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Comments on the teaching of chemistry, doing chemistry demonstrations, and a passion for chemical thermodynamics ☆

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ABSTRACT

The first part of this essay deals with interesting and effective and fun ways to teach chemistry. The second part is concerned with does and don't's in chemistry demonstrations, i.e., how you and the audience can have fun and learn at the same time. The last part is a discussion of what it is that fascinates me in chemical thermodynamics.

1. Introduction

Professor letcher and I met at a thermodynamics conference in Toronto about 35 years ago and learned that we shared passions for four things: teaching chemistry, doing chemistry demonstrations, chemical thermodynamics and research in it, and certain hobbies like hiking and traveling and woodworking. We have collaborated over the years on a number of papers, and I have contributed to some of the special books he has recently edited. We correspond regularly, and my wife and I visited with him and his wife earlier this year (2017). In this essay I am going to write about some of the things I have learned from him and others about teaching chemistry in various ways.

2. Interesting, effective, and FUN ways to teach chemistry

2.1. What is important

Perhaps the most important thing to keep in mind as a teacher is that if you are not openly and congruently passionate and interested in your subject, then why should the students bother listening? I recall a colleague who always walked into his classroom with eyes beaming and a face full of expectancy and joy. He was there to have fun and do what was most important to him in his life: teach and share and be totally immersed in his students and his subject. This is what he lived for, and it was evident in everything he did. We can all recall being bored into catatonic states by some teachers. Yet, the ones we remember most are the ones who were passionate about their subject, loved it, and respected their students. To a great extent being a teacher means that you are an *actor* on a special kind of stage. When you consider a lecture hall to be a theater, then you are on stage and performing. And yet, you are just the guide and facilitator since it is the student who in single combat really does all the work of learning. The bottom line here is that unless you are overtly enjoying yourself and having fun, you might as well do all of your teaching by referring students to a text book and just hand out your lecture notes.

With regard to books I recall reading about the history of Oxford University (before spending two months there as a visiting professor). There is evidence that teaching there began as early as 1096! What sticks in my mind was a remark that I paraphrase here, "In the beginning students gathered around a Master and they held learned discourse. *After printing was invented* the main method of learning was via reading books." Perhaps this observation needs to be taken seriously when considering "modern" teaching methods!

I have written about the importance of being polite [1]. Learn the names of as many of your students as you can. In a large lecture session, it may only be possible to learn the names of a few students in the front rows. In one university where I was a visiting professor they had relatively small classes of 30 or so. They regularly photographed the entire class, put the names of the students on the photograph, and it was expected of every lecturer that they would memorize the students' names! In a large class I would chat

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up a few of the students (had to arrive early) before starting the lecture. (This, of course, was noted by the other students.) On occasion I taught two sections of the same course, and told each one of them that I really enjoyed being with the best class of the day (hoping they would not talk to each other!). I even thanked them from time to time for just being there: recall the uniform practice of airline staff of thanking you for flying with XYZ Airline as you leave the plane.

Some teachers have difficulties with noisy classes. I do not, and have not tolerated this since it is impolite to me and the other students. I let the students know at the beginning of the course that if I hear or *see* anyone talking in the lecture hall while I am lecturing, that I will stop speaking. I silently write a note to this regard on the board or the overhead projector and stop talking. (The longest I recall having to wait for silence is fifteen minutes!)

Everybody loves hearing stories, and you may wonder about its relevance in a chemistry lecture. I have always told stories at all levels in my lectures. The main reason for this is that I learned over the years that a significant number of the students forgot the subject matter I was presenting, but they always remembered the stories! In this regard it is probably better for the story to be related to the subject matter of the day, nevertheless, my stories were most likely to be of something that just popped into my mind. [Please take note here that in relating the material in this essay that my not-so-hidden agenda is to give you permission to do some of these things in your own lectures.]

In an operational conditioning or Pavlovian manner I always started a general chemistry course with a full period chemistry demonstration show. I wanted that lecture hall to be a place where people were having fun, and in which they looked forward to being. My opening comment (after igniting a hydrogen filled balloon or two - always good to start with a bang!) was, "I am here to have fun and enjoy myself. If you happen to learn something while I am doing that, I will be pleased. Otherwise, I might be just a bit sad." Again, this opening is designed to create an attitude of expectancy about that space and the course and me. (The second lecture is all about the mechanics of the course like handing out the syllabus, etc.)

2.2. On the importance of being (or appearing to be) eccentric [2]

In the danger of offending some colleagues or countries with Britain related lecturers, I note that their chemistry lecturers have long had the reputation of being eccentric. ("Mad" scientists have a long history in the literature and theater.) The importance of eccentricity in lectures is that it establishes an expectancy of surprise in the actions of the lecturer. Is it better for students to expect an ordinary humdrum lecture, or one that may contain surprising ideas and comments and stories? It is my contention that chemistry lecturers not only may be expected to be eccentric, but that they also have the *obligation* to be so! Thus, if you are not naturally eccentric, then it behooves you to behave as one in your lectures. (I owe Professor Doug Rivett a special thanks for showing me the way to eccentricity.)

I cite here one of my own eccentricities from my days of teaching at the Illinois Institute of Technology (IIT). At that time I owned a blue serge suit (in those days we all lectured in suits or jackets and ties) and wore it to class *every day*. One day a brave student asked me about this in class. I told the class that it was a wonderful very durable suit, and that I would wear it until it fell apart! (I did.)

2.3. The sense of wonder and chemistry [3]

I suspect that a central motivating factor in becoming a chemist is wondering about the nature of the world around us and how it is put together and works. In a way, we scientists never get over the curiosity that we had as children. Why this? How that? Because of what? In that sense, if you are not openly and passionately filled with awe and wonderment about chemistry, why are you a chemist? Is it not amazing that a soft metal like sodium reacts with a green gas like chlorine to form the "salt of life?" And did you know that with the naked eye or a magnifying glass you can see that individual grains of salt are cubic? Wow! Incredible! And, how is it that two gases (H_2 and O_2) can react explosively to give liquid water? How was it possible for Michael Faraday to give six one-hour lectures on the chemical history of the candle? One of my cherished books is Faraday's "Chemical Manipulation" [4] which was published towards the end of his life. It is 655 pages long, and is a guide to students in chemistry. Buy the book just for its chapter on electricity! Can you find ways of sharing this wonderment with your students?

2.4. Piaget's developmental psychology and teaching

Piaget's four stages of psychological development have an important impact in particular on how we teach general chemistry. They are:

Sensorimotor: birth to age 2; movement and five senses

Pre-operational: ages 2 to 7; do not yet understand concrete logic

Concrete Operational: ages 7 to 11; need concrete objects to understand

Formal Operational: ages 11 to 16 and onwards; can do abstract thinking

This was discussed by Herron in a 1975 paper [5] explaining what "good" students could not understand, "... a substantial number of entering college students - perhaps as high as 50% in courses for non-majors - are unable to function at an intellectual level described by Piaget as *formal operational*." However, consider that studies of the content of general chemistry courses indicate that 90–95% requires formal operational thinking. *There is thus a major disconnect between content and thinking ability.*

Consider that the subject of chemistry is in some ways three times harder to learn than say English or history. The latter basically require mostly memory, while chemistry requires mathematics, memory, and abstract thinking. Balancing a chemical equation needs an understanding of chemical equilibrium, and calculating an amount of product from amounts of reactants requires some mathematical skills. The understanding of the structure of an atom needs visualization and abstraction. But, if one-half or fewer of your general chemistry students are functioning conceptually primarily in concrete terms, then they may be able to answer questions by rote, but not with understanding. (There is a place for rote learning in chemistry. See Ref. [6].) Here are two things that Herron states that concrete operational students *cannot* do: (1) measurement of density, heat of reaction, and other "derived" quantities that cannot be observed directly; and (2) conceive of atomic weight as the ratio of the mass of one atom to the mass of another atom which is selected as a standard.

Based on the preceding much of the content of a general chemistry course needs to be communicated and demonstrated in concrete terms. Live chemistry demonstrations where the students can observe "real" chemical reactions are better than verbal or written or projected descriptions. Let me illustrate this by describing some methods I have published about this. First let us examine a simple chemical reaction, the formation of water from H_2 and O_2. The typical way of presenting this is the following equation (on a board or an overhead projector or Power Point):

$$2H_2(g) + O_2(g) = 2H_2O(liq) \quad (1)$$

Sometimes this will be done showing the Lewis electron structures