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ABSTRACT

This paper received the 1976 Gustav-Ohaus - National Science Teachers Association award for innovation in college science teaching. Presented is a methodology for teaching chemistry to nonscience majors which involves the student in the methodology and interpretative aspects of science. Included are six overall considerations of teaching approach which will involve nonscience major students with science and five specific practical examples for implementing the teaching approach. (SL)

IDEAS FOR MORE EFFECTIVE CHEMISTRY TEACHING

1976 Gustav Ohaus-NSTA Awards Program

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INTRODUCTION

In the late 1960's I noted a disenchantment with science, especially by nonscience majors. The sixties represent a decade of discontent, but the total rejection of science by some students bothered me because 14 years of my life had been spent as a scientist and I was acutely aware of the need for scientific lit racy as a part of general education. I recognized the indispensable cultural value of a basic background in the scientific process and also the need for some factual knowledge about chemistry in order for a person to live a better life, individually and collectively, in our modern technological age. At the same time, I recognized some source of discontent in our approach to teaching chemistry to the nonscience majors. The post-Sputnik influence had led to an emphasis on rigor and an approach mostly suited for science and engineering majors. This influence spread from high school preparation to college courses and was of course effective in preparing a larger base of science and engineering students. However, large numbers of nonscience majors were caught in the tide. They had neither the time nor the motivation to get involved in a science or engineering preparatory course. Yet they needed, many unknowingly, a considerable exposure to physical science. With this background in mind, I requested a sabbatical leave for re-thinking, contemplation, and planning for the nonscience major's course in chemistry.

I was forced to envision a radical change in approach for teaching chemistry to the nonscience major. An overall plan and detailed descriptive materials were worked out. Both the approach and the relevant chemistry topical coverage were articulated in printed form for communication directly to the student. The new approach has been used at Ventura College over the past 5 years to provide a very effective program in chemistry for nonscience majors. The major thrust of the new approach is not new to science but is apparently new to teaching. It involves the student immediately and directly in the scientific process--through interpreting practical problem situations by models, theories, and structures.

The broad aspects of the plan are described first below, followed by some specific topical items to exemplify the way students are directly involved in the methodology and interpretative aspect of science.

OVERALL APPROACH FOR EFFECTIVE CHEMISTRY TEACHING

1. Recognize and capitalize on the basic human drive for understanding.

Today's students have shown a trend toward introspection or interiorization which should not only be met but emphasized in a chemistry course. Students have begun to show a growing interest in psychology, transcendental meditation, ESP, and similar interpretative and behavioral areas involving the mind and mind-matter interactions. Even the modern exercise and conditioning programs (like yoga, for yoke or union) recognize the connection between mind and matter and the value of a harmony here. Chemistry is a basic science involving intellectual, harmonious interpretations of material things via hypotheses and theories. Today's students especially appreciate this particular aspect. The early Greek idea of Aristotle is involved here: "All people by nature desire to know." And the "knowing" is basically understanding or interpreting rather than accumulating facts.

2. Spell out the way science proceeds and tie this in with everyone's basic psychological needs.

Some of the beauty of chemistry derives from its ordered development of the relations between things, and between things and ideas. The drive towards connection and order is a major aspect of scientific understanding. This should not merely be in the background of our teaching but must be spelled out and illustrated. This basic psychological approach of science has not been emphasized in our chemistry courses chiefly because of excessive preoccupation with ramifications and complexities of known factual details.

Mark Van Doren had this to say about this important facet of learning: "The student who can begin early in his life to think of things as connected, even if he revises his view with every succeeding year, has begun the life of learning. The experience of learning is the experience of having one part of the mind teach another; of understanding suddenly that this is that under an aspect hitherto unseen; of accumulating, at an ever-accelerated rate, the light that is generated whenever ideas converge. Nothing that can happen to people is more delightful than this; and it is a pity when it does not happen to them as students."

3. Tie in science thinking with everyday thinking.

Unfortunately, students most often see a listing of steps in the scientific method and get the idea that this is what scientists do in a far away laboratory--far removed from reality. This error has often been reinforced by our chemistry teaching in the past. We have, for example, initially introduced students to the scientific method by showing how atomic theory was developed from the laws of definite composition or multiple proportions.

Science thinking is more readily understood when we start with an everyday problem like a car which won't start or a leaking roof, and show students how they naturally attack the problem. This is by looking at it, thinking about it, guessing, and trying out the guess. Once established, these everyday steps can be later related directly to more formal interpretations as science has developed them. Once the connection is made and emphasized, the students accept and understand Einstein's idea: "The whole of science is nothing more than a refinement of everyday thinking."

And this is a tremendous change from the irrelevance of the past.

4. Use quotations freely.

The quotation above from Einstein is one example. Students erroneously think of Einstein as a theoretical person with no practical, helpful insights to provide them as they form their own personal outlook in life. Quotations from scientists help to make science and scientists more human and understandable. But, more importantly, they add insights to the student's life. Quotations by nonscientists should also be used. Quotations are useful not only for concise summaries but also to provide food for further thought. In addition, they serve as a bridge in the liberal arts area between the "two cultures" which really should be one. Here are a few other examples from the vast resources available:

"All religions, arts and sciences are branches of the same tree. All these aspirations are directed toward ennobling man's life, lifting it up from the sphere of mere physical existence and leading the individual toward freedom." --Einstein

"Nature to be commanded must be obeyed." --Francis Bacon

"Tell me what you eat, and I will tell you what you are."

--Brillat-Savarin

"We are as much gainers by finding a new property in the old earth as by acquiring a new planet. --R. W. Emerson

"Beauty is something wonderful and strange that the artist fashions out of the chaos of the world in the torment of his soul."

--W. Somerset Maugham

"The world is too much with us; late and soon,
Getting and spending, we lay waste our powers:
Little we see in Nature that is ours. --Wordsworth

5. Minimize formalized mathematics.

This is an area which has been found difficult by both chemistry instructors and text book authors. They rightly believe that you can have no physical science without the language of mathematics. However, we have to keep in mind that the purpose of a science course may not always be to prepare science and engineering majors. We have long recognized that a student can take a music appreciation course without being prepared to be a composer, conductor, or even an operator of a musical instrument. Yet our chemistry courses have found it hard to draw the same kind of line. It is essential that we learn to draw the line; otherwise we may deprive many nonscience majors of any exposure to the beauty and values of physical science. If some few of these students feel drawn to a science career, they will be able to take the necessary specialized courses later and will, incidentally, be better able to grasp the significance of the mathematics required.

6. Involve the students in experimentation.

Even if a course has no laboratory, there need be no complete lack of experience in this vital area. Simple experiments can be suggested for home or dormitory and others performed by demonstration or group student effort. All the world is a laboratory to one who is alerted and observant to the changes continually occurring. This involves the body, food, packaging, breathing, car, fires, kitchen, rain, dew, climate, etc. All of these involve numerous opportunities for interpreting the changing environment by making scientific judgements.

EXAMPLES OF PRACTICAL INTERPRETATIONS

The implementation of the different approach to teaching chemistry as interpretation of everyday materials is not at all difficult because chemistry is such a basic science. What is involved here chiefly is thinking and planning on the part of the instructor. Simple everyday materials and common experiences serve much better than elaborate, improvised demonstrations of the type which are often used in general chemistry classes. A few examples are given below.

1. Scientific Thinking

A car that won't start is an excellent example for application of science thinking as it is done every day. Observation, guessing, and trying out of the guess (hypothesis) are all involved, including discarding of an incorrect hypothesis. Varied student experiences with cars not starting provide good examples that a first guess may need to be modified or dropped just like a first hypothesis in science.

2. Kinetic-Molecular Theory

A refrigerator and a fly swatter can be used to make the ideas of molecules more relevant. For example, students may be instructed to place a carrot, lettuce leaf, and celery stalk in a refrigerator on an open plate along with similar samples as controls in a tied plastic bag. The obvious and extensive shrinkage of the vegetables after a few weeks in the open space of the refrigerator will make vivid the motion of molecules and involve many concepts of the theory. From this simple experiment extensive development is possible into solid, liquid, and gas states of matter and interpretation in terms of molecular arrangement.

A fly swatter with paper taped over the screen or holes will not be at all effective for swatting flies. But it is very effective for illustrating the kinetic-molecular theory and the nature of air. Considerable thinking about mechanism in terms of air molecules is involved in the interpretation.

3. Fire

Fire was understandably one of the Greek elements. Because of its apparently primitive nature it is fascinating even in the 20th century. Also, the nature of burning, combustion, and the physical phenomena associated with fire are fascinating at every age level. There is a vast amount of theory which can be easily developed via the fascination. This includes the concepts of heat energy, exothermic versus endothermic reactions, activation energy, the nature of energy storage in firewood, and the electronic energy levels of atoms evidenced by colored flames and fireworks. In addition, the control of fire can be tied to oxygen content of the gaseous environment. Fire can be used at several levels of sophistication as students develop their background for interpretation. Eventually, the inevitable carbon monoxide polluting effect of internal combustion engines can be tied to the nature of the hydrocarbons involved and the need for oxygen atoms in the combustion.

4. Newspaper and Magazine Articles

These should be used frequently as resource materials and points of departure for interpretation. This ties in the theoretical aspects very practically to everyday experience and also makes more vivid in each student's mind the habit of interpretation. There are endless possibilities here including gas explosions, foods, poisonings, fires, pollution, advertising. Here is a life-and-death example, of which there are all too many:

> "A twenty year old student nurse was found dead in a sleeping bag in the back of a locked and closed Volkswagen bus in a university parking lot. Alongside her feet was a hibachi containing charcoal briquet ashes. A partially empty, branded bag of charcoal briquets was in the back of the bus.
>
> The ignition switch of the bus contained no key and the investigation

did not implicate the bus's engine as the carbon monoxide source. Autopsy revealed that her heart blood contained a high level of carbon monoxide."

There seems to be no more vivid example than this of the value of understanding the atomic interpretation of chemical reactions involved in burning. Also, the fact that end products of combustion may necessarily include molecular species CO and CO_2 along with the heat which is the major product desired adds life to Francis Bacon's statement: "Nature to be commanded must be obeyed."

5. Foods

Why should we neglect the interpretation of food behavior in terms of molecules? Students are intrigued with interpretations such as "why the cookie crumbles" in terms of behavior of fat molecules. Here are a few examples of interpretative food questions: why bread gets stale, how instant puddings work, why corn starch is a better gravy thickener than flour, why postage stamps taste sweet, how they stick, how oil and water mix in mayonnaise, why olive oil is a liquid and butter a solid, why fats have higher calorie values per gram than carbohydrates and proteins. Practical applications such as these can lead to very effective and motivational teaching of science by showing vividly the great value of conceptual interpretations through molecular structures.

SUMMARY AND CONCLUSION

The brief outline above shows that a radical re-directing of our approach to teaching nonscience majors can lead to exciting experiences for both students and instructors. This does not mean an easy, non-challenging course which too often is associated with the old cliché of "watered down chemistry" for the liberal arts students. On the contrary, the interpretative approach can be challenging to the most gifted of the liberal arts students at the same time that it provides effective and practical insights to the average student.

What is done in this approach is essentially an explicit articulation of the purposes and methodology of science as it personally relates to each individual, and then an exposure of students to experience in the mode of science thinking as they experience the behavior of everyday chemicals. Thus it is less a different approach from that of working scientists than it is a different approach from the traditional fact-and-formula orientation of chemistry instruction. It represents essentially a return to the behavioral approach of science itself. This can be spelled out more formally in the terms <u>operational</u> and <u>conceptual</u>.

The scientist is basically observing how matter behaves and then relating that operational behavior to an idea or explanation via theories and models. This latter conceptual side is where much of the pleasure as well as fruitfulness of science resides. Chemistry is prolific with examples relating the operational--or <u>what</u> matter does--with the conceptual descriptions which relate to <u>why</u> it behaves the way it does. And the students can be taught to begin relating matter and mind in ever more refined and rewarding ways. An example of the way the operational to conceptual approach is open-ended relates to scurvy. Scurvy is a disease characterized by weakness, swollen and bleeding gums, skin blotches, and prostration. This is an operational description. Investigation over many years showed first that scurvy was caused by lack of certain foods like citrus fruit. This is a beginning of explanation--a slight move toward the conceptual. Eventually the cause of the disease was shown to be a lack of vitamin C in the diet.

This is an even better conceptual description: a disease caused by lack of vitamin C. We eventually go further and identify the molecular structure of the chemical vitamin C. Then we have an even better conceptual description. There is even more room for conceptualizing or developing ideas, for example, about the mechanism by which vitamin C affects the health. Indeed, the very conceptualizing leads to the progress as we move away from the operational.

Examples like this show that the very heart of science is the process. When students realize that science is more a verb than a noun they no longer fear the massive numbers of facts. They may even find delight, to varying degrees, in the psychological relevance of chemistry while they also recognize many of the lesser physical relevancies involved.

In our chemistry teaching we have often emphasized the accumulation of facts about nature and deprived people of the interior, intellectual pleasures which are fundamentally involved in the mind-nature contact. As it is in music, so it is in science: the thrills experienced by the specialist can be appreciated, admittedly in a great spectrum of variety, by everyone. In order to achieve this more universal appreciation, we need to articulate the indispensable intellectual values of science as process and method. Chemistry is, among other things, a liberal art which is liberating. Why bury or disregard ideas like the following of Poincare?

> "The scientist does not study nature because it is useful. He studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living. Of course I do not speak of the beauty which strikes the senses, the beauty of qualities and appearances. Not that I undervalue such

beauty; far from it, but it has nothing to do with science. I mean that profounder beauty which comes from the harmonious order of the parts and which a pure intelligence can grasp. This it is which gives body, a structure so to speak, to the iridescent appearances which flatter our senses, and without this support the beauty of these fugitive dreams would be only imperfect, because it would be vague and always fleeting."

Tom Hughes is a member of the Mathematics & Physical Sciences Division, Ventura College, Ventura, CA 93003. His ideas on more effective chemistry teaching are further amplified in the text for nonscience majors, Hughes, T., Chemistry: Ideas to Interpret your Changing Environment, Dickenson Publishing Co., Encino, California, 1975.