The potential of virtual laboratories for distance education science teaching: reflections from the development and evaluation of a virtual chemistry laboratory

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Introduction

A virtual chemistry laboratory has been developed at Charles Sturt University, based on an accurate 3D model of the Wagga Wagga undergraduate teaching laboratory. The initial version of the virtual laboratory has been designed to enable distance education chemistry students to become familiar with the laboratory prior to their residential school. It allows for free exploration and for collecting and assembling items of apparatus. It also allows students to read information about the items of apparatus and about laboratory procedures.

This paper describes the current features of the virtual laboratory and discusses the pedagogical rationale for its development. Results from questionnaires completed by pilot testers and by the first group of students who used it as part of their laboratory orientation are included. The results of tests comparing the laboratory familiarity of students who used the virtual laboratory with those who viewed equivalent still images are also presented. The paper concludes with a description of features to be added during the next stage of development, which will include the ability for students to undertake virtual experiments while exploring concepts using macroscopic, molecular and symbolic representations.

Context

At Charles Sturt University (CSU) one of the greatest problems that confronts us in providing undergraduate chemistry by Distance Education (DE) is how to adequately address the teaching of a laboratory component. This problem has also been frequently reported by others involved in teaching chemistry at a distance (Hollingworth and McLoughlin 2001). In teaching first year chemistry at CSU this is further compounded by the fact that over 90% of our students undertake chemistry as a service subject for degrees such as pharmacy, wine science, agriculture, nutrition, teaching and nursing.

At CSU there are two introductory chemistry subjects. *Chemistry Fundamentals* is taken by students in courses requiring a base level of understanding and *Chemistry 1A* is taken by students requiring a more in depth chemistry background. Combined enrolment for these subjects in 2003 was 523, of which 240 were DE students. Both of these subjects are available without prerequisites, a CSU policy. Students enrolling in *Chemistry 1A* are recommended to have completed a bridging course as a minimum standard. The bridging courses have no laboratory component.

The level of previous laboratory experience varies enormously across the cohorts. While some are already employed in professional laboratories, others have recently completed Year 12 Chemistry, and some have never previously experienced a laboratory environment. A survey of internal *Chemistry 1A* students in 2001 identified the highest level of Chemistry previously completed. 72% had completed Year 12 or higher, 5% had completed Year 11 and 23% Year 10 or lower, and informal polling of DE students has indicated that more than one third have little or no previous experience in performing chemistry experiments.

DE students are currently provided with printed materials and supported through an asynchronous online forum, plus email, phone and fax. The laboratory component of chemistry subjects is completed at intense three or four day residential schools. Providing a satisfactory laboratory experience for these students within that short period, and within the constraints of our resources, is the subject of ongoing review at CSU.

The initial orientation in the laboratory is a crucial step. Recognising that learning is best achieved in an environment where students feel calm and secure, initial exercises are employed to familiarise students with the laboratory protocols, layout and equipment locations. We endeavour to make them comfortable in the laboratory environment as quickly as possible to maximise their learning experiences during the brief residential school period. Nevertheless, some students experience a high level of stress and their 'survival' strategy is to merely plod through and 'satisfactorily' complete a lab. Often only surface learning occurs, as students leave the labs without having extended themselves to truly experiment and learn. Despite the inherently active opportunities offered in the laboratory learning experience, students frequently have passive expectations. They are unfamiliar with the environment and the equipment and want step-by-step directions. They adhere stringently to any written instruction, often without thought or understanding, and make slow progress.

Many of the problems that students experience in the laboratory can be ascribed to inadequate preparation. That preparation may be considered to have several parts: orientation (knowing locations of equipment); appropriate choice of equipment (understanding, for example, which piece of glassware to use); and grasp of the theory underpinning experiments. Adequately preparing DE students is a difficult task. Internal students have their laboratory experience spread over many weeks, and so have time to learn the locations of materials and evolve their preparative methods. Opportunities for DE students to reflect upon and refine their preparative strategies are limited.

Potential benefits of a virtual laboratory

3D environments have the potential to situate the learner within a meaningful context to a much greater extent than traditional interactive multimedia environments. The sophistication in the rendering of objects, the independent behaviour of objects within the world, and the degree of interaction available, allow for situated tasks that are both meaningful and intrinsically motivating for learners. Such environments have been used for a number of educational purposes. They can allow the learner to explore places that cannot be physically visited. For example Alberti, Marini and Trapani (1998) describe an environment modelled on a historic theatre in Italy. The exploration of a virtual laboratory by DE students before their residential school is a similar idea. 3D environments can also be used for practicing skills, especially where the tasks to be learned are expensive or dangerous to undertake in the real world. For example, 3D environments have been used to train nuclear power plant workers in Japan (Akiyoshi, Miwa and Nishida 1996 cited in Winn and Jackson 1999). 3D environments can also be effective for modelling abstract concepts. Winn and Jackson (1999; p.7) suggest that virtual environments 'are most useful when they embody concepts and principles that are not normally accessible to the senses'. A virtual laboratory allowing molecular visualisation is consistent with this idea.

A virtual laboratory that allowed students to explore the environment, read about equipment and procedures and locate, collect and assemble apparatus before they undertook their first laboratory session would potentially have the following specific benefits:
- students would feel more relaxed and comfortable in the laboratory;
- less laboratory time would be wasted looking for items of apparatus;

- students would be more likely to assemble and use apparatus in the correct way leading to more meaningful experimental results;
- greater familiarity with laboratory procedures may improve safety; and
- students could devote more of their attention to the chemistry concepts involved in the experiments because they would already be familiar with the procedural aspects of the task.

In addition to familiarising students with the laboratory, there is potential to replace some real experiments with virtual laboratory experiments. Laboratory work is traditionally considered to be an essential component in science subjects, where the practical skills for a discipline are imparted. However, where chemistry is taught as a service subject within a vocational degree this traditional role for laboratory work may need to be reassessed. In addition, running practical classes is expensive, time consuming and has inherent safety issues. The chemists at CSU have identified priorities for the ‘lab experience’, through consultation within the school, with course coordinators, students and with reference to current literature. (See Adlong, Bedgood, Bishop, Dillon, Haig, Helliwell, Pettigrove, Prenzler, Robards and Tuovinen 2003, for more details) Among these, the three highest priorities were developing:

- skills in recording, reporting and interpreting observations;
- higher level cognitive skills of deductive reasoning, hypothesis formation and testing; and
- skills related to manipulative and instrument use.

The use of a virtual laboratory, allowing virtual experiments to be undertaken, could help students to achieve the skills within two of these priority areas. Virtual experiments could potentially allow students to improve their skills in deductive reasoning, hypothesis formation and testing as effectively as through real experiments. Skills in recording, reporting and interpreting data could also be effectively developed through these virtual tasks.

Beaker: 250ml

Beakers are convenient for holding reagents and can be used as reaction vessels. Beakers are marked with very approximate volumes, which serve merely as a rough guide to the volume of liquid in the container.

General safety information about using glassware

General information about measuring volumes

Figure 1. The virtual chemistry laboratory

The CSU virtual chemistry laboratory

The CSU virtual chemistry laboratory (accessible at http://farrer.csu.edu.au/chemistry/) is an accurate model of the undergraduate chemistry teaching laboratory at our Wagga Wagga campus. The initial version has been designed to allow learners to become familiar with the layout of the actual laboratory, as well as to find out information about laboratory procedures. It has been developed using the Virtual Reality Modelling Language (VRML) (Carson, Puk and Carey 1999) and is accessed through a web interface. Learners can explore the laboratory and find out information about items of apparatus and equipment by selecting objects. Information about laboratory procedures is accessible through menus in the environment. Learners can also collect items of apparatus that they might need for an experiment, carry them to a desk and then assemble them. Figure 1 shows a screen dump of the virtual laboratory. In this screen dump the learner has picked up a beaker and information about the beaker has been displayed in the text area. The learner has also selected the lab procedures menu.

Evaluation results

A formative evaluation of the virtual laboratory involving 10 internal chemistry students was undertaken early in 2002. This involved observing students using the virtual laboratory followed by a questionnaire and interviews with each student on their perceptions of its potential. During the observations and ensuing discussions various user interface problems were identified. All learners were able to move around the laboratory without great difficulty. However, a number of problems with viewing and manipulating apparatus were identified, including difficulties with positioning the viewpoint to allow the contents of drawers to be viewed, the expectation that certain objects were able to be selected or dragged when they were not, and the fact that some objects could be dragged through the walls of cupboards and were then difficult to locate. The students' questionnaire responses and the comments during the interview were very encouraging. For example in response to the statement 'in its current form, you would recommend that new students use the virtual lab prior to their first laboratory experiment' 3 participants indicated very strong agreement, 4 indicated strong agreement and the other 3 indicated agreement. Overall, although the sample was small, there was a clear indication that students found the virtual laboratory a useful tool for familiarising them with the laboratory.

As a result of the initial formative evaluation a number of improvements to the user interface were made. Additionally a mechanism for students to collect and assemble apparatus was added. The new version of the virtual laboratory was used by all internal students in the subject *Chemistry Fundamentals* at the beginning of 2003, as formal preparation for their laboratory work. In order to explore various questions relating to spatial learning in 3D environments (part of the first author's doctoral work) these students were divided into three groups, each of whom used a different computer-based representation of the laboratory and then completed various test tasks. Twenty six students were allocated to a group that viewed an animated tour of the laboratory, 30 to a group that viewed a corresponding sequence of 428 still images of the laboratory, and 24 to a group that used the virtual laboratory. After using the environment, students completed a written test on their knowledge about the laboratory layout. A week later each student completed a questionnaire on their perceptions of the value of the virtual laboratory. A complete description of the methodology and results from this study is outside the scope of this paper, but results exploring the difference between viewing a series of static images of the laboratory and using the virtual laboratory will be discussed, along with the questionnaire responses.

One part of the written test required participants to indicate the location where each of a list of 11 items of apparatus would normally be found, given a plan of the laboratory, including labelled furniture, and given a colour photograph of each item. Correctly placed items were awarded one mark and items within 2.5 metres of the correct location were awarded half a mark. The mean for virtual laboratory participants was 5.62 items as compared to the still image participants who had a mean of 2.62 items. An Analysis of Variance (ANOVA) comparing the three test groups indicated that group was a factor in performance on this test item ($p=0.00$). Post Hoc analysis using Tukey's Honestly Significant Difference (HSD) test (Gravetter and Wallnau 2000) showed that the difference between the virtual laboratory group and the still image group was significant ($p < 0.0005$). These results suggest that the use of the virtual laboratory leads to substantially greater familiarity of the location of apparatus within the laboratory than viewing an equivalent series of still images of the laboratory.

A summary of questionnaire responses from the students who used the virtual laboratory is presented in Table 1. Twenty of the 24 students who used the virtual laboratory completed the questionnaire, as 4 were absent when the evaluation was carried out. The responses, while not as overwhelmingly positive as those of the pilot group, nevertheless provide us with encouragement to continue with the development of the virtual laboratory.

DE *Chemistry 1A* students were informed of the availability of the virtual laboratory in early 2003 and those that attempted to use it were asked to complete a questionnaire at the residential school. Fifteen students attempted to use the virtual laboratory; of the six who successfully used the virtual laboratory, five indicated that it helped them to become familiar with the real laboratory. The remaining nine encountered problems downloading, installing, and executing the required software and were unable to proceed; the problems with remote installation of the virtual laboratory are currently being explored. One possible solution is to deliver the software on a self-installing CD-ROM. A comprehensive evaluation of the use of the laboratory by DE students will be carried out in 2004.

Question	**Average**	**Number of responses**						
		7. **very strongly agree**	6. **strongly agree**	5. **agree**	4. **neutral**	3. **disagree**	2. **strongly disagree**	1. **very strongly disagree**
The virtual lab helped you to become familiar with the layout of the lab building.	5.7	4	9	5	1	1	0	0
The virtual lab helped you to be able to identify items of apparatus.	5.5	5	7	2	4	2	0	0
The virtual lab helped you to be able to locate items within the lab.	5.1	3	4	9	0	3	1	0
In its current form, you would recommend that new students use the virtual lab prior to their first laboratory experiment.	5.2	4	6	5	3	0	1	1
If the virtual lab allowed you to carry out virtual experiments, you would use it prior to laboratory sessions to practice the experiments.	5.4	5	5	7	1	1	0	1

Table 1. Questionnaire results from *Chemistry Fundamentals* students

Future plans

Development of the virtual laboratory is focussed on moving incrementally towards the eventual goal of allowing students to undertake virtual experiments. At present students can set up the apparatus for a titration. The next step is to model liquid within the environment in such a way that accurate quantities of solutions can be transferred from one vessel to another using a pipette, burette, beaker, conical flask or measuring cylinder. Once this is done, molecular simulations will be introduced allowing for a titration to be carried out with the facility to zoom in and visualise processes on a molecular level. It is intended to also introduce various symbolic representations, including a graphical display of the concentration levels and an equation view. Allowing students to move between macroscopic (laboratory level), microscopic (molecular level) and symbolic representations of chemistry concepts is consistent with research into chemistry pedagogy. For example Gabel (1993 cited in Russell, Kozma, Jones, Wykoff, Marx and Davis 1997) notes that when the macroscopic, microscopic and symbolic aspects of chemistry are taught separately, 'insufficient connections are made between the three levels and the information remains compartmentalised in long-term memories of students'. Tasker (1998) also argues for the importance of students being able to make linkages between symbolic equations and the molecular level. A challenge from an interface design point of view will be to provide these additional cognitive tools in such a way that they don't detract from the realism of the environment.

Conclusion

This paper has discussed the potential for the use of virtual laboratories within chemistry teaching, especially when this teaching occurs in distance mode. The features of a virtual laboratory developed at Charles Sturt University have been described and the results of evaluations have been presented. These results suggest that the majority of students can see benefit from the use of virtual laboratories. Initial data also suggests that the virtual laboratory provides for more complete learning of laboratory layout than the use of a web site containing still images. We have reason to be confident that the next version of the virtual laboratory, which will allow for students to undertake virtual experiments, will lead to significant learning of chemistry concepts.

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