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The role of distance learning in chemical education*

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Abstract: The role of chemistry as the central science [because it addresses the principles associated with the molecularity of the world] presages an increasing interest in the subject at the entry-level. Indeed, in some institutions the conventional, classically derived, teaching environment—lectures, laboratories, and, perhaps, discussions—is proving inadequate to the task at hand, i.e. the instruction of increasing numbers of students with a widening variety of interests in the subject. The present educational environment is generally passive and exercise-oriented instead of active and problem-solving-oriented. Over the past several years we have been addressing a number of educational issues in a distance learning environment.

Over the past ≈ 25 years, interactive digital technology has been shown to assist certain conventional learning and teaching environments. We present here a description of an *integration* of all previously described successful computer-based techniques as well as some newer techniques into a distance-learning environment. We describe the nuances of the use of on-demand delivery of quizzes, interactive homework, simulations in the context of lecture-oriented content, as well as audio digital lectures at a concept-bite level; additionally, we describe the use of a variety of electronic interactions intended to encourage collaborative learning.

INTRODUCTION

An ever expanding recognition persists that many of the intellectually challenging and important practical problems are those soluble from the perspective and insight of chemistry—the premier molecular science. Thus, it is not surprising that departments of chemistry, world wide, are finding it difficult to provide suitable instruction containing the classical elements of instruction—lecture, discussion periods, and a formal laboratory each week. Classes generally are too large and logistic factors often dictate the availability of rooms in which to conduct the discussion periods. Such large class problems once were exclusively associated with entry-level chemistry courses, especially those designed for students interested in the sciences other than chemistry and in engineering careers. Now, such large, resource-deficient courses are common in organic chemistry and, indeed, for physical chemistry in an increasing number of institutions. Thus, the logistic-driven problems of instruction, once relegated to the beginning courses of the standard chemistry curriculum are now prevalent in many other courses in that curriculum. Add to that the burden of teaching entry-level chemistry to nonscience students, a growing interest among those who would use chemistry as a vehicle to teach about the processes of science.

CURRENT MODELS OF CHEMICAL EDUCATION

Current practices of instruction exhibit certain characteristic features:

- Lecture- and laboratory-oriented subjects are often presented with few, if any, linkages established between them.

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- Students are passive in lecture courses.
- Students often do rote exercises in the laboratory that are unrelated to either the conduct of modern chemistry or to the subject matter of the lecture component.
- The administration of the lecture-laboratory experience is often fraught with difficulties that stem from a lack of resources, time constraints, and personnel that have inappropriate training.

These characteristics of current chemistry instruction often lead to courses in which:

- the student is passive with respect to his/her *entire* educational experience;
- collaborative work is not valued;
- teachers are assumed to be omniscient;
- the course content is stable;
- the course is homogeneous.

In other words, the environment in which we teach chemistry is the antithesis of the environment in which most of our students will do their life's work.

THE PSYCHOLOGY OF LEARNING

During the past several decades, our colleagues in the discipline of psychology have made enormous strides in learning, theory, instruction, and individual differences. A reasonable portion of what they have learned should be of direct interest to those of us who teach chemistry. I fear, however, that many passionate chemical education reformers are not connected to this information and many current suggestions for reform are superimposed on the classical approach to the education of chemists. Indeed, much of the reform of the science education designated for nonscience students seems to be derivative of the classical point of view and not at all connected to Sheila Tobias' observation of the 'Second Tier Students', that 'they are not dumb, they're different.' Students who would be professional chemists are 'true believers' and they will do whatever is necessary to achieve the goal as represented by their teachers. On the other hand, Tobias' second tier (different) students are more interested in chemistry as a tool to solve molecular problems which is their end unto itself. The differences lie in the learning styles, expectations, and interests of students. Much of chemical education reform suffers from the mismatch of the classical teacher-centered approach with the diverse learning styles of a large fraction of very good students in the student population. As long as we are only interested in the true believers, those students who would be chemists, the classical approach is sufficient. Good students who want to be chemists will do anything they have to do to succeed. However, the need for persons well-trained in chemistry is not limited only to those who would be chemists, indeed, even those students who will not be scientists.

Clearly, there is a great interest among many important people in enhancing the understanding of science for nonscience majors; my own prejudice is to use chemistry as a vehicle for this purpose because it is the central science. One can carry a wide spectrum of important ideas in science using chemistry as a focus. If there ever was a need to understand how individual differences affect learning, it is in this population. From the pedagogical point of view (Fig. 1) effective chemistry instruction includes not only learning by the students and instruction by the faculty, but also individual differences become an important component. Thus, teachers must not only worry about how they teach (instruction), but the style by which students learn.

In summary, we currently attempt to teach chemistry to all of our students in the same way irrespective of their needs for, and level of interest in, the subject and without regard to the way in which they learn. Our current, static model of instruction, that's supposed to fit all, consists of the following elements:

- classroom lectures in which the students are, for the most part, passive observers of a rapidly changing subject;
- teachers are expected to be—indeed they behave as if they are—the source of all information on the subject;

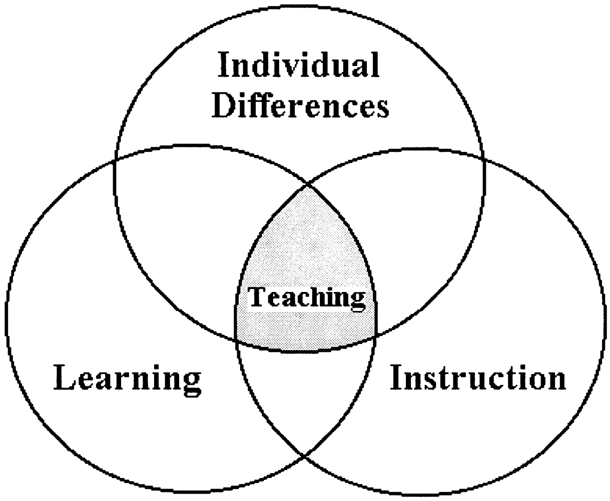

Fig. 1 The interaction of learning, motivation and individual differences.

- the content of the subject is often static, to the point that large parts of it are appropriate to 19th century practices;
- the subject is presented as homogeneous with little idea of its relationship to the real world or to other disciplines; and laboratory-oriented *experiences*, whether they be manipulative data analyses or cognitive, are often nonexistent.

Finally, the structure of chemistry instruction has changed little since the early part of the 19th century from which time we have direct knowledge of what was happening in the formal instructional processes for chemists.

THE ADVENT OF TECHNOLOGY

For a number of years—perhaps as many as 25—commentators on education have underscored the potential of interactive computing in the educational process. Often the early observations on the subject were derived from a theoretical point of view with little to back it up other than a 'vision.' Over this time period there were attempts to produce evidence of the promise of computing. Early in this period, when digital technology was not really 'interactive', the results were not definitive, although some interesting suggestions on how even batch computing could improve the educational process, even if the primitive interactive digital methods were neither useful nor practical. In the recent past, the technology has advanced to the point where the details of the promise of digital technology and telecommunications have become more obvious. In the past few years, sufficient effort and experience has been accumulated in chemistry instruction, and in all of science instruction to make clear the enormous advantage computing can provide to the teacher and to the student.

A variety of information sources make it clear that a growing, educationally oriented, digitally based infrastructure is being created that will allow individuals to acquire access to new instructional/learning tools.

Networking

The emerging technologies that are making the biggest difference in training and education appear to fall into two broad categories: networking and multimedia. Networking includes local area networks (LANs), wide area networks (WANs), and on-line services (especially the Internet), as well as applications enabled by networks, such as audioconferencing and videoconferencing, e-mail, collaborative software. and instructional management. Some observers suggest that telecommunications will probably have the most long-term impact on teachers and students. Networking will become a part of the infrastructure. Networking power will become the new metric of professional skill, much like being able to use a library. Knowledge of network-based communications and on-line resources, how to use them, and the cooperative society of the Internet all improve the creativity, productivity, quality, and quick responsiveness of professional work.

Mobility of computing—the use of notebook computers or the so-called 'palm tops'—is, in a certain sense, yet another outcome of networking, but it also comes about as a result of miniaturization. Schools and training centers all over the world are experimenting with giving students notebook computers to take home with them, setting up wireless LANs for instant virtual workgroups, or establishing dial-in services that permit anytime/anywhere access to course materials and fellow students. With networks and mobile access, time and space dependencies are eliminated or, at least, markedly diminished.

Multimedia

Multimedia has captured the imagination of educators more than any other technology. Multimedia, as such, encompasses a range of data types, including analog and digital video, two-dimensional and 3-D animation, audio, and even hyperlinks and digital ink. It also includes delivery media, such as CD-ROM discs and drives, graphics display hardware (e.g. compression/decompression, and acceleration cards), and sound cards. Specialized hardware devices, such as digital signal processors for speech and signal processing, are starting to appear in desktop systems and will play an increasing role in learning systems. Twenty-five per cent of school software budgets in 1994 were allocated to multimedia titles. Given the enormous growth of CD-ROM-equipped PCs in homes, multimedia could soon become the key 'crossover' application to link the home and school markets.

Proof of the effectiveness of multimedia isn't yet conclusive, but early studies and many anecdotes suggest its great power as a learning aid. Early reports on technology effectiveness cites accounts of measurable improvements from the use of animation, video, laserdiscs, CD-ROM books, and hypermedia. Studies show that we obtain 80% of our knowledge visually, but retain only about 11% of that. We acquire a smaller percentage through hearing and a combination of the two is the most effective, boosting retention rates to 50%.

Software

Layering collaborative software environments on top of a network is the basis for new modes of communications. For example, collaborative software permits the creation of classroom learning environment unbound in space and time, in which one can make a contribution that others can see and respond. This mode of interactive, collaborative software running on a network is ideal for curriculum development—a process that currently is not an efficient process. Networks allow all the parties interested in curriculum development to get together—for example, faculty members on one campus can interact with those on other campuses or world-wide. E-mail among students and teachers, free exchange of curricular tools and content, consultation with on-line experts, and access to remote resources are all hallmarks of what ubiquitous networking will deliver to education.

21ST CENTURY CHEMICAL EDUCATION

The promise of the impact of technology on the chemical education process that has been growing for the past 25 years or so is about to be fulfilled as the improved versions of the original technologies begin making their way into the educational system. This generation of new technology (*vide supra*) promises more than just an improvement in educational productivity; it has the potential also to produce a qualitative change in the nature of learning itself. Many of these tools are becoming useful in educating workers in the work place and much of the down-sizing in business is based on the expectation that successful employees will have to be more flexible. Organizations are linking learning to productivity, rather than attempting to train in advance of the act of production. Thus, as it so often occurs, employers and educational systems are coming together on expectations associated with the products of the educational system—the students. Employers themselves are using new technologies to educate workers and they expect future workers to be better learners.

Fundamental shifts in the use of technology associated with learning/teaching mirror those occurring in many industries, for example, away from centralized host-based computer systems to a networked, distribution model. They also echo a new way of thinking in education theory; instead of a one-way information flow, typified by broadcast TV or a teacher addressing a group of passive students, new technology associated teaching techniques are two-way, collaborative, and interdisciplinary. The common thread linking schools, colleges, and companies is that all are facing budget pressures and are looking for ways to improve education's return on investment.

Schools and companies are using similar technologies to address similar problems, because there is ample evidence that appropriate use of technology can boost retention rates, reduce boredom and misbehavior, and, in many cases, cuts costs. Numerous reports find that educational technology clearly boosted student achievement, improved student attitudes and self-concept, and enhanced the quality of student-teacher relationships. Especially promising technologies are interactive video, networking, and collaboration tools. Computers can be made to be amazingly patient teachers; they can spur creative thinking, promote enterprise, and whet curiosity.

Numerous studies conclude that technology alone is not the solution. Reaping the benefits of computers first requires extensive teacher training, new curricular materials, and, most important, changes to educational models. Modern educational concepts grounded in theory and research emphasize individualized, hands-on learning; teamwork; and guided discovery of information. These concepts are not only well suited to technology assistance, but, given the economics of teaching and training, they are nearly impossible to effect without the help of computers. Learning must be tailored to the individual student or employee which cannot be made to happen cost-effectively without technology.

People learning in large group environments are often afraid to speak out because the current culture makes them feel foolish if they make a mistake. One of the great attributes of computers is that they can be made to be nonthreatening when interacting with humans. Computers, as electronic mentors, can provide built-in experts that are available on-line, looking over your shoulder, so to speak. Thus instead of the current model, where one expert is at the front of the room talking to a large number of people, computer-based methods provide the student with hundreds of experts—all blind to human foibles. This condition permits—and makes economically feasible—the return of a very old model of education; apprenticeship, which many believe is the best learning model, whether from other people or from simulations. Computers allow apprenticeship in fields where it's hard or impossible to do it in real life, like surgery or learning to fly an airplane.

The implications of this transformation of education by technology affect both students and teachers. Instructors become more like coaches, while students become free to discover knowledge on their own. With computers, teachers become facilitators, collaborators, and brokers of resources. The networks have the information, but the students need a guide.

Computers are also a great aid in the preparation of course materials, whether through computer-oriented conventional tools, such as word processing, desk-top publishing, presentation or illustration packages or as a means of accessing far-flung resources. By making it easier to prepare materials, teachers can focus on explanations of information instead of transmission of information.

For many years, distance learning was the prime example of the potential of educational technology. The current video broadcast model of distance learning requires participating students to watch a live transmission (via cable or satellite) or wait for days to receive a video tape. New schemes involving a combination of networking and mobile access allow students to dial in at their convenience and participate in a class asynchronously. Even though the opportunity for feedback and participation does not occur in real time, the learning interactions are enhanced by rich two-way communication channels.

MODELS OF CHEMICAL EDUCATION

The interactive digital telecommunications infra structure being steadily established as described above can be imagined as a *system* that connects learners to information providers in ways that are unconstrained in time and geography (Fig. 2). By information providers I mean: (i) persons (now called teachers) who have produced instructionally useful software packages; (ii) database organizers like Chemical Abstracts or other publishers who have on-line journals; (iii) other learners, like other teachers. Thus, teachers who want to learn use the same educational system as students who want to learn. Teachers may want to learn more deeply about the same subjects that they are teaching their students, or they might want to learn about what other teachers are doing. In other words, a person's identity as a teacher or a learner might change from moment to moment depending upon his or her needs. Broadly speaking, the

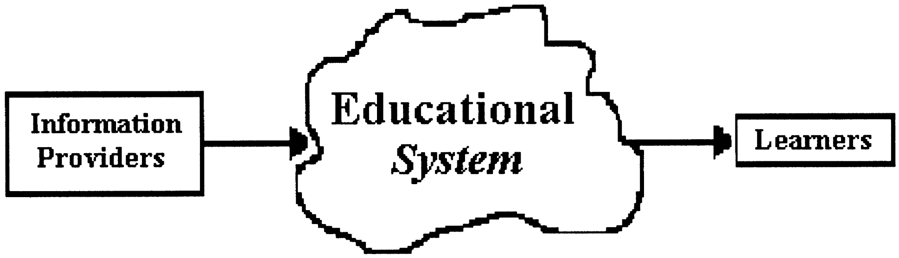

Fig. 2 A representation of the future educational systems.

developing educational system will permit new modes of learning incorporating the following elements:

- the simulation of real life environments;
- enabling self-paced learning;
- lowering the 'intimidation' factor;
- reducing classroom behavioral problems;
- increasing one-on-one instruction;
- providing access to more information; and implementing 'situated learning' or learning while doing.

The educational system will be a depository of high quality video images, both still and full motion. These images will be accessed on-demand and will be used for individualized local consumption. These images could represent reactions of exotic substances, e.g. the aqueous chemistry of gold or plutonium, as well as of complex processes, e.g. how to use a superconducting NMR spectrometer or the reactions occurring in the processing of crude oil to petrochemicals. The educational system will contain information on demonstrations, that is, either a video clip of the actual demonstration or the directions for doing the actual demonstration.

The educational system described by Fig. 2 will become a resource for learners at all levels in formal and informal educational environments as well as for traditional classroom instructors who want to incorporate modern *digitally based information* into their formal courses or to seek information for less formal reasons.

The new educational system shifts the education paradigm from the static, passive, and homogeneous environment described earlier in this paper to a new one with the following characteristics:

- individualization will be enhanced using networked personal work stations;
- team learning will be encouraged using collaborative software tools and e-mail;
- teachers will become guides to student learning through the use of networked experts;
- networks and new software publishing tools will allow us to adapt to rapidly changing subject matter content; and diversity of interactions—who is doing what for what reasons—will become the norm, replacing the homogeneous 'one-size-fits-all' approach to education.

The application of technology to educational processes can result in a new teaching/learning environment that includes the following characteristics:

- boosting of curiosity, creativity, and teamwork;
- changed role of the teacher;
- reemergence of the apprenticeship model of education;
- reduced intimidation and frustration among students;
- reduced behavioral problems and improved concentration and self-image;
- access to more information (i.e. background on demand);
- richer information environment to penetrate 'media overload'; and breaking down the walls of the classroom, integrating home, town, and world.