What factors contribute to students' confidence in chemistry laboratory sessions and does preparation in a virtual laboratory help?

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Introduction

Many undergraduate students studying chemistry subjects at Charles Sturt University (CSU) do so by Distance Education (DE). CSU has been offering subjects in chemistry in distance mode for more than 20 years. One of the greatest problems that confronts us, and others (Hollingworth and McLoughlin 2001; Kennepohl and Last 2000) in providing DE subjects is how to adequately address the teaching of a laboratory component. The practical work for CSU DE chemistry subjects is completed at intensive three or four day residential schools. Thus, DE students have only a few days to face the challenges that are spread out over many weeks for on-campus students. Providing a quality laboratory experience for these students within that short period and within the constraints of our resources is the subject of ongoing review at CSU. Problems associated with high stress and information overload for the laboratory component in DE had been noted anecdotally and in the literature (e.g., Loonat 1996). Adequately preparing DE students for residential school is a difficult task.

One strategy we have adopted to help prepare DE students has been the provision on CD-ROM of a 3D virtual laboratory, which is an accurate representation of the teaching laboratories. In a paper at last year's UniServe Symposium (Dalgarno, Bishop and Bedgood 2003), we hypothesised that as a pre-laboratory familiarisation tool, the virtual laboratory would include the following potential 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; 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 (p. 91).*

This paper presents the results of a qualitative and quantitative study of the laboratory experience of DE students in first year chemistry subjects which provides initial tests of these hypotheses, as well as expanding our understanding of factors involved with the student experience of laboratory.

About the Virtual Laboratory

The virtual chemistry laboratory provided to students on CD-ROM is an accurate 3D model of the Charles Sturt University Wagga Wagga undergraduate teaching laboratory. The initial version of the virtual laboratory has been designed to enable DE chemistry students to become familiar with the laboratory prior to their residential school. Though the virtual laboratory does not yet allow students to conduct experiments, it provides an environment where students can freely explore, collect and assemble items of apparatus, and find out information about laboratory procedures and apparatus (Figure 1). The virtual laboratory has been developed using the Virtual Reality Modelling Language (VRML) (Carson, Puk and Carey 1999) as well as using additional enhancements to VRML provided by the Blaxxun Contact VRML Browser (Blaxxun Technologies 2004). Blaxxun Contact runs within a web browser such as Internet Explorer, but can be run full-screen so that the web browser toolbars are not visible.

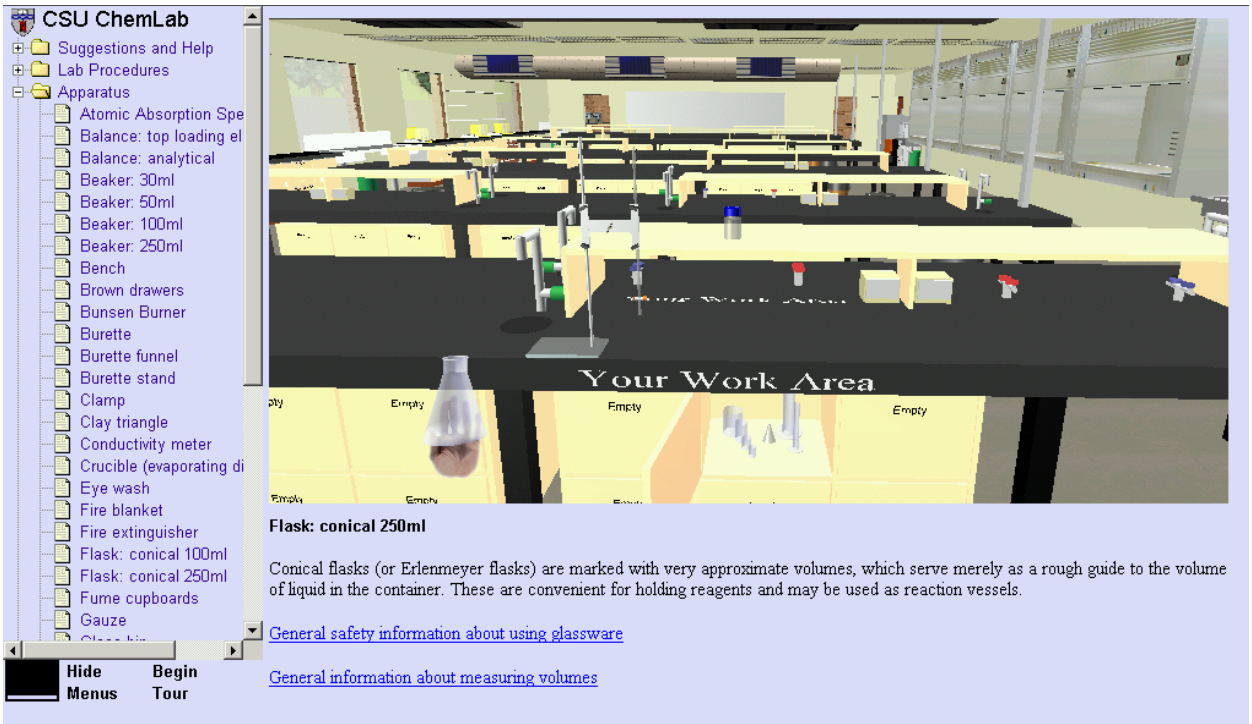

Figure 1. The Virtual Chemistry Laboratory

The Potential of a 3D Virtual Chemistry Laboratory

Dalgarno (2002) carried out an analysis of the potential of 3D learning environments in the context of contemporary theories of learning. Specifically, Dalgarno classifies the potential applications of 3D learning environments according to Moshman's (1982) interpretations of constructivism, endogenous, exogenous and dialectical constructivism. The current version of the virtual chemistry laboratory is primarily an example of a 'place simulation', that allows elements of 'skill practice', each of which were classified by Dalgarno as applications of 3D learning environments consistent with Moshman's endogenous interpretation of constructivism. Additionally, the embedded information about laboratory procedures and apparatus provide an example of what Dalgarno terms a 'situated instructional resource' which was found to be consistent with Moshman's exogenous interpretation of constructivism.

There are various non-3D examples of simulated chemistry laboratories, designed to familiarise students with laboratory procedures before entering the laboratory (see, for example Carter 1997), however, none has the level of fidelity provided by a realistic 3D environment. There has also been extensive use of 3D molecular animations in chemistry (see, for example Tasker 1998) but without the level of interactivity provided by a navigable 3D environment.

Results and Discussion

All students who attended a residential school in the two first year chemistry subjects were asked to complete a questionnaire. Of the 42 students from Chemistry 1A and 28 from Chemistry Fundamentals who attended the residential schools, 55 completed the questionnaire. Additionally 16 students agreed to be interviewed about their experience before and during the first laboratory session at the residential school. Although these 16 students were not randomly selected, they included equal numbers of students from each subject and equal numbers of students who did and did not use the virtual laboratory. Students were asked about issues such as:

- Feelings of confidence and anxiety;

- Difficulties in locating, identifying, and using apparatus;
- Prior laboratory experience;
- Ability to focus on underlying chemical concepts during the practical;
- Effect of laboratory partner on confidence; and
- Pre-prac activities contributing to confidence.

The questionnaire was laid out in parts so that only students who had chosen to use the virtual laboratory answered the main set of questions about the effect of the virtual laboratory.

In relation to questions about feelings of confidence and anxiety before the first laboratory session: 23 indicated that they did not feel confident that they would be able to successfully complete the laboratory sessions, compared to 20 who did feel confident, with 12 undecided; and 43 students indicated that they felt anxious about the laboratory sessions compared with 10 who did not and 2 undecided. As expected, a strong negative correlation was found between confidence and anxiety. Males were more likely to indicate that they felt confident than female students. Using a Likert scale where 7 = very strongly agree, males averaged 4.87 to females 3.54; the difference was significant (T-test, p=0.001). Burdge and Daubenmire (2001, p. 296) report that research suggests that women are still significantly less self-confident than men in introductory college science classes.

When the responses of those who had used the virtual laboratory were compared to the responses of those who had not, there was no significant difference in relation to level of agreement to statements such as, 'Before the laboratory sessions commenced, I felt confident that I would be able to successfully complete them'. Statistical comparison of the responses of the two groups suggests that using the virtual laboratory prior to the residential school did not have a significant effect on students' levels of confidence or anxiety, nor did it have a significant effect on the indicated ease with which students were able to identify, locate, choose, assemble or operate items of apparatus. More than half of all students indicated that they did not have difficulty identifying, locating, choosing, assembling and operating items of apparatus. However, there was a significant minority who indicated that they did experience difficulties with apparatus. There were differences between male and female responses to questions about difficulty in assembling (T-test, p=0.042, which is significant) and operating (T-test, p=0.088, significant only at the 90% level) items of apparatus. Male students were more confident in these tasks. Hazel and Baillie (1998, p. 37) suggest that women's lack of technical background and behavioural tendency to 'tinker' less, may be a problem in their science learning.

Understandably, the level of prior laboratory experience influenced student comfort in the practical classes. Students were grouped into three levels of prior experience: recent relevant experience—considered to include laboratory experience (in 1999 or since) in year 11 or 12, TAFE, University, or work; some experience—including any experience not in the first group, e.g., year 10-12, TAFE, University[1] or work experience since 1994; and no experience. Participants with recent, relevant laboratory experience were significantly less likely to indicate that they found it difficult to assemble items of apparatus than participants with 'some experience' (ANOVA, p=0.047).

Overall, students felt that a positive relationship with one's laboratory partner contributes to confidence. This was consistent with our expectations, and further supported by interview data. The opportunities to share the workload and discuss with a partner what steps to undertake can improve confidence. When asked whether they were able to concentrate on the underlying chemistry concepts while performing the experiments, 43.6% of all respondents felt that they were able to, 29.1% indicated that they were not able to, while the remainder were undecided. This is consistent with previous focus groups, in which a number of first year chemistry students discussed developing their understanding later when reviewing and reflecting upon their laboratory experience in relation to theory. Interviews in this study also revealed that a lack of mathematical grounding can detract from students' confidence: they feel that it undermines their ability to progress in chemistry. While

[1]Students categorised as having 'recent relevant experience' may have had that recent experience in a laboratory at CSU.

we have known this for some time, we were surprised at the percentage of students who mentioned it and the apparent magnitude of the influence.

Students were asked to rank ten pre-laboratory activities in order of their importance in contributing to their confidence in the first laboratory session. These results are summarized below in Table 1. The preparative activities that students considered most important were pre-reading of the laboratory manual, prior study, pre-lab exercises and pre-reading of the text book. Interviews revealed that students who felt they had a fair grasp of the theory prior to residential school were more confident of success.

Table 1. Student rankings of pre-laboratory activities in order of their importance (respondents were instructed to rank any activities that they had not completed as last; i.e. as unimportant)

Ranked activity	Mean	S D	Ranked activity	Mean	S D
Pre-reading lab manual	2.47	1.33	Prior work experience	6.09	2.95
Prior study	3.15	2.00	e- or online- resources provided with text	7.26	1.61
Pre-lab exercises	3.64	1.93	Online resources from lecturer	7.45	1.57
Pre-reading textbook	4.23	1.65	Using virtual lab	7.46	2.46
Lectures/tutorials prior to laboratory	4.72	3.05	Reading online subject forum postings	8.13	1.63

A significant difference was noted in the perceived importance of pre-reading the textbook for students of different levels of relevant experience. Students with recent, relevant laboratory experience ranked this 4.78 out of the 10, ranking it of significantly less importance compared to those with some experience, who ranked it 3.33 (ANOVA followed by Post Hoc Tukey's HSD test, $p=0.026$). Students with no prior experience ranked this factor 3.75.

Several online and electronic resources were available for student preparation: online and CD resources provided with the textbook, online resources posted by lecturers, the forum (asynchronous, electronic discussion forum provided for each CSU subject), and the virtual laboratory. These resources were all low ranking in their contributions to student confidence, and some differences between groups were evident. For example, older students (> 35 years) ranked forum discussions higher than other student age groups. This suggests that older students may get more out of discussions on the forum than the younger age group (ANOVA followed by Tukey's HSD test, $p=0.062$, which is significant at the 90% level). Hollingworth and McLoughlin (2001) also suggest that willingness to participate in forum discussions relates to maturity.

Males, on average, ranked online resources that came with the text as 7.92, whereas females ranked it 6.88. The difference was significant (T-test, $p=0.048$). Males were also more likely to use the virtual laboratory in preparation for the residential school: 40% of males compared to 24% of females chose to use it. The very low ranking of the virtual laboratory reflects the fact that only 29.1% of students used it and students were asked to rank activities they had not completed last. Students who used the virtual laboratory rated its importance in contributing to their confidence in laboratory session sixth out of 10 activities, behind pre-reading of the laboratory manual, prior study, pre-reading of the text book, pre-lab exercises and residential school lectures and tutorials, but ahead of prior work experience and use of online resources.

Contribution of the virtual laboratory

Sixteen students (29.1%) chose to use the virtual laboratory in preparation for the residential school. Only these students responded to a section of the survey that had statements about the value and effect of the virtual laboratory. Those who had chosen to use the virtual laboratory comprised 50% of the younger age group, 28% of the middle age group and 19% of the older age group. Twenty-four percent of the respondents with highly relevant laboratory experience used the virtual lab, compared with 40% of the 'some experience' group and 27% of respondents with no relevant experience. As previously noted, 40% of male respondents used the virtual lab compared with 24% of female respondents.

Users of the virtual laboratory were generally positive about the value of it in contributing to their confidence and reducing their anxiety about practical work. On average, they found that the virtual laboratory helped them to identify and locate items of apparatus, and to work out which items to use, but not to improve their ability to assemble items and operate items of apparatus. Males (5.40/7.00) were significantly more likely than females (4.33) to indicate that the virtual lab helped them to identify named items of apparatus in the laboratory (T-test, p=0.030).

The age groups of users of the virtual laboratory responded differently to the suggestion that use of the virtual laboratory helped them to select appropriate items of apparatus during the lab session. Students in the younger age group averaged 3.83, middle age group 3.25 and older age group averaged 5.00 (Likert scale where 7 = very strongly agree). A Post Hoc Tukey's test indicated that the difference between the middle age group and the older age group was significant at the 90% level (p=0.054), suggesting that students aged >35 were less likely to learn the utility of items of apparatus from the virtual lab. Further analysis is required to determine if prior experience correlates with age or whether there were interactions between age and prior experience in the degree to which participants thought the virtual lab helped them.

Consistent with the findings about confidence in the whole group, male users of the virtual laboratory (5.0/7.0) were significantly more inclined than females (3.9) to agree with the statement 'the virtual lab made me feel more confident' (T-test, p=0.030). Male students were also more likely than females to indicate that they found the use of the virtual laboratory enjoyable (T-test, p=0.079, which is significant at the 90% level) and to consider the virtual lab valuable as preparation for the lab sessions (T-test, p=0.089, which again is significant only at the 90% level). A preference to prepare by using the virtual lab rather than by reading a laboratory manual was significantly more frequently expressed by male students than females (T-test, p=0.040). Differences were also found for this preference based on level of prior experience: students with recent, relevant experience averaged 4.71, while those with some experience averaged 3.00, and the 'no experience' group averaged 5.00. Interestingly, 9 out of the 16 students who used the virtual laboratory agreed that a video tour of the laboratory would be more valuable than the virtual laboratory as preparation for the laboratory sessions, with 5 undecided and 2 disagreeing. This was surprising because it was anticipated that the ability to carry out simulated tasks in the virtual laboratory would make it more effective than a video as a preparatory tool. Loonat (1996), however, did find 'far-reaching' benefits to the use of a 35 minute pre-lab video with DE chemistry groups.

When asked whether they would recommend that future students use the virtual lab prior to their first laboratory session, 69% of users of the virtual laboratory agreed. It was interesting to find how the level of prior experience influenced the responses to this question: recent, relevant experience averaged 5.14 and those with no experience averaged 5.33, while students with some experience averaged 3.67. Overall, there was also strong support for the statement 'If the virtual lab allowed me to carry out virtual experiments, it would be useful as a resource to prepare for laboratory sessions.' However, this support must be qualified by the fact that the students can only imagine what such virtual experiments may include.

Conclusions

This study, based on the self reporting of students, allowed the development of the following conclusions about the value of preparation in a virtual laboratory.

The levels of confidence and anxiety were found to vary broadly across the cohort. Statistical comparison of those who used the virtual laboratory with those who did not suggests that it had minimal effect on student confidence in their first practical session in the subject, particularly for those with no prior laboratory experience. Nevertheless, students who used the virtual laboratory were generally positive about the value of the virtual laboratory in contributing to their confidence and reducing their anxiety about practical work. Many of these students indicated that the virtual laboratory helped them to *locate* items of apparatus, and *to work out which* items to use, which we expect would have improved their confidence. Responses of users indicated, however, that, in its current form, the virtual laboratory provides no improvement in student ability to *assemble* and *operate* items of apparatus. Extensions of the current software are now underway, including the addition of a virtual experiment that includes assembly and operation of the apparatus; we expect this addition will improve student skills in this area.

Younger students appear to perceive more benefits from the virtual laboratory, and are more likely to use it. Older students may not derive as much benefit from virtual laboratory environments constructed like this one; these students report valuing personal interaction more than younger students, and so may benefit less from such isolated resources. One way to address this issue is to allow for multiple students to explore the virtual laboratory together, to view 'avatars' representing other students – we have now begun investigation of such mechanisms. Older students also rate the virtual lab as less effective in developing skills in selecting apparatus for an experiment; it is hoped addition of the virtual experiment noted above will address this issue.

The fact that there was such diverse ranking of important items for student preparation suggests that students utilise a wide range of approaches in their study and preparation for the laboratory. Provision of this resource caters to the particular learning preferences of a minority of students. As such, we consider the virtual laboratory as one of the suite of options available to students, in catering to the range of learning preferences among them. Despite mixed impressions of the virtual laboratory, a large majority of students recommend the use of the virtual laboratory before attending residential school.

These results are likely to be of interest to lecturers in chemistry and other laboratory disciplines, whether teaching on campus or at a distance. A better understanding of the student laboratory experience is essential if we are to ensure that students obtain the maximum possible benefit from their laboratory sessions.

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