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Of Special Interest

Report On "Chemistry in a Biological Context"

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When you look at how institutions teach science, they all start with biology and chemistry before attempting physics.

The American Chemical Society has started its first large-scale project related to opening up new options for undergraduate majors. Tentatively titled "Chemistry in a Biological Context," the work has only just begun. Participants are invited to provide early feedback into the nature and shape of the project.

Descriptive Outline

The presentation began with Maureen Scharberg describing her own chemistry background to the participants. Chemistry

"Chemistry in a Biological Context" by Maureen Scharberg was presented at the "Day 2 to 40" workshop symposium held May 10–11, 1997. The two-day event was held in the Willard H. Dow Chemical Sciences laboratory building on the central campus of The University of Michigan in Ann Arbor, Michigan. Each of the articles that comprise this issue was written by one of the group of reporters whom I asked to attend each session to take field notes and then follow up with the session leader and participants afterwards.

—Brian P. Coppola, Proceedings Editor

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always excited her as a subject. In college, Dr. Scharberg double majored in Chemistry and Biology. Near the end of her senior year, she began to see the connections that supported the underlying structure holding the general chemistry curriculum together. After she began teaching, she realized that the textbooks in 1991 were basically the same as in 1981. While the barriers between Biology and Chemistry were being eliminated by massive research during those ten years, the textual material that the students were seeing did not reflect that scientific union. It was these issues that compelled Dr. Scharberg to work on this project.

Steve Branz continued by describing his own experiences. Being half a generation ahead of Maureen, Steve was excited by the chemistry/biology interface in science, however, as a biology major, he was not exposed to the connections between chemistry and biology and couldn't see the chemical nature of several important biological problems.

The presenters then began discussing the nature of the "Chemistry in a Biological Context" project. At San Jose State, one of the major problems for biology students was a feeling of being unqualified for the rigors of organic chemistry. The project founders believed this problem was caused by the students missing the vital general chemistry concepts that they needed to excel in organic chemistry. By presenting these general chemistry concepts within the framework of a biological context, the project leaders believed that the students would retain the important chemical information they would need later in the chemistry curriculum. Some examples of the concepts students were having difficulty retaining were Hess's Law, elementary organic reactions, bonds being broken, and bonds being formed. Some of these difficulties could be attributed to information overload. With so many new topics being taught to these students (~40 topics taught to U.S. eighth-grade students versus 5–7 topics for eighth graders in other countries), the students just couldn't absorb all of the information thrown at them. This led the students to rely on answering chemical questions numerically instead of conceptually. Students could handle the "plug-and-chug" questions, however, when they were confronted with a qualitative problem, they were lost. Conceptual teaching seemed to be lacking across the country. One of the main problems that the project leaders identified within the current traditional general chemistry approach was that once a topic had been taught, the students were asked to move onto another difficult concept without getting a chance to fully digest the previous topic.

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In order to solve this problem, the proposed text would like to include some type of spiral teaching approach. This approach could basically be defined as a presentation method that touches on a topic over and over again at different times in the teaching term and allows the student to access that topic at deeper and deeper levels of understanding. By hitting a concept again and again, the students retain the important concepts much better.

Question

1. How difficult is it to teach the spiraling approach, acknowledging that most texts are not assembled to promote that style of teaching?

I (Maureen) have been using the spiraling approach for several semesters now and have found it to be quite easy to teach. Here is an example. I teach a class where we assume that the incoming students have no chemistry knowledge; basically, we start from scratch. I have taught this class in several ways, but when I use the spiraling approach and revisit topics over and over, I can see that by the end of the term, the students are retaining the information much better than with a traditional approach. Take acid-base reactions. First, I concentrate on having the students recognize patterns: acids have H, bases have OH. Then I show the students how the acid and base interact. After getting them comfortable with these ideas, I add a little more information until they are comfortable working with acetic acid (looks like a base but acts like an acid). If at the beginning of the acid-base topic the acetic acid case was given to the students in a table with other more identifiable acids, the students would not have understood, but after several iterations the students are able to grasp the foreign concept. I feel that it is also very important to teach the students the language of chemistry while paying particular attention to their own language.

The course outlined by the presenters within this project is a one-year chemistry course for science majors. It would be listed as a general chemistry course in a biological context. This course would be aimed towards the large population of students that are biology and chemistry majors looking to enter medical school. At the beginning of this process, the project leaders needed to identify how students learn chemistry and what is the most effective way of teaching those students the general chemistry topics that would be most beneficial to them. Discussions lead to three models for teaching this information.

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- Topic-Oriented
- Microscopic-to-Macroscopic
- Macroscopic-to-Microscopic

The participants were asked to go through the same process that the textbook designers had been going through (or the course development team if you are referring to the actual lectures) and develop a list of concepts important to introductory chemistry courses. The participants were posed two questions:

1. What are the most important concepts to get across in the first year of a chemistry curriculum?

2. What are the most important topics to use in the first year of a chemistry curriculum?

Questions

1. One thing that is sorely lacking in the area of general chemistry is a text written by an organic chemist. Are their any organic chemists on your committee for this venture and what are your backgrounds?

Organic chemistry is always seen by the students as the most difficult class to be prepared for (and do well in). There are several organic chemists on the advisory board that will help in writing this book. The makeup of the advisory board includes members from all specialized chemistry areas except physical chemistry.

2. It seems that your teaching approach (spiral) is the right way to go, but the text that you are proposing doesn't seem to mesh very well with your teaching style.

Realistically, the market for textbooks is for a traditional, one-year chemistry text. This is a requirement. If we wrote a book to go with a spiral methodology, the audience for such a product would be quite small. Hopefully, this project will be a step towards a text catering to a spiraling teaching method. Everyone has an ideal of what and how they would like to teach, but when you write a textbook, you try to reach as many people as possible.

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The participants gathered a short list of important concepts to include in a first year chemistry course:

- Atoms and Molecules
- Acid-Base Reactions
- Le Châtelier's Principle
- Equilibrium
- Solubility properties
- Concentration/Molarity
- Reactions (simple organic)
- Thermodynamics
- Mechanisms/Kinetics

The presenters posed this question to several groups of faculty members around the country and were surprised to find that different chemistry departments (large and small) all came up with the same basic list of concepts—much like the one the participants assembled.

Question

1. Don't you guarantee that the list will be what you want it to be when you phrase the question as: Compile a list of things that should be in a general chemistry course, because you presuppose that there is a general chemistry course?

Probably true.

The participants were asked to split into three groups and were asked to imagine that they were on a committee that needed to convince a board of trustees that their concept of teaching chemistry (topic-oriented, micro-to-macro, or macro-to-micro) was best for the students. The groups were given ten minutes to devise their strategy. The participants were asked, for the purpose of this process, to try to defend their particular position even if they did not entirely agree with it. After the allotted time, each group was given five minutes to present the reasons why their particular theory of presenting chemistry was the one method the project as a whole should adopt. The other groups would then be given time to ask questions.

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Macroscopic-to-Microscopic Approach

All of science is based on observation and interpretation. We can't observe anything like an atom, so the macro-to-micro method of teaching chemistry is the correct way of presenting the material. You can see rocks, clouds, and water. The quest to interpret these phenomena is the way to hook the students. This ties in to one of the more outmoded ways to teach chemistry, the historical approach. Not to be mistaken for the wrote memorization of who discovered what in such-and-such year, but the search for how to understand the world around you. The search for understanding leads to the search for explanation which leads to theory. We looked through the topics that you wanted us to cover and believe that the macro-to-micro approach will work well for each case. When you look at how institutions teach science, they all start with biology and chemistry before attempting physics. Why do they do this? They do this because it is easier to explain the concrete before trying to explain the abstract. Things found in the natural world can be touched and heard and seen while abstract concepts like a atom cannot. The macro-to-micro approach allows one to understand and comprehend the concrete objects seen in the natural world before trying to understand the abstract materials that cannot be directly observed by the human eye. For example, if I were to talk about acid-base reactions and I write a chemical equation on the board that shows the hydrogen coming off and attacking the hydroxide, that would be a difficult concept for the students to understand. However, if I put the same example in a macro context, such as indigestion and how milk of magnesia or some other agent is able to neutralize the stomach acid and from there go to chemical structure, by going from macro to micro, the students can more easily learn a difficult subject.

Three major advantages to the macro to micro approach

- observation to theory
- concrete to abstract
- relation to what we observe everyday

We would all agree that chemistry is a molecular science, but the object of chemistry, and indeed science, is to describe and understand the phenomenon of nature. One makes measurements and observations at the macromolecular level. I have never seen an atom, but if you make observations of bulk quantities of material you can understand and predict what is going on at the microscopic level. Logically, it follows

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to make the observations at the macroscopic level because that is the only type of observations we can make, and then to try to understand those observations at a microscopic level.

Questions

1. Don't most scientific observations occur in this fashion? A scientist has a theory or a hypothesis that he wants to prove or disprove. In order to answer that question, an experiment is devised and observations taken.

Absolutely not. View it from a historical perspective. First comes the anomaly, the observation, why is the lightening striking the kite? Then you find data to support the anomaly; then you look at the data to form an opinion or theory about the observation.

2. But, in modern chemistry there is an established theory before observation.

We are not teaching students modern chemistry, that is, they don't know any chemistry, so they can't have any theories before observation. We are starting with an empty vessel. What they are bringing are their observations in the real world. Yes, we will finally get to the molecular level with our teaching, but that is not where to start with freshmen students.

3. I would like to thank this group for espousing the topic-oriented approach, which it seems you have done. You are identifying phenomena that you want to explain, but then you talk about indigestion and then go right to chemical structures. So, what you are doing is identifying a topic, and then, in order to explain it, you are starting at the micro and going to the macro. Isn't that true?

No, we are looking at macro phenomena and observations and going to micro to explain those observations. We do not have isolated topics, we just have a phenomenon that we can see. We are not suggesting a two-week indigestion unit.

4. I observed that in your discussion you could not last even one minute before mentioning the microscopic information. Aren't you really explaining chemistry in a micro-to-macro sense?

No, we are not debating that both the macroscopic and the microscopic are important, we are arguing that the arrow goes from macro to micro and not the other way around.

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(Aren't you really going from Macro to Micro to Macro?) That is because the observation is macro and the discussion is micro and the micro must support the macro observations.

Microscopic-to-Macroscopic Approach

When we thought macro-to-micro versus micro-to-macro, we thought we would have to teach gas laws and thermodynamics first without ever talking about molecules and atoms. From our end, just as the biologists always say, so should the chemists say, that function relates to structure. If we really are to understand the phenomena we see, we need to understand the underlying structure. When we get to the underlying structure, we get to the unifying simplicity that makes chemistry interesting and understandable. That underlying structure is microscopic. Does that mean I am going to jump right in and talk about atoms without talking about phenomena? Of course not. But it means that we will pick phenomena and explain them immediately in terms of identifying the structure that makes the phenomena occur. Also, I think that science has progressed enough that there are now areas where there is no theory about a scientific issue, and to expect the students to go from observations to theory without any prior hypothesis is not realistic. I think it is more reasonable to explain to a student that this is what I believe as a chemist and it allows me to explain the world in this fashion. It is important to give the students a good idea about what our framework is and the tools we use to explain the world, *and then* use those tools to explain the phenomena around us.

Questions

1. I am confused. What exactly do you think is micro and what is macro? Your argument sounds a lot like an argument for macro-to-micro. Can you tell us how you defined what is macro and what is micro?

I took the topics given to us and decided what were basically macroscopic topics (topics that are usually taught without a lot of reference to microscopic structure) and which are microscopic topics. If I were a macro to micro purist, I would teach the macroscopic topics first without any reference to the microscopic underlying principles and only after finishing all of the macroscopic topics would I then go to the microscopic topics.

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2. When I was on the high school debate team and I was given an undefendable topic, I tried to define the terms in such a way that they would further my own cause. This is what I see happening here. Both groups have defined their terms to turn their case into the topic-oriented approach.

Well, we are probably not very good debaters then, I usually only try to defend things I believe in and I think in this case my problem with the topic-oriented approach is this. When students come to chemistry, I don't think they really want to learn about indigestion in a chemistry course, maybe they do, maybe they don't. Whatever they would like to learn, I think they need to learn the concepts that are important to the instructor. The topic-oriented approach just doesn't, in my mind, allow for the coverage of all of the concepts that the students need to learn.

Topic-Oriented Approach:

All of us love chemistry. We all appreciate it and want are students to learn chemistry and see it through our rose-colored lens. In order for students to learn chemistry, they have to build on their own experience and observations as opposed to the empty vessel analogy. If you try to pour information into them and it doesn't connect to what they already know, they will not retain it. We really think that the topic-oriented approach is better. They can start with something that they already know or are interested in, something that will actually effect their life, such as the environment. You can build up the background and go from micro to macro to micro, back and forth, shifting theories until they can understand the topic they are researching. Ozone is O_3 so you can get into bonding and structure and spectroscopy, which takes you to light and questions like: What is light? Different wavelengths, energy, just keep building on these topics. You can even get into the chemical reactions that break down ozone and some other advanced subjects. Just starting from ozone you can gather a wealth of chemical concepts by talking about UV radiation and why losing ozone in the atmosphere is bad. You can look at how the UV radiation damages our skin and get into DNA and cancer and some of the medical applications. You can build all of chemistry around a good topic. One part that we would like to emphasize, is that you need to get the students interested to learn chemistry. You have to give them a reason to want to know what protons and neutrons are and the topic-oriented approach builds on this need to know.

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Questions

1. You said that the topic-oriented approach teaches chemistry by building on the students' own observations. I just don't see how you can get to atomic molecular structure based on their everyday experience.

I think what was meant to be said is that you need to get the students interested in learning about atomic structure through their own prior experiences and understandings. If they have never heard of an atom, you have to relate atoms to some observation they have had or they are not going to be interested in learning about atoms because it will mean very little to them.

2. How do you get the depth of knowledge and understanding about a chemical concept when you stick to talking about that topic in one particular context?

What we don't want to happen is to have students with this large microscopic understanding, but no connection to the macroscopic or the real world. In order to stop this from happening, we use the topic-oriented approach to get the breadth and depth of interconnected understanding. We want to get the students to master each of a variety of concepts within a framework that connects the macro to the micro. I would argue that micro-to-macro is good. I would also argue that macro-to-micro is good. The topic oriented approach is the best of both worlds because you are not tied to doing just one or the other.

3. Several colleagues that I know have tried the topic-oriented approach and found that it was rather unsuccessful at teaching the students the basic chemical concepts that we find so important to get across to the students. They have termed the approach "Chem lite". Can you defend it's use?

I have not tried the topic-oriented approach myself, so I can't say that it does work, but because you have heard from some teachers that they could not make it work also does not prove that it doesn't work. They may have chosen a bad topic, or the theory may not work. I don't know. The key feature to the approach is fostering the students need to know. If you can create excitement in the students about the particular topic, I believe this method could work.

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The discussion was then led back to the participants real experiences about which method or combination of methods works. A participant identified three things that need to be balanced in order to teach the students effectively.

- Informal Observation: These are topics such as indigestion or the ozone layer as well as the natural phenomena that the students see in real life. These are important to have in any learning structure because they give the students a reason to want to learn the chemical concepts.

- Formal Macroscopic Observation: Classical thermochemistry, Boyle's Law, etc.

- Atomic and Molecular Understanding: This allows the students to describe and understand the first two topics.

It seemed to this participant that all of the instructors in the workshop identified these three issues in one way or another as being important to the learning process. What they were all struggling with is: Which one will be the basis for their course out of which the other two concepts flow?

The presenters went on to say that they also will use a variety of methods to write this textbook and construct their course. They had given the participants the impossible task of deciding on only one method when the general consensus was that a mixture of these teaching styles would have to be used to best serve the students. One of the most difficult questions for the presenters to answer after deciding on the method of teaching was: What is going to be included in the course and what is going to be omitted? It was very hard to convince departments that the new "general chemistry" course that they were presenting will not cover all of the topics that their traditional general chemistry class covers. Although the concepts will be covered with much more depth than in the traditional class, this was not seen as enough positive evidence to move the department to the spiral curriculum. The current status of the project is that the basic research for the text will be completed by the end of 1998 and the actual product will most likely be unveiled at the Biennial Conference on Chemical Education in Ann Arbor in the year 2000.

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