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# Constructivism and Information Technology at Columbia: A Journey from the Wilderness to the Promised Land[1]

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## 2004 George C. Pimentel Award, sponsored by Dow Chemical Co.

by Nicholas J. Turro

I am not a teacher—only a fellow traveler of whom you asked the way on this journey. I pointed ahead—ahead of myself as well as of you.

*George Bernard Shaw*

In this Pimentel Award lecture I will try to describe the journey taken by myself and some of my colleagues, especially Leonard Fine, after we recognized and accepted an urgent need for reform in teaching and learning in undergraduate chemistry courses. I will first describe the struggle that Len and I endured through some wilderness years of ambiguity and ignorance of how to formulate, develop and implement reforms. Then I will then show how, with the emergence of information technologies (IT), we were able to formulate an action plan that used constructivist principles as a basis for inquiry and how we were able to develop an effective strategy that employed IT as a tactic to develop and plan to achieve reform. Finally, I'll discuss how, after several exciting years of collaborative inquiry and discovery, we implemented a certain level of both local reform in chemistry and university-wide reform through the use of IT at Columbia University.

### The Need for Educational Reform in Teaching Introductory Chemistry Courses

Faculty: a group that behaves wisely after all other alternatives have been exhausted.

*An Administrator*

The journey started when I was teaching general chemistry in the early 1980s. Len Fine was teaching a parallel general chemistry section of the same size. I was concerned about the number of students in a class of about 250 who were headed for a D or F grade after two exams. My teaching did not appear to result in these students learning the content of the course through the conventional lecture format. I wondered whether they could learn through some other approach. Conversations with my daughter Cindy led me to read about the work of Piaget *(1),* and I was inspired to use his ideas to see if this could help students who were doing poorly in the class. But not being involved in educational research, neither Len nor I was confident that we knew how to do it.

In my own personal research I am quick to go to colleagues for advice when I am entering a new area of inquiry. Columbia University Teachers College, right across the street from my office, is dedicated to research in understanding how students learn. Len Fine and I met with Jean Lythcott, since she performed research in science education at Teachers College and had taught courses in science education in which my younger daughter, Claire, was enrolled. Jean suggested some experiments that we could perform to see whether formats other than the conventional lecture could help the failing students learn some general chemistry. The plan was to invite the students who were headed toward failure in Len's and my class to attend voluntary help sessions with Len, Jean, and myself. It turned out that, of the 40 students who were invited, about 20 accepted the invitation and 20 did not, so we had an experimental group and a control group.

The help sessions did not consist of the traditional sessions in which the students asked questions and the instructors answered them. Instead, the students asked the questions, *and* the students answered the questions! Students worked in teams to solve problems. The faculty sat in the back of the room and listened to students teaching and learning from each other. We entered into the discussions as needed, but basically the students were able to find acceptable paths to correct answers on their own. The 20 students who attended the help sessions took two more hour exams and a final exam and received a $B^{-}$ for the course, which was the median grade. The 20 students who did not attend the help session all received a D or failed the course.

We learned several important lessons from this experiment:

1. The students' methods and tactics for solving problems in chemistry were very different from those that the faculty used. For example, we found that students generally understood the rules for solving problems pretty well; however, they had trouble when they had to choose between two or more rules that had to be applied simultaneously. The revelation to us was that the students did understand the fundamental rules, not that they had trouble applying them. In answering a question, they would think of a rule and apply it, but without considering the possibility that other rules might be operating simultaneously and be both relevant and competing. In other cases, the students knew how to apply rules that they understood, but they were not the correct rules. These observations had implications concerning how we could improve these students' learning and also improve our own teaching methods. There were, in my mind, clear examples of students who were at Piaget's *(1)* "concrete operational" level of intellectual development.

2. Students benefited from active engagement with peers and appeared to learn more effectively from this interaction than from the conventional lecture.

3. The students benefited from having material placed in context by the instructor during the process of problem solving.
4. The students benefited from visualization of material relevant to the problems being addressed.

In conclusion, our experience validated the principles of constructivism *(2)* by demonstrating (1) that students have to create their own knowledge, (2) that interactivity is an effective method of learning, (3) that student-learning benefits from the addition of context to the material being learned, and (4) that visualization and appeal to analogies (prior knowledge) benefit the learning process. These were valuable lessons in teaching and learning that we could eventually apply if we could develop a plan and strategy to use the constructivism principles on a large class somehow.

## The Wilderness Years (1980–1992) Application of Information Technologies (IT)

Something not worth doing is not worth doing well.

*N. J. Turro*

With the above constructivist model of teaching and learning developed from the works of Piaget, we started to think about how to develop a general strategy and model for using IT materials to enhance undergraduate education, since IT seemed amenable to effective use in large lecture classes.

Our starting model postulated that a student's understanding of the world around him/her is fundamentally linked to visual and auditory stimulation and the tactile experience of manipulating objects in the environment. Thus, a commonsense model of human intellectual development suggests that the tools used to test and adapt to the environment should include a combination of (1) interactive skills (manipulating objects and knowing where you are in space); (2) perceptual skills (imagining, visualizing, recognizing, comparing, and contrasting); (3) auditory skills (processing and connecting auditory information with other stimuli from the environment); and (4) symbolic skills (the ability to understand long sequences of abstract reasoning). These hypotheses have led researchers to try to build interfaces that explicitly addressed all four of these fundamental ways of manipulating and understanding the environment around us. Thus, we expected that effective IT presentations must engage one of these skills or some combination of them. In addition to these common-sense tactics for effective contextual and cognitive software design, the constructivist model teaches that the social aspects of learning are also important.

During the late 1980s and early 1990s, it was not possible to get anything going in IT that worked well. Indeed, these were the "wilderness" years of our IT adventure. During this period, Len Fine and I searched long and hard for IT tools that would be useful to assist teaching and learning, but the barriers were many: poor software for producing models that allowed visualization and animation of important ideas of chemistry; absence of delivery systems (projectors, electronic classrooms) to display the modules; high cost of software and hardware; lack of support by the federal agencies in enhancing undergraduate education; lack of local administrative support for programming and computer maintenance; and lack of enthusiasm for any significant curricular changes by the chemistry faculty.

## The Development Years (1990–1993) An Education Toolbox

Prediction is difficult, especially about the future.

*Attributed variously to Bohr, Yogi Berra, Mark Twain, and others*

With financial support from Perkin-Elmer, we decided to test our ability to make an effective IT module as a learning tool. Perkin-Elmer wanted us to design a tutorial on infrared (IR) spectroscopy that would be useful for its customers, who might have had only basic chemical training. This group would have the demographics and background of undergraduates in the introductory general chemistry and organic chemistry courses. In producing IR Tutor we discovered three pillars of effective learning: content, context, and cognition. Without explicitly recognizing it, I had been using the three pillars for many years in my teaching. For IR Tutor, the *content* was going to be IR spectroscopy; for *context* and *cognition,* the following aspects were to be incorporated into the program:

1. An *introduction* module that provides a brief presentation to spectroscopy, the nature of light, and the measurement of an infrared spectrum (with a Perkin-Elmer instrument). The quality of the graphics and presentation, using a new program called Director,[2] was quite remarkable, reflecting both the excellence of the program and the talent of the programmer, Charlie Abrams, a graduate student who developed IR Tutor under Len Fine's and my supervision.
2. A module on the *theory* of IR spectroscopy, discussing the classical and quantum-mechanical modes of a vibrating molecule. At this point the power of the software in producing very powerful and effective visualization of difficult ideas comes into play. It is expected that the student has studied the classical harmonic oscillator and is familiar with the example of a pair of masses connected by a spring. This exemplar is brought to life through an animation that simultaneously shows the masses vibrating relative to one another, together with an animation of a representative point moving back and forth in a harmonic potential well. For the concrete operational student, this animation may present an understanding of the coupling of these two ideas for the first time. For the formal operational student, this animation may serve to confirm and reinforce a model of the harmonic oscillator that was already understood, or may clarify a model that was imperfectly understood. The theory is extended to introduce quantization of the vibrational energy levels and animations of the effects of the absorption and

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emission of light as inducing transitions between the energy levels.

At this point the module introduces the cognitive principle of active participation and feedback to engage the student and enhance the learning process: with a mouse click, the student can cause an absorption between $v = 0$ and $v = 1$ and note the effect on the vibrating masses. Then the student can choose to cause an emission between the $v = 1$ and $v = 0$ energy levels. The idea of selection rules appears in a brief discussion.

3. The heart of IR Tutor is the third module, *interpretation* of spectra, that attempts to exploit many key constructivist ideas to provide an excellent environment for learning how to understand IR spectra. This module displays the IR spectra of 13 organic molecules, including saturated hydrocarbons and simple hydrocarbon chains that possess a number of the key functional groups (alkene, alkyne, cyano, aromatic, carboxylic acid, and ester). This module provides a strong motivational context for learning IR spectroscopy by incorporating the constructivist principles of active engagement of the student with the content, constructive reinforcement resulting from the engagement, and student control of the learning process.

The main feature that provides active engagement is the ability to connect the IR signal with the vibrational motion of a set of atoms by simply clicking on the IR signal, which causes an animation of the vibration to appear on the screen. The student can then connect the entire spectrum with the displayed molecular structure by marching down the spectrum and clicking on all of the signals.

By starting with a saturated hydrocarbon, the student sees the "backbone" of the IR of simple organic molecules. When signals other than those of the backbone are present, there must be a functional group present. The student may compare the IR of the saturated hydrocarbon to the IR of compounds possessing functional group. To make the comparison easy, the student may *simultaneously overlay* the IR spectrum of a saturated hydrocarbon with that of a hydrocarbon chain possessing a functional group. The signals that are absent in the saturated hydrocarbon, but present when the functional group is present, are clearly due to the vibrations of the atoms of the functional group. By running through the set of functional groups and comparing the overlap of their IR spectrum with that of a saturated hydrocarbon, the program allows the student to create new and robust knowledge of how to interpret infrared spectra.

### The Discovery Years (1995–1996): The VizKids

The art of teaching is the art of assisting discovery.

*Mark Van Doren*

The success of IR Tutor and the ease of its construction from available software encouraged me to test the hypothesis that *students*, if provided with faculty mentors and support in learning how to use the powerful new software, could construct comparable modules on content of interest to chemical educators. I was able to obtain from the National Science Foundation a small grant to hire a total of 30 students from 13 universities, and recruited faculty from chemistry, physics, and engineering departments at Columbia University to spend the summers of 1994 and 1995 participating in an Information Technology Experience for Undergraduates (ITEU).[3] After a week of training by one of my postdoctoral associates in the use of Director software, each undergraduate student would be coupled with a faculty mentor who would assign the student a topic of interest to the faculty on which an IT module would be produced. The students were charged with taking the knowledge of chemistry that was in their heads and taking advice from the faculty to use the IT tools to visualize the chemistry of the IT module. We had just the perfect name for our students who engaged in this creative visualization of chemical principles: *the VizKids!*

An important, unanticipated spinoff of the ITEU workshops was the collaboration with undergraduate institutions in producing the IT modules. Through various connections, we established partnerships with the University of Richmond (Ray Dominey), Diablo Valley Community College (Ron Rusay), and the Claremont Colleges (Tom Poon). These partnerships, produced in the image of collaborative research models, have provided valuable resources in bringing an undergraduate perspective to the strategy of developing modules.

The results of these experiments in producing IT modules gave rise to the following principles:

1. Postdoctoral associates who are interested in education and IT are potential valuable resources to train undergraduates and faculty in the use of powerful software to produce chemistry modules.
2. The assignment of trained undergraduate programmers acts as a hook to draw in early-adopter faculty as mentors for the design of educational IT modules for undergraduate courses.
3. Undergraduates are an inexpensive, competent, and renewable resource to couple with faculty mentors to produce excellent IT modules.
4. Constructivist principles provide guidance for the structure of the modules, since the undergraduates are "creating new knowledge" by working with faculty and other students to produce the IT modules.
5. Constructivist principles of collaborative and interactive learning can be effectively applied by having the undergraduates trained as a group under the mentorship of a postdoctoral associate.
6. The graduate research model of a mentor–apprentice relationship proved to be an excellent exemplar for the relationship between the faculty member and the undergraduate producing the module.
7. Inter-university partnerships can be readily and successfully established in which IT module production takes place collaboratively.

The next step in the plan was to convince the university that it should support the diffusion of the use of IT for undergraduate courses and to consider how to make the use of IT a part of a university-wide reform of undergraduate education. Hopefully, if we were successful, the university would provide funding to make the IT effort sustainable.

## The Implementation Years (1996–1999): University-wide Curricular Reform Using IT

Be not the first by whom the new is tried, nor the last to lay the old aside.

*Alexander Pope*

In 1996 there were a number of obstacles to the adoption of IT as a tool to improve undergraduate education in science—or any subject, for that matter. The projection systems (or electronic classrooms) for delivering the IT modules were generally not available because of their expense and logistical problems. There were no administrative mechanisms available for systematically funding the development of IT modules or training faculty and students in the use of software to produce them. The small grants from NSF were useful to get us off the ground with summer ITEU workshops, but sustainable development of the IT modules and the adoption of IT as a broad and powerful tool to enhance undergraduate education in science required both a substantial financial startup from the university and a commitment for sustained funding of organized IT development on campus as part of the base budget and ordinary structure of the university.

In order to get the university to buy into the idea of joining the IT world, I concluded that it was necessary to demonstrate grass-roots faculty enthusiasm for the adoption of IT in their undergraduate courses. This demonstration in itself required support. There was the usual problem of finding funding for an innovative project in a university with many competing needs and fiscal demands. A key strategy was to use the research model of mentor–apprentice relationships, that would be familiar and attractive to research university faculty, to attract faculty to work with undergraduates to explore the uses of IT for reforming the undergraduate curriculum.

A way to get the project jump started fortunately appeared in 1997 when NSF announced a new program.[4] It occurred to me that we might propose to employ the results of the ITEU workshops to construct an ambitious program to use IT to stimulate educational reform at Columbia. Looking for some background in the successful practices of causing the acceptance of innovation, I discovered an excellent text by Everett Rogers entitled *Diffusion of Innovations (3),* which describes a general strategy for successful acceptance of new ideas and reforms by a wide range of social groups. A key conclusion of the book is that the group that is to be convinced that an innovation is ready for acceptance can typically fall into the following categories, in order of descending likelihood: (1) innovators; (2) early adopters; (3) early majority; (4) late majority; and (5) laggards. For us in universities, sometimes it seems that there is a sixth category following laggards: (6) *faculty!* Only kidding!

Using the *Diffusion of Innovations (3)* model to create a strategy for university-wide reform using IT and the results of the ITEU workshops as prior results, our NSF proposal was funded. The university, with strong and vigorous leadership provided by Vice Provost Michael Crow and enthusiastic encouragement by Provost Jonathan Cole, made a serious financial commitment to assisting the diffusion of our IT model into the undergraduate curriculum. Columbia also provided important encouragement by constructing infrastructure (electronic classrooms) to support the delivery of IT modules and by providing substantial financial support.

The strategy for university-wide reform was to use the NSF grant and supplementary aid provided by the university in the following three-year plan:

> Year 1 would involve the recruitment of the early-adopter science and engineering faculty to serve as mentors of undergraduates to produce modules for undergraduate courses. The NSF grant provided funds to support the undergraduates during the academic year and the summer and to provide for the purchase of hardware and software as required for module development. An administrator, Norman Chonacky, a physicist and former professor from Evergreen State University, screened the undergraduates for reliability and ability to produce the modules. Norm, a hands-on computer buff with an excellent background in educational research, served as the interface between faculty and students. We decided to name the organization we were creating the Faculty–Student Information Technology Cluster, or ITC for short.
>
> Year 2 would involve the expansion of the faculty involved in the ITC program from exclusively science and engineering to include the humanities and social sciences.
>
> Year 3 would involve the phasing-out of the ITC and the simultaneous creation of a university center for assisting faculty in the use of IT for undergraduate and graduate courses.

The strategy proved very successful, and in 1999 as the ITC went into its sunset, the university created a Center for New Media Teaching and Learning, which now assists the faculty on the Columbia University campuses in all aspects of using IT for instructional purposes.

## IT Use in My Undergraduate Organic Chemistry Courses

Pity poor students who struggle to find
What is important in a Professor's mind.

*Anonymous*

Now for a brief description of some of my own experience with the use of IT in undergraduate teaching. In 1996, after the second summer workshop, I decided to make a serious effort to incorporate IT to improve my teaching and to assist student learning in my course, Organic Chemistry for Freshmen. This is a small, talented class that is limited in

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enrollment to 40 or fewer first-year students who have scored so high on entrance exams that they can opt out of general chemistry and go directly to organic. The World Wide Web had just appeared, and it was exciting to try to take advantage of contextual material that appeared on the Web and to use software modules in class and in recitation sections. With university support, I was able to set up a computer lab that allowed recitation sections for my class to take advantage of the IT materials I was producing. An electronic classroom was constructed in 1997, and I was able to show modules in class.

Among the features that appealed to students, according to end of the year surveys, were:

- An online PowerPoint review of each chapter of the textbook we used in the class, generously provided by its author, Frank Carey. I happened to find out that Frank had produced an excellent PowerPoint presentation to go along with his text for classes at the University of Virginia. The university's computer services division put the review on the Web for me, and I built a homepage for the review that mirrored the chapters of the text so that students could easily find the material. In addition, for each chapter, I searched the Web for contextual materials that could be linked to each chapter. The combination of the online review and the links to resource material offered the interested student the chance to expand on the content and context of course material to a much higher level if desired.

- A chemical structure drawing tool, ChemDraw *(4).* In recitation sections, students learned to use this highly intuitive and easily taught module for drawing molecular structures in 2D or 3D representations. The 3D representations are readily manipulated in space. One interesting feature of this tool, which is an example of a strongly interacting IT module, is that many students immediately explored its capabilities and used it to draw molecules that came completely from their own imaginations. Chem3D, a module associated with ChemDraw, allows the translation of a 2D structure into 3D and the rotation of the structure in space. This module, especially in conjunction with classical ball-and-stick models, is an excellent tool for students to learn and understand stereochemistry. After a student drew some incredibly complicated molecular structure, the inevitable questions would come up: Does this molecule exist? How would you synthesize it? What kind of IR spectrum would it have?

- Using IR Tutor was a big hit, both in class and in recitation sections, for the reasons described above.

- Animations of mechanisms of organic reactions. These were another big hit. The $S_N2$ (Substitution Nucleophilic Bimolecular) reaction, the Diels–Alder reactions, and the chlorination of methane were all available on two excellent modules, Organic Mechanisms and ChemTV.

- Although trivial from the faculty's point of view, having previous exams with detailed answers available on the Web was very much appreciated. In general, the hour exams and final were generated from the huge number of exam questions available on the Web.

A key concept in this small course was to get the student to view the instructor and other students as partners in the learning process, in the same way that a mentor and his or her research group view themselves as partners in the process of inquiry and discovery. This goal was enhanced by having *an absolute grading system*, in which everyone in the class could get an A if they performed at a high level on all of the exams and recitation sections, and by gathering the students in groups of three or four during class to answer questions put forth by the instructor and then giving a group answer on a note card. The student answers were discussed in class in real time; the students could see how other students were thinking, and so could the instructor. These sessions allowed the instructor to obtain some insight into the preexisting knowledge of the students and how they used this knowledge to devise strategies to answer questions.

### General Chemistry: Starting a Class Off with a (Big) Bang

During the Fall of 2003 I started teaching the large introductory general chemistry course of 150–200 students. Could IT could be used as effectively in a large class of 150–200 students as it was for a smaller class of 30–40? In seeking an answer to this question, I had the very good fortune to have Tom Poon, who was on sabbatical from the Claremont Colleges for the academic year, work closely with me on the course and the IT materials. I had first met him at a Gordon Conference on Chemical Education in the late 1990s and was impressed by his expertise in producing effective modules for undergraduate teaching and putting them on the Web.

Having Tom's expertise available allowed me to explore ideas for using IT that he could implement during the semester. In particular, we wanted to use IT and the Web both for assessment and for assisting students in learning the content of the course. Our tactics included the following:

1. *Start the class with a (Big) Bang!* To get off to a good start, we decided that the first thing the class would see would be an IT module within the context freshmen are accustomed to: a movie about chemistry. The content of the movie would be the backbone of all of chemistry, the periodic table. To engage the student, the movie would mimic the classical introduction style of the *Star Wars,* movies which always start by showing the text ramping through the universe, with the music of *Star Wars* in the background. The text (see List 1) describes the purpose and expectations of the course and then refers to the creation of the periodic table as the result of the Big Bang. The instructor then comments that a key feature of the course will be the memorization of the periodic table (groan from the

class), but that we have an IT means of assisting the class in learning the table. At that point, to the threatening music of the "Death Star" of *Star Wars*, a large object begins to make its way on the screen. It looms large and rolls about a bit, then settles down. It is now clear that the object is a copy of the periodic table! Then the Death Star theme fades and a lighter, bouncy song is heard. It is Tom Lehrer introducing his song, "The Elements." Lehrer then sings through each element, which is highlighted on the screen as he mentions its name (a sing-along script of the song appears at the bottom of the screen so the students can sing along).

Agreed, this is sort of special, but it was a big hit and in my view got the class off to a great start.

2. *Give an online survey requesting an evaluation of the course* after each of the three hour-long exams but before the students knew their grades. The results of the evaluation (uncensored) would be shown in class and discussed; the comments of the evaluation would be analyzed, and the three or four most commonly cited points for improvement would be explicitly recognized and discussed after each evaluation in class. The philosophy behind this simple idea is the notion of "continuous quality improvement" (CQI), a well-accepted paradigm in the business community. The basic idea of CQI is that it provides a context for the teaching–learning arena because the students have the ability to interact with the instructor in a manner intended to adjust the delivery of course materials continuously to best address their learning abilities and backgrounds. CQI ideally provides the students with the feeling that the instructor wants to make them stakeholders in the educational process.

   There were a number of concerns regarding the online survey—the most important was whether a significant number of students would complete it—but the response for the surveys turned out to be greater than 90 percent for all of them. Why? Because the survey operated in the *context* of student currency: points toward the final grade. Students were offered 1 point (out of 500) toward their final grade if they completed the survey. The maximum number of points for filling out the three surveys was 3 points out of 500.

   The survey results (Table 1 shows the results for the NMR and IR IT modules) were extremely helpful to determine how the class was going and allowed Tom and me to adapt in real time to making adjustments that could lead to more effective learning.

3. *Give online practice exams* that would be typical of the hour exams and final exam. There were a number of rationales for this tactic. First, I wanted to create a test bank that was tested thoroughly so that poor questions could be weeded out and would never appear on actual exams. Second, I wanted to create a test bank for which the degree of difficulty of each question was known in advance. These two features were very important to me because in my previous experience with exam questions for large classes I found it difficult to make up an exam that did not have some "busted" questions for which a typo or ambiguity would make the question useless—and also creates a huge and unnecessary (and sometimes embarrassing) discussion after the exam. Third, I wanted to cultivate the idea of fairness in the exams. The questions of the practice exams on the Web were typical of the actual exams given in class.

4. *Use in-class modules and movies that provide context* or engage the class with materials directly connected to the content in the course, or to science in general. For example, IR Tutor was made available online to each student in the course, and the module was used in class to teach IR spectroscopy. In addition, we arranged with the CambridgeSoft Corp. to allow the students in the class access to ChemDraw *(4)* for the last month of the course. The students learned how to use ChemDraw, but more importantly for the content of

**Introductory Text,**
**IT Module used in Chemistry C1403x**
**(with apologies to George Lucas)**

Before the beginning there was nothing but darkness… deep, deep darkness which held sway over the entire universe. This was not good.

Then God decided that something had to be done and so She said, "Let there be light…

…and we might as well have atoms, molecules, and chemistry for good measure."

And the light shined on the darkness; and the darkness comprehended it not. The empty space of the universe was filled with tiny atoms that formed the first stars…

…In these stars, hydrogen was consumed to create all the elements in the universe through the process of fusion. It was the victory of the (electromagnetic) force (a.k.a. light) over the dark side.

Chemistry C1403x is the story of atoms, molecules and light. It is the story of

*CHEMISTRY, THE SCIENCE OF CHANGE*

In only three short months you will also learn why Chemistry is the Central Science and how the properties of everything in the world around us, organic and inorganic, can be understood in terms of the structures of atoms and molecules.

You will also learn why learning Chemistry is a key to admission to medical school, a training for many other opportunities at gainful employment, and an exercise in both rigorous and qualitative thinking.

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the course, they also learned to use a nuclear magnetic resonance (NMR) program that is built into it. This program allows the student to draw a structure in ChemDraw and then view the $^1$H or $^{13}$C NMR spectrum of the structure that was drawn. This is a tremendous tool, because it is so easy to use and so highly interactive. In class or recitation, if a student asked about the NMR spectrum of a molecule, the class could offer suggestions, then compare the proposed NMR spectra with those produced by ChemDraw! The ideas that make IR Tutor a success were built into the ChemDraw package.

5. *Use video cameras* to display student suggestions to the class for answers to questions in real time. The idea here is that there are serious logistical obstacles in transmitting students' written ideas to the entire class for large lecture sections. The use of a video camera can help to overcome this difficulty. For example, when discussing IR or NMR spectroscopy, students in the class were handed out blank spectra, which just contained the usual parameters for the *x–y* coordinates. We then asked students to draw spectra of certain molecules on the blank sheet and to discuss their drawings with their neighbors. After about two or three minutes of discussion, a random spectrum was collected and demonstrated to the class through the video camera. The spectrum was discussed and then the class was asked if there were any other spectra (given by anonymous students) that differed from the first shown and that deserved to be discussed. Of course, many different spectra will always be available from a large class. The beauty of the exercise is that students can see what is in other students' minds and then debate what is correct and what is not, with minimum guidance from the instructor—putting the constructivist principles into action.

   For example, the use of projected spectra will invariably elicit questions such as the following: When is a peak a signal or an artifact? What value is to be associated with the position of a signal, the shape of a signal, or the absence of a signal? Sometimes the student does not perceive the conflict at all. Good teaching requires exposing that conflict clearly to create a motivation to resolve it.

6. *Use an online PowerPoint slide show* of course materials. I decided to use chalk rather than PowerPoint presentations most of the time. However, Frank Carey had produced a PowerPoint presentation for his general chemistry course and generously, as he had done for my organic chemistry course, allowed me to put the slide show on the course Web site.

**Table 1. Student Survey Results, IT Modules Used in Class**

| **Questions about NMR Spectroscopy** | Very (5.0) | Somewhat (3.7) | Neutral (2.3) | Not at all (1.0) |
|---|---|---|---|---|
| How easy was the ChemOffice/Chemdraw software to use? (If you did not use the program, please choose "NA" as your response.) | 26 | 42 | 21 | 10 |
| How helpful to you was your use of ChemOffice/Chemdraw in learning NMR spectroscopy? | 24 | 46 | 24 | 10 |
| How helpful was the instructor's presentation of ChemOffice/Chemdraw to you in learning NMR spectroscopy? | 38 | 53 | 20 | 6 |
| **Questions about IR Spectroscopy** | Very (5.0) | Somewhat (3.7) | Neutral (2.3) | Not at all (1.0) |
| How helpful to you was your use of IR Tutor in learning infrared spectroscopy? | 29 | 52 | 11 | 5 |
| How helpful was the instructor's presentation of IR Tutor to you in learning infrared spectroscopy? | 41 | 51 | 12 | 4 |
| How helpful were the lecture exercises (the ones where we projected your NMR and IR spectra on the screen) to you in learning spectroscopy? | 40 | 55 | 14 | 9 |

7. *Use real-time context materials from electronic media sources and the World Wide Web*. There are many electronic media sources (including the instructor's library) that are available for real-time context enhancement of materials.

## Graduate Course in Photochemistry

Fiat lux.

*Genesis*

Of course, IT materials can also be put to excellent use in enhancing graduate courses in chemistry. In addition to the same use of the Web for context materials as in undergraduate courses, graduate courses take advantages of the tremendous potential of the electronic library available to all research universities. This IT feature allows the instructor to bring up literature in real time in class and to use literature materials in totally new and effective fashions. In addition to the traditional IT materials, I videotaped 13 lectures, which constitute the core of the course, and then had the tapes digitized and placed on the Web. These lectures are available to any student who cares to view them: *http://www.columbia.edu/itc/chemistry/turro_video.html* (accessed Jun 2005).

## Acknowledgments

The author owes an enormous debt to many colleagues and students who provided the inspiration, support, and assistance to my learning during the past six decades. In particular, I must single out Len Fine, with whom I've worked side by side in the trenches and on the stage over many years, struggling to discover new ways to help students learn better. I also am pleased to thank Tom Poon for his outstanding assistance, advice, and unquenchable enthusiasm in many IT projects over the past decade, and especially for his invaluable help in using IT during C1403 in Fall 2003. Norman Chonacky was an exceedingly important component in the creation, organization, and administration of the Faculty Student Information Technology Cluster.

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## [W]Supplemental Material

An essay that the author was written on his philosophy of teaching, learning, and conducting research will be available in this issue of *JCE Online.* The essay, which the author hopes is highly provocative, describes attempts to make global linkages between the ideas of Darwin's natural selection, Piaget's studies of the intellectual development of children, Kuhn's notion of paradigms, the impact of geometry on intellectual processing, and the principles of constructivism.

## Note

1. This article is based on the award address for the year 2004 George C. Pimentel Award in Chemical Education, sponsored by Dow Chemical Company. The address was presented at the American Society Meeting in Anaheim, CA on March 30, 2004.
2. Macromedia Director is a Videoworks software program. It was one of the first programs to allow production of high-quality videos.
3. The funds for an Information Technology Experience for Undergraduates during the summers of 1994 and 1995 came from a supplement to NSF CHE 94-17323, "Undergraduate Workshop. Creation of Hypermedia Modules to Stimulate Systemic Change in Undergraduate Chemistry".
4. This was the NSF program, Institution-Wide Reform of Undergraduate Education in Science, Mathematics, Engineering, and Technology.

## Literature Cited

1. Piaget, J. *The Construction of Reality in the Child;* Routledge and Kegan Paul: London, 1955.
2. Dede, C. In *Constructivist Learning Environments: Case Studies in Instructional Design,* Wilson, B. G. Ed.; Educational Technology Publications: Englewood Cliffs, NJ, 1996.
3. Rogers, E. M. *Diffusion of Innovations,* 4th ed.; Free Press: New York, 1995.
4. ChemDraw is a software product of CambridgeSoft Corp., 100 Cambridge Park Drive, Cambridge, MA 02140.

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