IS A TOTALLY CONSTRUCTIVIST APPROACH TO THE TEACHING OF HIGH SCHOOL CHEMISTRY POSSIBLE IN PRACTICE?

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Chemists generally think of themselves as "empirical" scientists without bothering to consider why this view prevails. In a vague sense they believe themselves empirical because they are experimentalists while a theoretician such as a physicist or mathematician is not. In contrast to this segregated view modern cognitive scientists have tried to develop a constructivist model for acquisition of knowledge (Resnick, 1983). The constructivist model states that:

"Knowledge is constructed in the minds of the learner" (Bodner, 1986). Of course such a model makes no arbitrary distinction between experimentalists and theoreticians in how they cognitively construct their schematic models.

Herron (1983) describes the two theories of learning which are applied to chemistry instruction. For learning theory (A) "the purpose is to inform, the teaching procedure used can be described as INFORM, VERIFY and PRACTICE." Learning theory (B) "also has the purpose of the mastery of content, but an additional overt purpose is

to lead the students to adjust the understanding held about a field and/or concept." "Each of us tries to develop the understanding we hold about a particular phenomenon." "Theory B is based on the assumption that learners create for themselves what is to be learned." Herron curtly remarks that "we believe in theory B but teach theory A !" Theory B corresponds closely to a constructivist model for the teaching of science. Much of the pertinent background literature reviewed for this paper does not explicitly state the author's constructivist outlook (see background references), however the view is evident even upon casual review.

Assuming that knowledge of chemistry can be gained cognitively, what approaches to the teaching of high school chemistry are appropriate? Before we consider this question several other questions must be answered. How is chemistry in high school generally taught today? Of great importance is the Piagetian level of cognitive development. Are most high school students truly in the formal development stage and thus capable of abstract thought? If some remain in the concrete stage how should we proceed? How effective are present teaching methods? I will try to answer these questions using both my own experience and the views of several cognitively inclined chemistry educators. Their

papers appear primarily in the Journal of Chemical Education.

Chemistry in the high school today is often taught passively and abstractly, i.e. theory "A". By passively is meant that the students are fed masses of descriptive symbols, facts and theories for memorization. The theories are presented as gospel. No attempt is made to show or involve the students in the intellectual processes which resulted in the theories. Whether the periodic table, gas laws, stoichiometric relationships, quantum orbitals or whatever, the students are taught "rules" or "formulas to plug numbers into". The laboratories generally contain dull or repetitious mixings of solutions with "fill in the blanks" type questions. Little correlation occurs between lecture and laboratory exercises.

Why is chemistry taught this way and what are the results? In the post Sputnik hysteria of the late 1950's new study programs were introduced to keep us up with the Russians. Among them was "Chem Study" which this author took in the 1960-1962 school years. The program, while well meaning, was heavily influenced by input of theoreticians who literally took the chemistry out of the chemistry course! Heavy emphasis on quantum mechanics, thermodynamics and molecular orbital theory lead to a students lack of exposure to basic familiarity with chemical substances. The laboratory was more inclined to molecular spectroscopy or thermodynamics. This pedagogic approach resulted in students deprived of learning to construct a cognitive model of chemical phenomena based upon their intimate knowledge of chemical substances and their transformations. Real chemistry, indeed all real scientific research is performed when we gain intimate first hand knowledge or "feel" of our chemicals, reactions and instruments. Then we may cognitively construct models and theories to explain the phenomena being observed.

Have we taught students to think constructively in chemistry? Anecdotal stories abound of students who think that "magnesium is a green gas" or who cannot solve any problem presenting unfamiliar chemical symbols, equations or applications that are not in the book.

Many students think of sodium as "a group 1 element with a single electron in it's outermost orbital" but have no conception of the real metallic element. "Why can I not throw sodium into water?" Answer: It explodes! "Do really mean to say that table salt forms when I throw this silvery soft metal into this greenish gas?" "How about that." "Do you mean to say that I can figure out formulas and stoichiometries by weighing substances in the laboratory rather than by memorizing from books?" How far many high school students are removed from the practical chemical world!

On a more competitive international level the United States fared thirteenth out of fifteen industrialized nations on a recent science test (Rosner, 1992). We obviously need to improve our scientific literacy. Educators such as Barrow (1991), Beistel (1975) and Nurrenbern -Pickering (1975) argue that we must discard our sterile feeding of the facts or concepts and more actively involve students in how real scientists work and learn. The remainder of this paper will describe several of their techniques, the limitations of the constructivist approach, and this authors experiences.

Barrow (1991) advocates removing the students from standard "paper" chemistry by intensively immersing the students in lecture demonstrations and lab on a DAILY basis. These demonstrations are with a a limited number of substances such as calcium salts, metallic sodium etc. The same substances are worked with again and again. For example, sodium metal may be used to illustrate metallic character, reactivity, stoichiometry etc. In this manner the student develops a "feel" for the substances and may begin to construct cognitive schema for valency, mass-law relationships and comparative reactivities. Calcium salts , being inert and non-toxic, may be employed both in lecture demonstration and laboratory to formulate student familiarity with weight relationships and qualitative tests. Students worked with the same substances demonstrated in lecture during their laboratory periods. Sodium metal, being more hazardous, was limited to lecture demonstration. While Barrow gave no quantitative achievement data, individual students "did appear to benefit", a subjective analysis.

Beistel (1975) developed a general chemistry program geared to Piagetian intellectual development. The lectures and laboratories were based upon intensive instruction in more practical aspects of physical chemistry such as volume/temperature/pressure effects on gases, colligative properties of solutions, i.e., freezing point depressions/boiling point elevations, and heats of fusion. The more abstract concepts of quantum mechanics, thermodynamics and molecular orbital theory were de-emphasized. The approach seems to infer that non-science majors will never need these concepts while science majors will definitely be exposed to them in college.

Nurremburg and Pickering (1987) employed a visual and iconic method to displace traditional rote "plug and chug" procedures for stoichiometry. The students worked on paper with collections of blocks and circles which represented atoms and molecules in various bonding configurations. Since they could not use rote memorized algorithms to predict molecular formulas or balance equations, they had to "construct" an intuitive understanding of stoichiometry in order to succeed.

Sawrey (1987) demonstrated that students trained to work with gas law equations via traditional plug in procedures performed miserably when confronted with problems presenting gas molecules visually in a dots = molecules format. The same problems presented in traditional numerical formats were solved several times more successfully. While she thus showed the failure of traditional methods to promote deeper understanding of molecular relationships, no data was presented to show increased achievement via this approach.

Pickering (1987) decried the rote "cook book" procedures found in most student laboratory notebooks. In order to force the students to construct their own algorithms for efficiently performing their laboratory tasks, they are not allowed to bring their lab text to the laboratory! They are allowed to bring notes or "step out" to the hall-way for text referral. Comparison of the student notes with time for lab completion showed strong correlation of concise condensed notes with efficient lab practice. Students who could construct procedures

to filter out the extraneous textual material were more successful. This approach was successful in forcing students to displace from memory textual concepts or information of less than immediate utility. For example the "solubility product constant" of barium sulfate, a very small number, is always presented in the text of an analysis experiment. The student need not concern himself with this concept, however of immediate need is a lower level practical knowledge that, because of the very low value for this constant, he may wash his precipitate repeatedly with water without measurable weight loss.

In summary, the constructivist approach to high school chemistry instruction emphasizes the student's cognitive creation of chemical concepts via daily active practical involvement with a limited number of chemical substances. Rote procedures, formulas and rules are deferred until the student is given the opportunity to construct his own rules based on his assimilation of the observed chemical phenomena. Molecular models and conceptual diagrams are also used.

An obvious advantage of constructivism is that it is more "concrete". Since it is quite possible that many high school students have not developed to the Piagetian formal stage, they should be more

comfortable with the emphasis on real substances. While there is considerable uncertainty as to whether the Piagetian stages can be accelerated, the opportunity is at least presented by this approach. Another advantage is that constructivism can be fun! Many of the chemical reactions are multicolored or involve visually stimulating gas evolutions, mini-explosions, colored flames etc. Hopefully many disinterested students can be motivated by this approach.

What are some of the disadvantages and limitations of the constructivist approach? Obviously the intensive daily demonstrations and labs may severely limit the topics that may be covered in a semester. Daily lecture demonstrations are time consuming therefore the instructor must carefully allocate sufficient time for lecture and discussion. A totally constructivist course appears to this author to be impossible. Certain facts, such as chemical symbols, must be memorized. Also, Barrow (1991) vividly describes an incident where many students, after seeing a marvelously constructed series of chemical transformations illustrated by sodium metal, were asked to describe it's properties in an exam. A common answer was "sodium is a Group 1 metal with one electron in it's outer orbital" (abstract attributes).

It appears that passive knowledge acquired earlier may not be easily displaced. The constructivist approach may need implementation at the elementary science level. This author has consulted with several high school chemistry teachers who claim that their accelerated groups do poorly in the chemistry achievement when they teach a heavily constructivist course. The test as presently constituted has much descriptive chemistry which they say cannot be covered with available time.

This author's experience and opinions of the constructivist method are influenced by his tinkering with A.C. Gilbert chemistry sets during the pre and early teenage years. The familiarity gained with many chemicals and their reactions may have been a cognitively constructed knowledge base. I found most laboratory work and descriptive chemistry "intuitive" or "obvious" thereafter. In this instance the constructivist approach may have been initiated at a concrete (11-13 yrs) development stage prior to exposure to rote chemical learning in high school. This author intends to employ the construcivist approach as far as is practically feasible when teaching high school chemistry, with some compromise to cover critical achievement test topics for the honors groups.

This author has employed constructivist techniques to a limited degree when teaching general and organic chemistry at the college level. While these students supposedly are at the formal stage of intellectual development, they nonetheless showed great difficulty understanding abstract or two-dimensional representations of stereo-chemical relationships, atomic radii, and resonance theory. Herron (1975) believes as many as fifty percent of entering college students to be at the concrete intellectual level! In my experience molecular models, space-filling as well as ball and stick, proved extremely effective in clarifying molecular concepts. These chemical "tinker toys" are powerful teaching tools at all levels and should be used extensively in high school chemistry. They are fun, non-hazardous and educational. The instructor must emphasize, of course, that they are merely models which help us to visualize abstract concepts of molecular structure and size. Bent (1984) reviews the uses and abuses of molecular models.

Another constructivist technique employed by this author in the teaching of gas law relationships is applicable to high school. The students are exposed to the expansion of gases upon heating and their contraction upon cooling via experimentation in lecture and laboratory

with room temperature, heated, and cooled air-filled balloons. A piston apparatus is used to illustrate the decrease in volume of a gas with increased pressure. Afterwards the students are not allowed to plug numbers into the standard gas law equation but must CONSTRUCT APPROPRIATE CONVERSION FACTORS based upon whether the physical changes occurring result in expansions or contractions. For example, "The volume of a gas is 3.0 liters at 760mm pressure and 298 degrees Kelvin, what is the volume at 1000mm pressure and 400 degrees Kelvin?" Must be solved thus:

V2 = 3.0 X 760mm/1000mm X 400K/298K. Since the

pressure is increased the conversion factor must be <1 (contraction) for the pressure factor while the increased temperature results in a temperature conversion factor >1 (expansion). This technique forces the student to construct his own equation based upon his knowledge of physical phenomena. He should not be confused again regarding which values go in numerator and denominator.

In conclusion, the constructivist model for high school chemistry instruction, based heavily upon cognitive and Piagetian influences, is gaining increasing popularity among chemical educators. At present high school implementation is limited and there appears to be some faculty resistance due to time and achievement exam constraints. The constructivist approach is by itself not enough to improve the United States competitive position in science. Public perceptions of science and scientists need dramatic improvement. Positive media coverage of a young science "superstar" can be highly effective in dispelling negative stereotypes. Nonetheless constructivism is an important tool destined for greater use in today's high school chemistry classrooms.

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