creation and evolution.

A study of prebiotic evolution must begin with speculation about the physical conditions prevailing on earth at that time, thought to be 3.5 to 4.5 billion years ago. It is generally believed that the atmosphere was still highly reducing and Miller's classic experiments in the early 1950's seem to provide experimental support for this hypothesis. Discussion of Miller's work not only provides some very interesting chemistry but also raises the question of the validity of closed flask experiments in simulating natural systems.

As one progresses from discharge experiments which produce simple amino acids to those which generate polypeptides, you are confronted with a greater need to understand the chemistry of the covalent bond. At htis point a need for discussion of some chemistry of selected carbon-containing functional groups is useful. A brief look at some major concepts of chemical kinetics, including catalysis, applied to functional group reactions greatly aids the understanding of certain reactions which may have begun to dominate in the chemical soup of prebiotic earth.

The Machinery of Life

For non-science students this topic is clearly the most difficult to sort out and understand. The major emphasis is upon recognition of the functional groups and chemical linkages which allow molecules to be classified as carbohydrates, lipids, proteins, and nucleic acids. It seems best to approach these classes of compounds by starting with the simplest chemistry first. I begin with a look at the elemental composition of the human body and compare it with the composition of the earth's crust and the sea. Such a comparison requires a further examination of periodicity and provides for additional descriptive chemistry. At this point one can speculate about the role of nutrient availability in water and its relationship to biological dependence. One might also choose to discuss the biological progression of a chemical species from poison to tolerable impurity to useful element to essential element. This sequence provides a useful way to think about the consequences of technological activity upon the biosphere. It also suggests a reason why vanadium, chromium, silicon, tin, selenium, bromine and fluorine have recently been classified as essential elements for humans.

The composition and chemistry of carbohydrates may be somewhat simplified if one views these hydroxy compounds as derivatives of water and focuses attention upon the -OH functional group. This topic also provides the first real need for stereochemistry and optical activity. The "handedness" of molecules is frequently a revelation to beginning students and the conjecture about how organisms developed a preference for one or the other is frequently lively. One may be able to effect an "idea implant" of this phenomenon if the chiral nature of quartz is shown and discussed during the previous study of earth geochemistry.

The second class of biologically important molecules which we discuss is the lipids. The emphasis is upon the hydroxy, carboxy, and ester functional groups, and the interconversion of these. The study of proteins follows lipids and again the emphasis is upon recognition of the functional groups which characterizes the amino acid building units and upon the polymerization and depolymerization reactions of proteins. Since we will later study air and water pollutants, the coordination ability of proteins for metals is noted and this leads to a brief look at enzymes, catalysis, and the participation of trace elements in many of these systems.

This discussion of biochemicals ends with a cursory view of nucleic acids, indicating the important components and differentiating them from the other biochemicals already discussed. Only a very little time is spent with the replication process.

At the end of this crash course in chemical concepts, even the poorest prepared student has developed some ability to grapple with molecular science. Most students seem to have acquired a certain appreciation and enthusiasm for some aspects of chemical science and all agree that this was not a rerun of the material they might have studied in high school.

CHEMICAL EVOLUTION

A Selected Bibliography

By Larry Wilson
Ohio Wesleyan University

These books are arranged in generally increasing order of chemical background needed to fully appreciate the material.

1. The Origins of Life, C. Ponnamperuma, E.P. Dutton and Co., 1972. Also for H.S. background, very well done.
2. The Origins of Life, L. Orgel, John Wiley, 1973. Assumes only high school science knowledge.
3. The Machinery of Life, D.E. Woolridge, McGraw-Hill, 1966. Another introductory level book which focuses on the biochemical implications.
4. Origins and Development of Living Systems, Brooks and Shaw, Academic Press, 1973. Has a heavy biological flavor.
5. The Origins of Life on the Earth, by S. Miller and L. Orgel, Prentice-Hall, 1974. Probably the best one volume for persons with general chemistry background.
6. The Chemical Origin of Life, A.I. Oparin, Thomas Pub. Co., 1964 A readable account of the topic by one of the leading proponents.
7. Chemical Evolution, M. Calvin, Oxford Univ. Press, 1969. A good balanced book by a foremost worker in the field.
8. Molecular Evolution and the Origin of Life, S. Fox and K. Dose, W.H. Freeman Press, 1972.
9. The Distribution of Elements on our Planet, L.H. Ahrens, McGraw-Hill, 1965. Probably the most readable book for the geology-chemistry approach to the earth's formation, age, and elemental match-ups.
10. The Origin of Life by Natural Causes, M.G. Rutten, Elswier, 1971. Has a heavy geological flavor to the topic.
11. Cosmochemical Evolution and the Origins of Life, Oro, Miller, Ponnamperuma, and Young, D. Reidel Publ. Co., 1974, 2 vol. More advanced than most of the others, but very good on certain topics.
12. Exobiology, C. Ponnamperuma, North-Holland Publ, Co., 1972. Another more advanced book.

CURRENT CONCEPTS IN CHEMICAL EDUCATION
The Doctor of Arts Program in Chemistry at Atlanta University

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A. Introduction

I have two sons, aged 7 and 8. They are in the first and second grades and I'm often surprised at the things they learn there - sometimes from the teachers, but usually from the other kids. Several weeks ago Mark, the youngest, and I were talking about girl friends. "Is it important to have lots of girl friends," I asked, "Yes," Mark said, "but it's a problem when you get older and want to marry, 'cause then you got to choose." "Well how will you do that?" "Oh, all the girls will put on their finest clothes and I'll pick the one that's dressed the best." I'm afraid women's liberation has yet to seep down to this southern grade school. More seriously, I open with that story as an example of ingrained attitudes.

I would like to talk about a program, the Doctor of Arts degree, which goes against some ungrained attitudes in chemical graduate education and which, hopefully, will evolve into a real change rather than just a change in name or dress.

Briefly, to give you an outline of my talk, I will give a little of the history and reasoning behind the degree as it has developed across the nation, comment on our particular interest in developing this program at Atlanta University, describe our program itself, and finally say something about the relation of our interests to your's, that is, chemical education in the community college.

B. History and Justification

The Ph.D., as it has evolved in this country, centers on a sustained research effort culminating in a thesis. This degree has served its purpose very well in the sciences of developing a range of competent to creative researchers. It was not intended as a program to develop interest or skill in teaching - its major interest in teaching has been only as a source of financial aid for graduate students. Given that a sizeable body of chemists expend their major efforts on teaching and not research, one is lead to a series of questions.

Roughly speaking there are 1200 community colleges, about 1300 four-year colleges, less than 200 institutions offering a M.S. in chemistry as the highest degree, and about 185 Ph.D. granting chemistry departments. In 1976 only 528 schools had ACS certified B.S. programs. Should doctoral training that focuses on narrow in-depth research be the only respected doctoral option open to potential college chemistry faculty in light of this breakdown?

Doctoral training is important. It provides a valuable space of time and resources when one can begin to learn, study, research, and think on one's own. A doctoral student will spend two or more years of his or her life in real and sustained effort. What if, for a future teacher, that creative effort were to focus on and lead into the issues involved in their work rather than being an isolated experience which recedes further and further into the past, perhaps with a touch of nostalgia, but with little connection to the present?

I have not observed that good teaching comes easily to my colleagues or myself. We are often perplexed by the students, we tend to lay the blame for their lack of responsiveness and learning back on their heads, we ignore the not so hidden signs that the way we teach, the way we let students go about their work, is frustrating and ineffectual. It seems to take real effort, real work, and real thought to bring about a learning situation that one feels good about and which adds positively and significantly to what the students bring with them. Is the Ph.D. training the most effective doctoral training one can devise to develop the base, the fund of knowledge, the interest, the confidence, the skills needed in this teaching-learning effort?

What type of students will most chemistry faculty teach? What fraction of these students will go on in chemistry? What aspect of chemistry is valuable to the great majority of students taking at most one or two chemistry courses? Is the ethos the atmosphere of a graduate program which focuses on training researchers compatible with the realistic answers to these questions?

Without being dogmatic about it, I suggest a reasonable response to the above questions is that the present Ph.D. training is probably not the only or the best or the most effective doctoral experience for someone whose major activity will be teaching undergraduates.

These and similar concerns led to a rising interest in the development of a new doctoral degree program at a number of universities beginning in the late sixties. Broadly put - the new program was to be subject matter based, to emphasize breadth of background, to involve a thesis project which related knowledge in a given field to the teaching of the knowledge, and to include a critically evaluated teaching experience. The degree acquired the title Doctor of Arts.

Carnegie-Mellon University enrolled the first D.A. student in 1966. In 1970 the Carnegie Commission on Higher Education recommended the new degree and awarded slightly over a dozen planning grants to a variety of universities. In 1970 and in

1972 the Council of Graduate Schools endorsed the degree and issued guidelines to promote the development of quality programs. Despite the financial and job-market crunch which hit higher education in the 70's, 25 institutions offered, and 4 more were definitely planning to offer, the D.A. degree in early 1976. At that time 416 degrees had been granted and 556 students were enrolled in D.A. programs. In response to a national survey only one institution felt it had been more difficult to place its D.A. graduates than its Ph.D. graduates. Narrowing down to chemistry, 9 institutions offered a D.A. program in chemistry and 2 indicated plans to do so. This is about 50% of all institutions offering a Ph.D. in chemistry.

C. Atlanta University's Interest

Atlanta University was started shortly after the Civil War to provide high school education to former slaves. It is now the graduate and professional part of the Atlanta University Center which includes, in addition to Atlanta University, four undergraduate colleges and a theological center. The Atlanta University Center institutions as a whole enroll about 7,000 students and with Howard and Meharry Medical Center, Atlanta University is one of only three Black institutions to offer doctoral degrees. The chemistry department at Atlanta University has 8 full-time faculty members and offers a research M.S., a M.S. in Industrial Chemistry, and the Doctor of Arts. The department enrolls between 30-40 graduate students each year which represents about 10% of all Black chemistry graduate students in the country.

Around 1972 the department began asking itself how it might best impact on chemical higher education, particularly with regard to improving chemical education for minorities. We placed some stress on this focus not to be exclusive, but because we are historically a minority institution and because we did not see any other graduate institution taking a serious interest in what we saw as a pressing need - the development of a corp of people with a solid understanding of chemistry and the commitment and skills to teach chemistry effectively and creatively in those institutions with a large majority of black and other disadvantaged students.

To place our concern in context let me share some figures on minority participation in the physical sciences and the central role of community colleges in minority higher education. In 1974, minorities exclusive of Asian-Americans comprised upwards of 15-20% of the total population but only 2.8% of the physical scientists and only .9% of those holding a doctorate in the physical sciences. In the same year Black full-time enrollment in the physical sciences was 4.6% as large as the white for undergraduates (4,790) and 2.0% as large for graduate students (600). At the same time Black college students aged 18-21 were 10% as numerous as whites. Everyone recognizes, I think, that the minority college going rate is not as high as among whites. However, if one takes account of college going rates as a function of socio-economic level, minority and white rates are comparable. More important, for you and me, is the question of field allocation and retention. That is for the minority students already in college, the rate of entrance into the physical sciences is only .43 as large as the rate for whites.

Why focus on community colleges? Again in 1974, of the 500,000 full-time undergraduates who were Black 32.9% were in community colleges as compared to 27.7% among whites. Outside the South (Virginia to Louisiana) the average CC figure is 36.5% rising to 63% in California and 49.8% in Illinois and 36% in New York and New Jersey. It is estimated that 50% of entering Black college students are in community colleges. The College Entrance and Examination Board compiles an annual roster of talented minority community college graduates who wish to go on to a 4-year college. Out of 1225 minorities students listed in the 1977 roster 11(.9%) were in the physical sciences and only 3 in chemistry. Finally, we have no hard figures, but estimate that the number of Black faculty in community college chemistry departments is around 50.

Given all these figures we felt we could make a unique and significant impact on chemical higher education by developing a D.A. program. And so in 1974 we submitted a proposal to the National Science Foundation. We received a sizeable 3-year grant to start our activities.

D. The Program

What is our program and how did we arrive at it? Mooney and Brasted authored an Advisory Council of College Chemistry report on the education and training of community college teachers in 1969. It recommended a training program which included:

(1) A broadly based masters with some interdisciplinary education in chemistry, math, and physics.

(2) Emphasis on basic principles rather than special topics,

(3) Development of communication skills and an understanding of community colleges,

(4) Some chemical research,

(5) A Co-operative internship.

The report noted that courses taught by education departments were unpopular but that teachers wanted skills in developing laboratory experiments, using instruments, and production and use of teaching aids.

The program we have evolved so far, ie. 2 years into actual operation, includes:

(1) 33 semester hours of required chemistry courses including six hours of masters level chemical research with thesis. The courses cover the full range of chemistry.

(2) 12 semester hours of electives in chemistry, biochemistry, math, physical science, and computer science.

(3) An education-teaching component of 18 semester hours which includes a progression of varied activities which build sequentially to a semester internship where the D.A. student is in full charge of a course. The student can add one or two electives in this area. This component is handled by a regular member of the department. It includes periodic seminars.

(4) A dissertation project which must involve as one of its parts the relating of chemical research or knowledge to a teaching context.

Included in the education-teaching component is some background on and issues of higher education and community colleges, a course in the history of science, the use and development of various computer and media tools, some learning theory and a look at various current trends such as the Keller approach, and some testing theory. During the internship, students are video-taped twice for staff and student discussion during subseauent seminars. We have also subjected our own staff to this process.

The D.A. students are exposed to the chemistry industry through weekly industrial chemistry seminars which are a part of our industrial chemistry program.

An off-shoot of the program was the restructuring of our first year for regular M.S. students involving a team-taught intensive course involving general-physical-and inorganic chemistry which proved (to the staff involved) that teaching can be enjoyable.

We expect a B.S. student would take four years to complete his or her degree. However, many if not most, of the students will enter with some sort of masters and previous teaching experience. We have five D.A. students in the second year of operation, two of whom come from CC faculties.

We are just beginning to get to the dissertation stage and I'm not sure as it will be easy at first as the faculty is as new at this as the students.

We foresee some possible auxiliary activities such as summer faculty development institutes on new ideas in teaching, production of media materials, and participating in the start-up of a new science oriented high school in Atlanta. There are, in fact, more beckoning and beguiling paths than we have the time or manpower to explore.

E. Relation to Community Colleges

How will our D.A. program involve community colleges. Thus far we have done so in a number of specific ways. In April of last year we invited 10 community college chemists to a conference on the D.A. degree to obtain their ideas and advice on what activities should be included in a D.A. program.

Two members of the department have spoken at $2YC_3$ conferences - Dr. Polk on the industrial degree and myself here. Next week you or your chairperson will receive a survey we have sent to all community college chemistry departments to get an overview of what is happening in your world and where it is going. Hopefully we can publish the results as a report and in the J. Chem. Ed. In the long term we would like to become a resource for the $2YC_3$ and the junior college chemistry community as a whole in gathering data, providing reports, providing teaching-learning materials, and as appropriate, sponsoring or co-sponsoring conferences on special topics.

Currently two of our five D.A. students are former CC faculty. One student interned at Atlanta Junior College last year and moved from having had no prior knowledge of Community Colleges to wanting to work in one as her first choice. We held three D.A. seminars at Atlanta Junior College last year, and used one of their faculty as an adjunct professor in our program. Overall, I expect about half of our D.A. students and half of our focus will be on the community college scene.

As the program expands we will want to place more students as interns at CC's outside Atlanta.

As you may know career counseling is getting more and more computerized. The story is told of a student in California who sought out the computer's advice on what he should do after his impending graduation. The computer asked him what he had majored in - Black Studies and Dance. The computer responded shortly with the letters: R T B B P T P C
The student was puzzled and asked for clarification. The computer obliged with the message:

"Report to Bakersfield. Be prepared to pick cotton."

I'm not sure I would agree with the computer's assessment, but I would hope that for 50% of our D.A. students the computer would respond:

"Report to X community college. Be prepared to teach Chemistry.",

and the student would not panic.

Enhancing Changes for Success in Chemistry

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The construction of an effective course in chemistry presents us with a formidable set of problems. In other words how do we go about doing the job in keeping with the high standards that ought to characterize college education while the open-door policies (which I endorse) typical of state and community colleges presents us with a mind-boggling variety of student types and backgrounds? Obviously, we cannot have separate courses for veterans, repeaters, career-changers, the temporarily jobless, and society's born losers and rejects whom we euphemistically refer to as "culturally disadvantaged".

It seems to me that one of our primary jobs is to identify those needs that are common to the whole spectrum of student types. This may be an impossible objective, but no one has ever suggested easy solutions. It may be that we are dealing with a problem for which there is no solution, but rather we will have to be content with a steady evolution from bad to better.

A successful chemistry program, as I envision it and try to implement it, should include the following components: competent and caring instructors who are committed to humanizing our discipline, a concern for values not measurable in dollars and cents; and in addition to flexible methods for teaching knowledge and skills, a set of decent attitudes that are derived from the supporting base of values. This latter concern is often referred to as "competencies", and when we talk about competencies -- skills, knowledge, and values -- we encompass the whole range from most general (in a global sense) to the very specific (individual course) that will prepare our students for the business of living meaningful and productive lives.

The joy I find in my profession as a science educator is a special one because it is shared equally between me and my students. It is a joy that blossoms most fully in our midst when subject matter, teaching methods, objectives, and all the other particulars of the educational arena become inseparably fused with human values. These values are not philosophical abstractions that so often exist in our minds as unattainable (or even pretentious) hopes. They are, rather, the functioning products of our human tendency toward trust, warmth, and compassion. J. Bronowski enumerates these values, at least in part, when he writes of freedom of thought, justice, honor, human dignity and self-respect.[1]

We are in the process of rediscovering the enormous satisfaction found in the commitment of our energies and talents toward the restoration of the service ethic. That we as educators can serve our students in the process of educational fulfillment, and as scientists we can serve our communities in the promotion of the health and welfare of its citizens.

Certainly, contributions of science to war, pollution, and the reckless exploitation of natural resources bear witness to the awful consequences we suffer from ignorance or disregard of the centrality of human values in scientific endeavor; but as Bently Glass states, "It has been said that science has no ethical basis, that it is no more than a cold, impersonal way of arriving at the objective truth about natural phenomena. This view I wish to challenge, since it is my belief that by examining critically the nature, origins, and methods of science we may logically arrive at a conclusion that science is ineluctably involved in questions of values, is inescapably committed to standards of right and wrong, and unavoidable moves in the large toward social aims."[2]

The essence of Glass' statement, which I whole-heartedly endorse, is the belief that any separation of scientific activity from man's concern for human values is a gross distortion of the nature of science. My joy in sharing science with students comes from a concern for human dignity and self-respect and it generates a whole approach to science teaching -- not just a particular methodology -- that recognizes and utilizes the Force of Personality.

If we as educators are prepared in depth to teach a particular discipline, and if we find excitement in our subject matter, and if we make an inner commitment to communicate this excitement to our students, then we need to do so through the medium of our own personality. Each of us has our own style of speaking, our own experiences, sense of humor, and anecdotes.

To a large extent, the degree to which a student finds a course meaningful and memorable is related directly to the infectious enthusiasm of the teacher. Underlying this aspect of personality is the question of values. If the teacher does not have a clearly defined sense of justice regarding expectations and evaluations then student enthusiasm can be stifled. If the student is spoken-down-to, subjected to remarks and treatment that take away human dignity, the excitement is replaced by resentment. In effect, regardless of how excellently the subject matter may be presented, the student must really believe that the teacher cares about him as a person.

There are many who would take strong exception to the whole concept of the Force of Personality. They might suggest that effective education should depend on the adoption of a proven system that works regardless of the teacher involved. Some proponents of "systems" approaches[3] and an inflexible use of an individualized learning techniques such as the Keller type plan[4] would shift the emphasis from personality to methodology. In some cases we are faced with an admittedly honest difference of opinion. The thrust of my argument, however, is not to create battle lines and say it's man vs. machines, or personality vs. methods. It is a plea for us as people to bring our excitement and concern for the dignity and well-being of our students into the classroom so that any system or method becomes more humanized.

The most elegantly conceived self-learning packages, cassette-tapes, computer programs, lists of behavioral objectives, and criteria for accountability cannot fully communicate the essence of science and the joy of learning. Many years ago, J.W.N. Sullivan wrote "Science is valued for its practical advantages, it is valued because it gratifies disinterested curiosity, and it is valued because it provides the contemplative imagination with objects of great aesthetic charm."[5] One might ask, rhetorically, how much aesthetic charm can be provided by any system, method or device which ignores the Force of Personality.

I believe that we ought to assume that no one method will be a panacea. If we are going to demonstrate the validity of the continuing application of the interplay between experiment and theory to problem solving, and show our students the point-counterpoint of inductive and deductive reasoning, we must allow that there are a variety of pathways toward finding the answers. An attitude that suggests that our definition is <u>the</u> definition or our method for solving problems is <u>the</u> method, smacks of an arrogance that is the very antithesis of what scientific mentality is supposed to be.

We all know very well how the scientific community is prone to hop on the bandwagons of new pedagogical techniques. Our submission to the new fads and fashions of our craft prove that we are as human as any other segment of society. We like to be "modern" and stay abreast of new developments. But the trouble is that our acceptance of the "new" sometimes makes us less critical than we might be -- even contemptuous or scornful of the "old". The term "lecture" has become a dirty word. Nowadays we "discuss" things. But is "discussion" always possible, and does the rejection of a "lecture" take into account the nature of the material being taught, the many variations that remove the lecture experience from the traditional stereotype, or the personality of the lecturer.

Our war is against mindlessness and for this there is no single panacea. Let us show our students the varieties of scientific thinking and give them flexibility and choice. Whenever we tend to believe there is some special merit in sticking unswervingly to one method of problem solving because it makes us "consistent", we might remember Oscar Wilde's words, "Consistency is the last refuge of the unimaginative".

The teacher, then, operating through the medium of his own uniqueness and using a concern for values as a cornerstone in the construction of the course, can relate to the needs of the students. The teacher's operative values manifest themselves at the very beginning of the course with regard to the question of, "Why bother with science at all?" Yet another question dealing with the attitude of the teacher toward examinations and grades projects another dimension to his system of values.

The validity of grading, in terms of today's educational realities, is challenged by Max S. Marshall . He says that the use of grades has been stretched far out of joint in that the dehumanizing characteristics of "pure" objectivity in ranking by percentages and percentiles, symbolic relatives (A, B, C, and so on), or GPA's take away from what educational is meant to be.

Whether or not we can do away with grades as Marshall suggests, is a very debatable point. He does, however, provoke our thoughts on the subject to the extent that we must resolve our attitudes and let the students know where we stand at the beginning. If we diminish tension, and the grim, humorless preoccupation the student tends to have toward grades we are taking a giant step in the direction of humanizing our craft.

Grade consciousness can be diminished further, if we can justify to the students why they should expose themselves to the rigors of a particular scientific discipline. Most importantly, our rationale must include reasons quite apart from the practical necessity of science courses for students pointing toward a career in a science related profession. Pragmatic justification is really *sine qua non*, but justification in terms of moral and cultural values is the challenge to our imaginations.

One reason is that students, as citizens, have a responsibility to become literate in science. It is a concern for truth and accuracy (if not self-preservation) to be able to evaluate critically the claims made by scientific industries in popular magazines and newspapers. Perhaps, more importantly, scientific literacy can help our citizens cope with the exalted status of science often granted by people who have only a vague notion of what constitutes scientific activity. We need to learn about the historical forces at work in the theoretical-experimental interplay that led, and still leads us today, to meaningful scientific constructions. Structures that are aesthetically pleasing and useful to mankind. Structures that are unique insofar as much of the beauty inherent in them lie in their tentative nature -- an amalgamation of hypotheses, theories, physical laws and bold assumptions. In effect, scientific literacy, in addition to providing the knowledge to make sensible decisions in the area of commerce and government may enable us to distinguish between science and scientism.

The aspect of aesthetics is no mean consideration in choosing science as a career. Erwin Schrodinger tells us that as we try to find out something about our planet we find it extremely interesting and we delight in it[8]. Another great scientist, Werner Heisenberg, succinctly relates the aesthetic nature of art to science: "Therefore, the two processes, that of science and that of art, are not very different. Both science and artform in the course of the centuries a human language by which we can speak about the more remote parts of reality, and the coherent sets of concepts as well as the different styles of art are different words or groups of words in this language."

Of course, each teacher, again through the medium of his own personality, can arouse the students' imagination by way of responding to the fundamental question of why study science. Each of us has an immediate opportunity to communicate our personal enthusiasm for what we teach.

The interjection of values, without which I cannot find the joy of teaching, can start with those factors that constitute scientific method. Not the scientific method as it is often presented in the form of a sacred list of steps that start with "identify the problem" and end with "verify the results experimentally and draw conclusions," but rather the method as an all out assault on a problem in which its own peculiar nature will dictate the systematics to be employed. Then, regardless of a particular form finally assumed by a scientific method, its success (and our success in becoming fulfilled human beings) will ultimately depend on attitudes such as openmindedness, humility, and a sense of wonder at the beauty of the challenge. The total prospects for success in any scientific method will also depend on our acceptance of the facts, a sensitivity to where the facts lead, and an intellectual preparedness to gather and discriminate among the facts, and above all a processing of the facts in an atmosphere of absolute integrity. Thomas Huxley says it so well when he writes, "My business is to teach my aspirations to conform themselves to fact, not to try to make facts harmonize with my aspirations. Sit down before a fact as a little child, be prepared to give up every preconceived notion, follow humbly where ever nature leads, or you will learn nothing."[10]

Finally, scientific method needs to be concerned with the dignity of human beings; indeed, a reverance for all life. Ways in which we can demonstrate our concern for people must never be confused with techniques of human engineering -- how to manipulate people and make them like it. The show of solicitude and courtesy toward people as a personally advantageous technique is as reprehensible as arrogance and nastiness in our relations with people. While the latter actions are discouragingly boorish, human engineering is fundamentally dishonest and therefore corrosive to scientific method.

Positive and human attitudes inherent in scientific method can, and ought to be demonstrated to our students right from the beginning. We need to show by our words and manner, that we are concerned with their dignity and well-being. We are anxious for them to persevere and find the joy that we find in science. In order to accomplish this, we should clarify for the students just how we regard some of the aspects of the academic scene which they consider to be very important; method of instruction, the basic skills to be acquired, the factual and conceptual content to be mastered, and our attitudes toward testing and grades.

I propose no magic recipe for instructional method and the best method, in any case, is that style most completely geared to the personality of the teacher. Regardless of various systems or plans currently in vogue, there are times when we need to meet our students en mass so that we have the opportunity to inspire, arouse curiosity, reaffirm the purpose of it all, and in the process let them be entertained. Do we have to be apologetic for our tendency toward showmanship? Many of us are perhaps needlessly embarrassed because we assume that while true scholarship may admit a degree of levity, it should never stoop to being theatrical. But are the famous demonstrations of Hubert Alyea, J.A. Campbell, and others less valuable for the inspiration they provide because of the histrionics involved?

Of course, some of us are are not showmen in a dramatic sense, and we prefer to communicate our enthusiasm in a more low-keyed manner. While a "magic show" type presentation may be sensational when presented by an Alyea it could be a complete dud or even a subject of mockery when done by someone else.

The important thing, however, is not that we debate low-key vs. on-stage dramatics, but that we turn-on our students by the human impact that cannot be obtained from books, programmed packages and tapes. Let them absorb what they can from the written page and then come to us for guidance, experience, perspective, enthusiasm, and a touch of human warmth that reassures them that we really care.

The speed with which we move through the topics in science and the amount ultimately covered has to be varied if we are to avoid boring some students and losing others. To paraphrase an anonymous sage, it is a teacher's function to uncover a book rather than cover it. It is very unrealistic to assume, placement tests notwithstanding, that any class is going to be truly homogeneous with regard to student background and ability. A lock-step progression through a course is almost certain to result in some failure, not necessarily failure with a grade of "F", but failure in our efforts to turn students on to science and give them a significant measure of subject matter mastery and a gain in wisdom and judgment.

There seem to be four outstanding areas of need in the improvement of basic skills; reading speed, reading comprehension, study habits, and mathematics. We have all seen example of students reading at a junior high (or lower) level. They read slowly and comprehend with difficulty. The fact that they also must read and re-read for a number of hours that far exceeds our expectations creates a demoralizing condition -- if not a nearly impossible hurdle for them to leap. Students who read chemistry problems and fail to identify clearly what they are trying to solve and who are unable to organize the data available need help desperately.

Our college has a Learning Center equipped with the hardware and software designed to help these students. It is staffed with specialists in the field of reading and study. And we direct our student to these specialists. Periodically, free short courses in reading and study are provided and they are advertised. It seems to me that this is the only reasonable way to handle the problem. As long as we maintain an open-door admissions policy, the availability of reading and study specialists and programs are essential for student prior to, or concurrent with, developmental (remedial) courses. This is not a redundant operation although it may seem to be so.

Remedial work in mathematics requires patience and reinforcement. The "new math" is an easy scapegoat when we choose to envision it as it was in its early days. But the "new math" is changing toward a more practical orientation and we should agreeably move toward a fuller cooperation with mathematics teachers. We cannot, and should not, expect them to function as servants to the sciences. Mathematics teachers are starting to realize, as Keith Laidler (University of Ottawa) says, that "Mathematics may be the Queen of the Sciences, but she should be prepared to mingle with her subjects."[11]

In our effort to bridge the gap between pure and applied math, our remedial work could profitably concentrate on percentage calculations, graph construction and interpretation, basic algebraic operations, dimensional analysis, scientific notation, and the proper use of significant figures. I would suggest further that we emphasize the quantitative aspects of our laboratory exercises so that numerical data are constantly moved from the realm of the abstract to the concrete.

Many will assert that in a free society the student must have the right to fail. But this morsel of intelligence becomes increasingly unappetizing as we reflect on it. To put it bluntly, many students fail because we have failed as teachers. Of course there are exceptions since we have no control over many external influences that affect a student's progress. But the center of my thesis is that near universal success is possible if the pressures of lock-step progression is replaced by allowing the student to gain mastery at his own pace and in an atmosphere of encouragement and understanding. Only when a student feels that the stated objectives for a particular topic have been fulfilled, should he encounter that special learning experience we call a test.

The administration of tests for the purpose of arriving at a grade is perhaps the poorest reason of all. Most students, however, have been conditioned to see tests used in this way. It often takes an enormous amount of persistence on the part of the teacher to fracture this traditional viewpoint. If the grading aspect of a test can be reduced to just-another-evaluative item, we might be able to measure subject mastery rather than a student's reaction to mental stress.

Let us emphasize that a test can be an excellent learning device. It can point out to a student those concepts and problems that need further investigation. It gives the student a chance to tie related facts and concepts together into a meaningful whole. And it indicates to us teachers where we might do a more effective job.

Assuming that we are humane beings (if not amateur psychologists), it would seem to me that we ought to be concerned with some self-image building or damaged-ego repair for many of our students who come in with a feeling of hopelessness and little or no self-esteem. After all, we can't do much with students who tend to give up before they start. With an attitude toward our students that encompasses gentleness, humor, and an insistence on their intrinsic worth and human dignity we can generate the optimal climate for learning. We need to balance criticism with praise when possible. We should encourage and reassure with unflagging patience. And we need to be accessible to students who would come to us for help and understanding.

We need to re-evaluate our objectives periodically so that we can distinguish between the ideal and the realistic. We should constantly remind ourselves about who we are teaching and what we are preparing them for. Realistic goals probably lie somewhere between the extremes of high standards (flunk'em if they can't hack it) and the dispensation of an oversimplified pablum that is not quite honestly called college chemistry. A partial answer might be found in the use of individualized and self-paced programs.

My own approach has been effective to such an extend that I would like to share it with you. The students are provided with a list of competencies so that they might be aware of the variety of skills and kinds of knowledge they ought to derive from the course which are relevant to their future careers. In addition to the competencies we expect them to acquire, they should also have a clearly stated list of learning (behavioral) objectives so that they know what is expected of them in terms of content mastery in a chapter. Questions and problems are assigned as a loosely constructed pre-test. Then all students take an exam at an announced time.

While the exam is not open-book, the students are permitted to bring a 5"x7" card to the exam on which they have written any information they deem essential. The advantage of the legalized "crib-sheet" is that it forces the students to study, organize, and identify gaps in their understanding of concepts and capability to solve problems. I've found that open-book exams, by contrast, encourage poor preparation and a frantic riffling of pages in an effort to find answers that are usually not there.

On the basis of their individual results, the students can identify their specific problems and remedy them by additional study. When the student has achieved a more solid mastery, he or she can arrange a re-test and demonstrate their improvement. The re-test opportunity has been a tremendously positive force in student learning. It makes the exam more truly a learning instrument as opposed to a mere grading device. The slower learner is not penalized in this way.

In order to make the re-test a less time consuming operation, I require the students to retake only those problem types that need improvement. Hence, a student who scores 80% may need to take only two problems of a type that were incorrectly done in the first exam.

The enormous improvement often shown by students on the re-test is gratifying to them and their teacher. I think we can teach a lot more chemistry outside the shadow of the guillotine.

Regardless of whether or not we institute a contract system for grading or use a more fluid system as we "play it by ear," the greatest justice might be realized if the student's grade is related to his own ability and effort in covering a lesser or greater portion of the course content. Whatever the extent of coverage and regardless of the number of tests taken per unit, there will be no meaning to the concept of failure.

In the final analysis our true job as teachers is not to be dispensers of grades and defenders of ancient academic traditions (including the handing out of grades of F), but it is to communicate the excitement and joy that we find as scientists and teachers of science.

When a student has set unrealistic goals for himself as, for example, the student who wants to go to medical school although he consistently demonstrates a very limited aptitude for science, he can be counseled in another direction, be it allied health technology or something else. In any case, there should be no compromise with human concern, a compassion if you will, for the individual. If we do, we are guilty of paying mere lip service to the fundamental belief that moral values cannot be separated from scientific endeavor.

Perhaps it is a dreamer's dream that someday our profession will be wholly and ineluctably involved in questions of values and that we will have rooted out all vestiges of those dehumanizing traits that conspire to destroy our vision of things as they should be. Let us address ourselves to the communication of the excitement and joy that we ourselves experience. It is a beautiful commitment in which the force of our unique personalities can bear witness to the values of open-mindedness, integrity, perserverance, justice and a warm concern for those people we call our students.

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Laboratory Courses in Chemistry — A Great Idea But Can We Afford It?

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Today we are addressing ourselves to several of the current problems involved in teaching chemical laboratories. We have already heard about the increasing concern about safety and I will return to that subject from a different point of view later. I shall address myself to the topic of the cost of operating chemical laboratories at either a two year college or four year university.

To give you an idea of the viewpoint of my comments let me give you a brief history of my connection with this topic. As a recent Ph.D. graduate I directed the freshman chemistry laboratories at Stanford University for two years. Then after a few years out of touch with Freshman Chemistry, I was Chairman of the Freshman Chemistry Program at Louisiana State University for three years and for the past six months have been Chairman of our Chemistry Department. I am active in theoretical physical chemistry research in addition. Therefore, I speak as one who is interested in chemical laboratories themselves, in new and better teaching methods, and in the costs of operating chemical laboratories in a university environment dedicated to teaching and research. While in previous positions I was most concerned about pedagogy, the topic of the economics of teaching chemical laboratories is probably of most importance to me in my present capacity as Chairman in a period of essentially static budgets. I shall also primarily address myself to laboratories for students who do not plan to become practicing chemists, but will need to use chemistry in their work as the arguments concerning professional training are certainly quite different.

Let us first review the situation in general. Why is the topic of the cost of chemical laboratories of such immediate concern today? I think there are at least four major reasons, probably more, but let's at least address ourselves to these four. First of all is the obvious problem of the last few years, namely inflation. What cost a dollar a few years ago is, or could be as high as a dollar and a quarter or more today. As an example, recently average chemical costs have been increasing by about 9% per year, with plastic products increasing by close to 17%. None of us can deny that inflation is certainly a major factor in our concern for funding at the moment. However, inflation would not be so serious were it not for the fact that the current level of funding of public, and certainly private institutions, has almost become constant, at least in terms of real dollars. In fact, in many institutions the funding levels are being reduced or sometimes remain constant in terms of real dollars. Therefore, in order to maintain ones' present program in the face of inflation, economy is essential. These are the two basic factors influencing the urgency of our concern. However, there are two other factors which affect the cost of the operation and yet have their origin in other areas.

First of all, let me briefly address the subject of safety. As we have already heard in the previous talks safety is of increasing concern in the chemical laboratories but the point I would like to make right now is that to have a very safe chemical laboratory, to "accident-proof students" costs money. This cost is certainly involved in building modern buildings, but it is also involved simply in the operation of the laboratory itself. It is very difficult to put a dollar sign on many of these safety features since in many cases we are not yet sure what will be ultimately required for us to meet high safety standards in the laboratory. Therefore, we cannot really face this problem adequately at the moment and therefore let me abandon the topic for the rest of this talk. However, it is certainly going to be a factor in the future as it is evident from the few items already being brought to our attention. These items obviously include safety glasses, maybe safety shields, various types of shielding for experiments, solvent cabinets and almost an endless variety of other items.

Finally, however, I believe there is a more important reason for being concerned about the cost of laboratories today and this is a very positive feature, namely people today are concerned about the quality of laboratory instruction. They are searching very hard for ways to improve and modernize our teaching of chemical laboratories. As with most innovations in chemical education it costs money. Several of the methods of teaching involve individualizing the instruction to the student and along with this some sort of modular laboratories in which not all students are doing the same thing at the same time. Very often these are open ended experiments in which the students go off on their own to explore various new things that intrigue them. These are all exciting possibilities and very successful ways to teach laboratories. I am all for them. However, they usually involve increased amounts of instructor time and often special chemicals and usually equipment. Great ideas but can we afford them! The problem of equipment is very serious; it is serious even in a large research oriented institution such as ours since the research equipment is almost used constantly by graduate students and other research personnel and therefore is not available to undergraduates as much as one might first imagine. At smaller colleges, obviously the equipment is utilized more by the undergraduates but there is also less justification, in some sense, for purchasing the equipment. Certainly, standard arguments relating to chemical research are less applicable and fewer grants are available for purchasing the equipment.

It always amuses me to see people try to sell new innovations in the teaching of chemical laboratories as being more cost effective. In most cases they are not. This doesn't mean that they shouldn't be done; it just means that one must be honest in presenting the real facts of the case. In the case of modular experimentation there are savings both in equipment and possibly in supplies by having no more than one or two groups of students do the same experiment at any one week. However, the costs in terms of faculty or teaching assistant time increase dramatically. Either one has to have smaller classes or one has to have more instructors involved for the same size class. I remember one case at Standford where we had an extremely successful laboratory program for the better students in our freshman laboratory. It was so successful because the teaching assistant spent all of his time preparing for the students' activities and unfortunately spent none of his time on his graduate studies. He quickly flunked out of school and we lost an exceptionally able future teacher.

With this background let's address ourselves to the real issues, especially the ones which we can categorize and identify in some quantitative sense. Let's ask the question: Is the chemical laboratory really worth it? First of all, let's look at costs and I will use the numbers that we've been gathering at LSU for rough comparisons. They are probably not too far from costs at other institutions. First of all, in regard to chemicals and other disposable items like filter paper and the like, we estimate that our freshman laboratories cost between eight and ten dollars per student. In 1971-72 we estimated that the department expended about $34.27 per student in all undergraduate laboratories for all types of purchases.

Then we can address ourselves to the cost of teaching those laboratories in terms of an arbitrary number of, say twenty five students per laboratory and roughly $4500 for a graduate teaching assistant whose only duty it is to teach one six hour laboratory. In using those numbers we arrive at a cost of roughly forty-five dollars per student credit hour for the instructor's time. If you use a reasonably cheap professor the number could be around seventy dollars per student credit hour, again assuming 25 student laboratories which certainly is far from ideal. The number of students should be less. On top of these costs are the costs of basic equipment for the laboratory and those costs can be whatever number you like. That's where the real problem lies in establishing the chemical laboratory. However, as we will see later, there are even problems with the numbers we have presented so far. When we were faced with establishing a new organic laboratory because of increased enrollment a few years ago our estimate was that it cost us roughly $300 per student to furnish a typical organic laboratory student's desk.

Is it worh it? What are the benefits? Could we do something else? In my opinion the chemical laboratory is an essential part of chemical education. Chemistry is a laboratory science, and I say that from a background as a theoretical chemist. It is only in the laboratory that the student really experiences what chemists do, what chemistry is all about. I think that if we were only teaching a list of certain basic abstract chemical facts there would certainly be no need to have a chemical-laboratory. One could teach those topics in a lecture format by lecture demonstrations, by video presentations, or a variety of other means. However, I think that we are teaching in some sense the flavor of chemistry. This is in addition to our training of chemistry majors who certainly need to learn techniques and become proficient in them. It may have been overstating the case, but I remember one professor saying that one couldn't teach chemistry without the smells. In a limited sense he made an important point.

We do have alternatives with which to present the facts of chemistry, but we have no alternatives to really get the student to fully appreciate what chemistry is all about. I think that this is important to keep in mind since maybe in some cases we do overdo the need for laboratories or at least tye type of laboratory we teach. For this reason in most cases it is not necessary for the chemical laboratory to be intimately correlated with the lecture course going on at the same time. We and many other schools have been forced to abandon the laboratory course during the first semester of our course for purely economic reasons (about 40 percent fail the first semester, at least half of whom never retake the course). I am not convinced that we have really lost much from a pedagogical sense because those students who do not get the laboratory experience are those who have, in general, dropped out of school or have realized that their real interests lie in non-scientific areas. In multi-sectioned courses, there is no easy way to have all professors stick to the same schedule anyway without greatly restricting their individuality. Then too, for many students "armchair chemistry" satisfies everything we need for much less cost.

We are then faced with the real question of how do we finance chemical laboratories? I would like to spend some time on this topic as I think there are some aspects of it that often we as professors do not pay attention to, and only if you become a chairman or some higher administrative official that you realize the full impact of certain practices on day to day operations.

I would first like to address myself to problems of state supported institutions operating under formula funding. One issue that we have mentioned before is the magical, mystical, student credit hour, SCH. Most costs and allocations in universities are assigned the funds based on the number of SCH's. However, in most cases this number is calculated on a salary basis alone. For example, if one has a professor making $18,000 a year teaching 12 credit hours in which there are 100 students in each class the cost per student credit hour would be $15. It is realized by people drawing up such formulas that this is not covering all of the costs - there are building costs, supplies and a whole host of other things. And so, usually after one has arrived at these arbitrary numbers and the totals are tabulated another equally magic fudge factor, greater than one, is negotiated. This multiplies the SCH production numbers in order to arrive at the total funding of a university or college.

I go into this detail only because it is of importance to anyone teaching a laboratory. I believe we have already made the case that laboratories are expensive. I would like to reiterate that not only because it is true, but because laboratories have costs which go beyond simplistic formula funding. One must be very careful not to allow administrators to judge the costs of operating a laboratory based on the implementation of this formula using the total costs and not only the cost of salaries. We have already seen that the salary costs of operating a laboratory course are in general quite high as are the equipment and supplies expenses. For example, I might say that at Louisiana State University the laboratories cost significantly more, almost double, what is allocated under the simple formula. Therefore one can look at funding of say chemistry departments on two bases: one, the total amount of funds coming to the department, or simply the amount of salary funds expended on a given activity. The latter is the only, way appropriate under most types of formula funding. If one would try to analyze the budget of chemistry departments based on their total funding per SCH they would of course have substantially higher percentage implementation of the formula than is really appropriate. One of the major reasons for this exaggeration is the cost of chemical laboratories. If we accomplish nothing else it is important that we convince the higher administration that chemical laboratories are expensive. In private universities one also has to convince the administrators that laboratories are expensive. The arguments probably are not quite so quantified as with formula funding but none the less are similar. We need to continuously make the case for increased funding of chemistry departments where a large laboratory teaching is involved. Unless we make this case very strongly, the situation I am afraid in regard to chemical laboratories will become even worse.

Another issue of concern to us and to many schools is the possibility of directly charging students for their expenditures in the laboratory. On this subject one faces two arguments, one being that the students have selected to take the laboratory course and therefore should pay for the costs involved. On the other hand, the view that students have already paid their tuition and therefore should get everything free. At Louisiana State University we do charge for breakage but have not yet been allowed to make a direct charge for other supplies. In my view, we are being forced into a situation in which the student must pay for the fact that he has elected to choose a curriculum which requires chemical laboratories. It is unfortunate that we then in a peace meal fashion pass on the charges to the students who already face increasing tuition costs, but someone must pay the bill.

Above all, however, on the question of funding of chemical laboratories, I want to make an urgent plea that each of you even if you only teach a few sections of a chemical laboratory to familiarize yourself with the funding policies of your institution. You might well be surprised that there are inherent biases against chemical laboratories in the system, whatever it is. These biases also probably apply to any department heavily engaged in laboratory work.

Finally, we come to the question of what is the future of chemical laboratories? I believe at the moment they are doing alright. We are becoming concerned with teaching laboratories better. However, the problems of inflation and limitations on funding of higher education are going to get worse. I believe that laboratories will continue to do well if we convince everyone that they are vital. It seems essential that we who are involved in teaching laboratories and administering departments heavily engaged in laboratory research make this case strongly to as many people as possible in order to guarantee that chemical laboratories will not be something the ordinary student sees only in a science fiction movie or in industrial situations.

A great idea but can we afford it? I conclude we must, but in the most economical way.

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