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Using Computer Simulations to Supplement Teaching Laboratories in Chemistry for Distance Delivery

Dietmar Kennepohl

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Abstract

Computer simulations employing digitized video images were incorporated into the laboratory component of an existing first-year university chemistry course as part of a pilot study. The students were surveyed about their experience and their performance in this distance course was also tracked and compared with students who did not do the simulations. No difference in overall course performance was observed between students who did the simulations and those who did not. However, simulation students completed in-laboratory work in a shorter time frame and showed a slightly higher performance in the practical laboratory component.

Résumé

Des simulations par ordinateur utilisant des images vidéo numérisées ont été incorporées, dans le cadre d'une étude pilote, dans la composante laboratoire d'un cours existant de chimie de première année universitaire. Les étudiants ont été interrogés sur leur expérience et leur performance dans ce cours a été suivie et comparée avec celle des étudiants qui n'ont pas utilisé les simulations. Aucune différence n'a été observée sur la performance d'ensemble dans ce cours entre les étudiants qui ont utilisé les simulations et ceux qui ne l'ont pas fait. Cependant, les étudiants ayant utilisé les simulations ont complété le travail en laboratoire dans une période de temps plus courte et ont montré un degré de performance légèrement plus élevé dans la composante pratique du laboratoire.

Introduction

Laboratory experimentation is a crucial part of the education of a chemist, and as a direct result of this, fundamental university-level chemistry courses often require a practical component for them to be considered bona fide or recognized in the science community. In addition, the quantity of laboratory work carried out is frequently equated with the quality of education and skill achieved by the student. Many traditional institutions that deliver supervised laboratory sessions are under immense financial and regulatory pressures to minimize the practical aspect their chemistry courses. Teachers and institutions are questioning not only the value of the laboratory experience, but whether proficiency and learning traditionally developed by students in the laboratory can be introduced elsewhere.

These issues, as well as the challenge of effectively delivering any laboratory-based course, have always occupied much of the attention of distance educators working in the sciences. Factors such as the cost of equipment and safety issues have made the experimental laboratory the most difficult component of the course to deliver at a distance. A survey of postsecondary institutions that offer distance education indicates hat comparatively few contain a substantial number of laboratory-based science courses or complete science programs (Holmberg & Bakshi, 1982).

Some of the strategies used by Athabasca University and others to deliver chemistry laboratories at a distance have been reviewed elsewhere (Kennepohl & Last, 2000; Koshy, Bonato, & Faasalaina, 1994; owntree, 1992). However, with the increased availability of new educational technologies, distance educators have the opportunity to design chemistry courses that could provide their students with a wider range of learning aids while potentially providing an equivalent amount of experience in standard laboratory practice (Boschmann, 1995).

In this article I describe the use of an interactive computer program enhanced with digitized video images to simulate chemistry laboratory experiments. For this pilot project, I incorporated the computer simulations into the existing laboratory component of our general first-year chemistry course (CHEM 218), which is offered through distance education. The intent is to supplement and enhance the students' laboratory experience. I outline how the program is used, provide a summary of resulting student performance, and present an overview of the students' experience in using this technology.

Computer Laboratory Simulations

The computer has played many roles in the modern teaching laboratory including being used for pre-laboratory tutorials, interactive quizzes, molecular modeling and theoretical calculations, animations, collaborative learning, as well as a tool to speed up data collection and analysis. However, it is the interactive experimental simulations that offer a viable solution for distance learners in the sciences to meet their laboratory requirement. Often it is the specific technology and its ability to bridge physical distances that becomes the center for discussion rather than its value to enhance learning. However, research does indicate that the use of computer simulations in laboratory sciences like biology, physics, geology, and chemistry does promote learning in those disciplines. Simulations also have advantages over hands-on laboratory work such as allowing students to do more complicated and hazardous experiments, obtain reproducible results more quickly, and foster a deeper understanding of the experiments, to name a few. Disadvantages like the lack of human contact, boredom, and ability to experience experimental errors are also associated with laboratory simulations. The pedagogical benefits and limitations of computer simulations have been reviewed in detail elsewhere (Muth & Guzman, 2000).

In chemistry, the available software for simulations varies greatly in sophistication depending on the animation used and the degree of engagement and interaction with the student. Simulations can include simple graphical or numerical representations of how chemical or physical processes operate. A typical example of the latter is a simple simulation of the ideal gas laws, such as reducing the size of a vessel and observing that the pressure increases. Simulations can also include representations of molecular events that improve the understanding of particulate matter and stereochemistry. In contrast to simple interactive animations, more sophisticated simulations of laboratory experiments focus on trying to recreate the results of a real experiment while also duplicating some of the real-life visual and audio information for the student. The strategy here is to engage the student by making a strong impression that stimulates more senses, with the hope that material will be better understood and eventually retained longer. Simulating the operation of analytical instruments is one common subgroup of these more sophisticated simulations. However, it tends to concentrate narrowly on replicating the machine itself. The other subgroup is a more general simulation of chemistry experiments that also encompass some of the laboratory environment. Good chemistry laboratory simulations using digitized video images have been achieved through interactive CD-ROM (CDi-ROM, Smith & Jones, 1989). In the range of chemistry simulations available, this is one of the more sophisticated and forms the basis of our study.

Procedure

With permission, this commercially available interactive laboratory simulation using digitized stop-action video from Falcon Software Inc. was nested into a computer program developed at Athabasca University (AU). The program allows students to log on securely, provides quizzes for each of the topics, keeps track of each student’s performance for both course and self-evaluation, and provides seamless access to the simulations. Students access the laboratory simulations at any of our learning centers. The simulations are divided into four major topics: (a) oxidation and reduction; (b) acids and bases; (c) reaction rates; and (d) equilibrium. Students can navigate freely through these simulated exercises and can stop at any time and continue later. They can also repeat exercises as many times as they like. Each of the four major topics has an associated 10-question multiple-choice quiz. The quiz can be taken only once, and a small grade is assigned to encourage students to use the program. A student will take anywhere from four to eight hours to complete the exercises and quizzes in the simulation package.

It was intended that the students use this computer laboratory simulation as part of their laboratory exercises, thereby allowing the amount of in-lab time to be slightly reduced (from 32 to 24 hours). The goal in using such methods is not to replace laboratory work with simulated experiments, but rather to provide the student with a better idea of what to expect on entering the laboratory. Our hope was that this kind of pre-laboratory exposure would enable students to make more efficient use of valuable laboratory time. In fact improved efficiencies have already been observed in titration experiments using an interactive videodisc as a prelaboratory exercise (Stevens, Zech, & Katkanant, 1988). Our pilot study should indicate the effectiveness of incorporating the computer simulations into the existing laboratory component of CHEM 218.

In this study I looked at two groups of students. Group A students completed the regular 32 hours of supervised laboratory sessions without doing any simulations. Group B students did the laboratory simulations (including simulation quizzes) independently and individually in one of our learning centers prior to 24 hours of regular supervised laboratory sessions. Both groups of students also completed laboratory quizzes. The regular theory part of the course work was completed through distance education. The laboratory and course performance of all students was tracked, and the students were surveyed on their opinion of the simulations after they had completed the course.

Results and Discussion

A summary of student performance is provided in Table 1. The bulk (80%) of the overall course grade was determined by tutor-marked assignments and invigilated examinations. The laboratory grade (20% of the overall course) was mostly (90%) determined by written laboratory reports. The average overall course grade and the laboratory grade of the two groups of students are statistically identical by *t*-test analysis. Despite the decrease in face-to-face laboratory hours (from 32 to 24 hours), overall performance in the course and the quality of laboratory reports remained unchanged. However, the grade from the laboratory quiz, which tests practical in-lab knowledge, is considered statistically different between the two groups and is slightly higher (74.5% vs. 67.5%) for the laboratory simulation students (Group B). This suggests that computer simulations enhance the students' in-lab knowledge even when the amount of in-lab time has been reduced.

Table 1
CHEM 218 Student Performance

	Group A	*Group B*
Amount in-lab work (hours)	32	24
Computer simulation done (students)	0	72
Simulation grade (%)	N/A	64.0
Overall course grade (%)	73.9	72.6
Laboratory grade (%)	77.3	80.1
Lab quiz grade (%)	67.5	74.5
Student numbers	82	87

Earlier studies comparing laboratory computer simulations with real laboratory experiments have shown varied results. This is not at all unexpected considering the variety of applications, student groups, and particular experiments being investigated. One study of high school chemistry students clearly showed more laboratory learning occurred with the hands-on group compared with the computer simulations group

over a series of three different experiments (Bourque & Carlson, 1987). However, using a spectrometry experiment in a university setting, it was shown that students learned more doing the laboratory simulations than either the traditional laboratory work or using the learning cycle (Jackman, Moellenberg, & Brabson, 1987). Still, several other studies show no measurable difference in student achievement between hands-on experiments and simulations (Kofke, Grosso, Gollapudi, & Lund, 1996; Fawver, Branch, Trentham, Robertson, & Beckett, 1990; Bobbert, 1982). Although investigators do not always agree on the effectiveness of computer simulations, the universal observation seems to be that they are more time-efficient than real-life experiments. However, in our study we are not directly comparing real laboratory work with simulations alone, but rather comparing real laboratory work with a combination of simulations and a reduced amount of real laboratory work. The slight improvement in student performance we observed is consistent with other studies that show that a combination of simulation and hands-on laboratory work is better than either on its own (Bourque & Carlson, 1987; Bobbert, 1982).

The students going through these laboratories were also surveyed at the end of their course, and the results are summarized in Table 2. Note that the first few questions of the survey give a student profile. Both the average age and educational experience shown in the survey correspond well with the CHEM 218 student profile we have amassed based on a larger sample size. However, the actual gender distribution for CHEM 218 is closer to 50:50, which is not reflected in this particular survey. Compared with chemistry students from traditional institutions our first-year

Table 2
CHEM 218 Student Survey of the Computer Laboratory Simulations

Female	16 students
Male	28 students
Average age	31 years
University degree	24 students
College diploma	6 students
No postsecondary experience	0 students
Average time since last science lab experience	2.0 years
Average time since last chemistry lab experience	4.1 years
Did computer laboratory simulations	32 students
Simulations easily accessed	76%
Instructions easy to follow	84%
Simulation experiments interesting	68%
Quizzes reflect simulation material	88%
Course material reinforced	82%
Simulations help prepare for real labs	46%
Prefer lab simulations on CD-ROM*	88%

*This percentage also includes students who did not do the computer laboratory

chemistry students are more mature and have more educational experience (Kennepohl & Last, 2000). This trend is true for our other chemistry courses and is generally true for all courses at AU. In general, the scores given by the students in the survey were not strongly correlated with sex, educational experience, age, or whether they had previously taken an AU course. The only exception to this was that the under-25 age group gave a low score (41% compared with the overall average of 76%) in response to the question of accessibility to the simulation itself. Although the simulations were available at our main campus and our learning centers and offered more flexibility than paced laboratory sessions, they are indeed less flexible than home study.

Of more significance to this study is that an average time of four years has passed since students' previous chemistry laboratory experience. This long absence from the laboratory certainly would indicate that some sort of laboratory preparation might be of particular benefit to this group of students. Most students in group B (72 out of 87, see Table 1) did make use of the computer simulations. The students who had been away from a chemistry laboratory for at least two years gave a higher score (66%) for the ability of the simulations to help prepare for real laboratory work than students who had recent experience (24%). The only other score that varied significantly between these two groups was whether the simulated experiments were interesting. The students with more recent chemistry laboratory experience were less impressed (56%) than those who had been away from the laboratory more than two years (74%).

Overall, students surveyed found the actual operation of the computer simulations to be fairly straightforward. That is, the simulations were easily accessed on the computer (76%), and the instructions were clear and easy to follow (84%). A slightly lower score (68%) was assigned to the attraction or interest level of the experiments themselves. It is not clear whether this lower score is a reflection of the particular experiments that were being simulated or whether the students found the simulation itself not that stimulating. The low *interest* score may reflect the repetitious nature of computer simulations in general. This element of weariness and boredom in simulations has also been reported by others (King & Ryan,

2000). We were encouraged that students felt that the quizzes in the program reflected the information presented in the simulations quite well (88%) and that this also strongly reinforced the course material (82%). In the light of this and coupled with the reduced in-lab time spent and the improved mean laboratory quiz grade, it was surprising that the students gave a low score (46%) to the ability of these simulations to help them prepare for real laboratory work. We cannot account for this directly and note only that it may be an expression of the difference in a high student expectation compared with the reality of their experience in the laboratory. The request by most of the students (88%) to have the same simulations available to them on CD-ROM also seems to contradict that previous score. Nonetheless, the wish for CD-ROM and therefore the ability for individual home study is seen as a desire to obtain these simulations in a more accessible and flexible manner.

Summary

The introduction of computer laboratory simulations to supplement existing traditional laboratory work in this first-year general chemistry course did not seem to affect the overall performance of students in their chemistry course. The combination of simulations and in-lab components offers advantages in time efficiencies so that the in-lab portion can be reduced in length. In addition, students using the simulations have a slightly better knowledge of the practical aspects directly related to laboratory work.

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Dietmar Kennepohl was born in Toronto, Canada and received his Bachelor of Science (Honours Chemistry) degree from McMaster University and his doctorate from the University of Alberta. This was followed by a two-year stay in Germany as a Humboldt Fellow at the Universit�t G�ttingen. On returning to Canada he carried out postdoctoral work at the University of Guelph and is

presently an associate professor of chemistry and Chair of the Center for Science at Athabasca University.

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