The influence of a pre-laboratory work module on student performance in the first year chemistry laboratory

Siegbert Schmid
University of Sydney, Australia
s.schmid@chem.usyd.edu.au

Alexandra Yeung
University of Sydney, Australia
yeung_a@chem.usyd.edu.au

Abstract: The use of information and communications technology has an increasing influence on teaching activities in higher education. Information and communications technology offers the opportunity to improve students' learning experiences provided it is used in an educationally sound way. Material such as online pre-laboratory work can be accessed by students off campus at any time to allow students some timetabling flexibility whilst offering the university a cost effective means of delivery. The effectiveness of a particular online pre-laboratory work module on students' learning and their academic performance in a related practical exercise was investigated for this study. This investigation clearly demonstrated that those students, with a relatively poor chemistry background, who completed this module performed significantly better in a laboratory titration assessment than those who did not complete it.

Keywords: pre-laboratory work, computer assisted learning, chemistry education

Introduction
Traditionally chemistry courses at university level incorporated a significant amount of time spent in laboratory classes and it has been argued that working in a laboratory is an integral part of any complete chemistry education (Johnstone & Al-Shuaili, 2001). Laboratory work allows students to acquire technical skills such as handling glassware and equipment, which is a necessary preparation for any career involving chemistry. At the same time, laboratory work also offers the chance for students to develop a number of more 'theoretical' skills in areas of experimental design and method, observation and interpretation as well as analysis of results. These skills cannot always be gained through lectures and demonstration alone (Abraham, Craolice, Graves, Aldhamash, Kihega, Palma Gal & Varghese, 1997). However, it has also been suggested that chemistry is not a laboratory science, in particular concerning non-majors having no use for the manipulative skills they develop in the laboratory as they would not continue in the field of chemistry and work in a laboratory (Hawkes, 2004). No data were given to support that assertion. The skills even non-majors gain through laboratory work in chemistry may eventually be used in their respective careers. Furthermore many university departments outside chemistry rely on their students to obtain such manipulative skills, for use in higher year units of study,
by completing the traditional laboratory based chemistry courses offered. If these departments did not believe that the skills, which their students gain, are valuable, they would not require the completion of the chemistry course as a pre-requisite for obtaining the degrees. This clearly is an ongoing discussion and arguments both against (e.g. Hawkes, 2004) and for (e.g. Baker, 2005) the continued use of laboratory work have recently been published. This study does not aim to continue that debate but rather tries to improve the outcome for students who are still required, and will be for the foreseeable future, to complete traditional laboratory instruction.

First year chemistry undergraduate laboratory work in a majority of universities may be considered ‘manufactured’, as students are told to interact with certain materials and observe phenomena (Rollnick, Zwane, Staskun, Lotz & Green, 2001). This is a consequence of students’ relatively undeveloped knowledge of chemistry, coupled with the pressures imposed by large numbers and limited time and budgets. Despite the ‘directed’ nature of the laboratory work, the amount of material covered in a typical three hour laboratory session remains vast. This includes instructions – both written and oral – technical skills, observation, recording of results and attempting to build connections to the theory that underlies each experiment (Johnstone, Sleet & Vianna, 1994). As a consequence, many students are overwhelmed and only focus on the most prominent tasks, which involves performing the experiment in a recipe style by simply following instructions from the laboratory manual, concentrating on the immediate technical skills without spending time on deeper thoughts or developing an understanding of the underlying theory (Johnstone & Al-Shuailli, 2001).

Learning is often explained by the dominant educational paradigm, the theory of constructivism, which is based on the notion that learning is an active process of knowledge construction and ‘sense-making’ (Phillips, 1995). In contrast to an older information processing model, where knowledge development involves the learner passively absorbing and storing a knowledge structure in their memory which replicates that of the instructor (Fox, 2001), constructivism implies that knowledge is never transmitted from one individual to another (Herron & Nurrenbern, 1999). Hence, understanding will only develop if the individual is considered more carefully.

Since constructivism requires individual learners to construct representations that are meaningful to them, it is inevitable that prior knowledge will be used as the basis of ‘sense-making’. Indeed it has been claimed that the ‘most important factor influencing learning is what the learner already knows’ (Bailey & Garratt, 2002). Research has shown that information presented by instructors tends to be interpreted as more important by learners when it fits well with their pre-existing knowledge, whilst information which is in conflict with prior knowledge is often seen as unimportant (Johnstone, 1997). This rating of the importance of presented information can be regarded as part of the selection process in which learners engage. This can be understood in terms of the information processing model (see Figure 1) reported by Johnstone (1997), which is in turn a development of Mayer’s selecting-organising-integrating (SOI) model (Mayer, 1996).

An important aspect of this model concerns the limited capacity of working memory (Miller, 1956; Voss, 1989). Since working memory has limited capacity (7±2 concepts (Miller, 1956)), if too much information is presented, some will be judged as unimportant and filtered out, or will be discarded from working memory without integration. As a consequence, instruction needs to take account of existing knowledge if integration is to be facilitated, and this is especially true in situations when a large amount of new information is presented and thus the risk of overloading working memory is high.

First year chemistry undergraduate laboratories are a place where large amounts of new information are presented to students. It is unrealistic to expect first time, unprepared learners to be able to process all
laboratory experiences with understanding, and indeed students with little or no prior knowledge find it difficult to derive meaning (Berry, Mulhall, Gunstone & Loughran, 1999).

Figure 1. Information processing model as developed by Johnstone (1997)

Much research has been done attempting to address this issue. It has been shown that conceptual understanding developed prior to the laboratory session influences students’ ability to process information in the laboratory (Johnstone, 1997). Furthermore, students become more mentally engaged when they know the content assumed in the task. Thus, it is desirable to have some kind of pre-laboratory work to prepare students for the laboratory session. Such work should not only force the student to read about the activity in the laboratory manual, it should also involve “revision of theory, reacquisition of skills, planning the experiment to some extent, [and] discussion with members of a team” (Johnstone, 1997). This revision, if well designed, serves to pre-construct a scaffold, which the students can use to help integrate laboratory presented information into their existing knowledge structures.

So, the principal reason for using pre-laboratory work is that exposure to related theoretical concepts and experiments increases students’ deep learning and performance in the laboratory (Tasker, Miller, Kemmet & Bedgood Jnr, 2003). However, there are other benefits. Pre-laboratory work eases the transition into new laboratory experiments by allowing students to familiarise themselves with the experiment and gain a clearer understanding of what is expected of them in the laboratory (Koehler & Orvis, 2003; McKelvy, 2000; Nicholls, 1999). This, in turn, means that time is not wasted and a greater amount of productive work can be completed. In addition, effective preparation reduces anxiety while increasing student confidence. This produces a more productive and a more positive learning experience for the student (Koehler & Orvis, 2003).

Pre-laboratory work can assume many different forms and most will be effective to some degree. Originally much of that pre-work knowledge would have been tested at or prior to the beginning of a laboratory session. Owing to the decrease in laboratory hours it is now more likely that on-line pre-laboratory work needs to be completed before the session and compliance is monitored via on-line tests that are automatically graded. The use of information and communications technology (ICT) has an increasing influence on teaching activities in higher education. While a technology in itself will not be effective
in increasing learning (Moreno & Mayer, 2004), it will be beneficial if its use is educationally sound. ICT offers the opportunity, for example, to help students develop understanding of abstract concepts by illustrating them with multimedia simulations, thereby making them more concrete. Both formative and summative assessment tools can be incorporated into such online modules and allow to give instant feedback to students thereby enabling them to get a deeper understanding of concepts underlying the practical tasks. Online pre-laboratory work can be accessed by students at any time thereby allowing them some flexibility whilst offering the university a cost effective means of delivery.

The aim of this study was to examine the influence of a particular online chemistry pre-laboratory work module dealing with the preparation of a standard solution (including titration techniques) on academic performance in a laboratory titration assessment of first year chemistry students at the University of Sydney. Titrations are still widely used in university settings as students develop practical skills as well as complete calculations associated with titration exercises. The effectiveness of the module as pre-laboratory work was investigated by determining whether students who completed the module performed better in a laboratory titration assessment than those who did not.

Background to the chemistry pre-laboratory work modules

The online module considered in this study is from Bridging to the Lab: Media Connecting Chemistry Concepts with Practice (Jones & Tasker, 2002). The modules in Bridging to the Lab can be used as laboratory preparation as they contain simulations, which emphasise aspects of experimental design and allow visualisation of structures and processes at the molecular level. Each module is set in the context of a real life problem, which students work to solve in a virtual environment. Students make decisions regarding experimental design, observe simulations of reactions (both at macroscopic and molecular levels), record and interpret data, perform calculations and draw conclusions from their results (see Figure 2).

Figure 2. Sample screen from the standard solution module demonstrating the types of calculations that students complete and illustrating feedback provided
The illustration of reactions at both macroscopic and molecular levels is designed to help students to link their observations with both the molecular level explanations offered in lectures as well as symbolic representations. Step-by-step instructions are given in a simple way and students are able to replay the animations at any time.

Each module is divided into sections and a student can only progress forward once the set activities have been completed correctly. Feedback boxes are provided to assist students when they make mistakes and they are free to navigate backwards through past sections. A summary is provided at the end of each module, followed by a ‘self test’ section in which students can test what they have learned by applying their freshly gained knowledge to new situations. Instructors can use this feature for setting grades.

The particular module used in this study, Concentration: Preparing a Standard Solution, is set in the context of research on the therapeutic effects of wearing copper bracelets on the symptoms of arthritis. It is essentially a quantitative module, requiring familiarity with stoichiometric concepts (moles, concentration) and also emphasises the appropriate use of significant figures. Students are required ‘to prepare’ a standard solution of a particular concentration, including selecting and handling glassware in an appropriate manner. Therefore this module may usefully introduce students to the concepts used in volumetric analysis experiments and help them to prepare for titration assessment tasks.

Methodology

Participants
Three different groups of first year chemistry students participated in this study at the University of Sydney in 2004. All students were enrolled in one of the semester 1 chemistry units of study available to students undertaking mainstream science qualifications. These units of study were CHEM1001 (Fundamentals of Chemistry 1A), CHEM1101 (Chemistry 1A) and CHEM1901 (Chemistry 1A - Advanced). All three units cover very similar material, but differ in the level of assumed prior knowledge and the level at which material is presented. CHEM1001 students have either not completed chemistry for the Higher School Certificate (HSC), i.e. university entry level, or achieved comparatively poor results. CHEM1101 students have satisfactorily completed HSC chemistry, whilst CHEM1901 has an entry requirement of a HSC chemistry mark above 80. A look at the chemistry syllabus taught at high schools in the state of New South Wales (Australia) as well as some previous examination papers will allow a deeper appreciation of the different levels of prior knowledge students have when they start chemistry at the University of Sydney (see http://www.boardofstudies.nsw.edu.au/syllabus_hsc/pdf_doc/chemistry_stg6_syl_03.pdf).

Pre-laboratory work
Students were asked to complete the online pre-laboratory work module, Concentration: Preparing a Standard Solution, during week 10 of semester 1 (note: no laboratory classes were held during that week). They were advised that the modules would help them to further their understanding of key chemistry practical skills, to make useful observations and to draw inferences. They were also told that the modules covered techniques relevant for their semester 1 practical assessment, as well as providing useful revision of some of the theory presented in lectures.

Laboratory work
In preparation for a laboratory titration assessment (common for all three units of study) in week 12, E22 (Simpson & Holland, 2004), students completed two full laboratory sessions (in weeks 9 and 11)
in which they carried out various titration exercises such as strong acid/strong base and other titrations with the help of student demonstrators and academic supervisors. Each demonstrator supports a group of eighteen students. Before commencing each lab session, students were required to complete pre-laboratory work (text-only, with an associated online test) and they also needed to complete related post-laboratory work exercises that were marked by the demonstrators in the following laboratory session.

Results

The laboratory titration assessment was completed by 1102 students and the results collected for data analysis. Titration marks range from 3 (answer within 1 % of correct value) to 0 (answer more than 5 % wrong). There were large variations in titration marks across individual units of study, however, as might be expected, student performance was higher in CHEM1101 than in CHEM1001 and higher still in CHEM1901 (see Table 1).

<table>
<thead>
<tr>
<th>Unit of Study</th>
<th>N</th>
<th>Mean (out of 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHEM1001</td>
<td>356</td>
<td>1.86 ± 0.06</td>
</tr>
<tr>
<td>CHEM1101</td>
<td>603</td>
<td>2.05 ± 0.04</td>
</tr>
<tr>
<td>CHEM1901</td>
<td>143</td>
<td>2.34 ± 0.07</td>
</tr>
</tbody>
</table>

Table 1. Mean marks for titration assessment in first year chemistry (individual units of study)

779 students (68 % of all students) started the online module, while only 671 of those students (86 %) completely finished the module.

Effect on CHEM1901 and CHEM1101 students

Table 2 shows the mean titration marks out of a possible 3 marks. After completing independent sample t-tests using SPSS (SPSS Inc., 2004), it was found that there was no significant difference in mean titration mark for students in CHEM1901 who completed the module and those who did not ($t_{141} = 0.036$, $p = 0.971$). Similarly, independent sample t-tests also confirmed that there was no significant difference between the mean titration mark of students in CHEM1101 who completed the module and those who did not ($t_{601} = -1.625$, $p = 0.105$).

Effect on CHEM1001 students

As shown in Table 6 there is a more than 30 % increase in titration mark for CHEM1001 students who completed the module compared with those who did not. An independent sample t-test was conducted, which confirmed that this increase was not due to random chance and that the difference in mean titration marks for students who completed the module and those who did not ($t_{354} = -4.133$, $p < 0.001$) was statistically significant.
<table>
<thead>
<tr>
<th>UOS</th>
<th>No. of Students</th>
<th>Mean/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEM1001</td>
<td>240</td>
<td>2.02 ± 0.07</td>
</tr>
<tr>
<td>CHEM1101</td>
<td>418</td>
<td>2.10 ± 0.05</td>
</tr>
<tr>
<td>CHEM1901</td>
<td>107</td>
<td>2.34 ± 0.08</td>
</tr>
<tr>
<td>Did not complete module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHEM1001</td>
<td>116</td>
<td>1.53 ± 0.10</td>
</tr>
<tr>
<td>CHEM1101</td>
<td>185</td>
<td>1.95 ± 0.07</td>
</tr>
<tr>
<td>CHEM1901</td>
<td>36</td>
<td>2.35 ± 0.17</td>
</tr>
</tbody>
</table>

Table 2. Mean titration mark for first year chemistry students (considering module completion)

Discussion

As shown above completion of the online standard solution module was not associated with improved titration marks for students in CHEM1101 and CHEM1901. Most of these students would have completed titration exercises in the past, since a pre-requisite to enrol in their units of study is completed HSC chemistry or equivalent and titrations are widely used in high schools. Given these students would be familiar with the techniques involved the additional pre-laboratory work would merely act as a revision exercise for those students. They would be unlikely to suffer working memory overload (see above) whether or not they complete the online module. Consequently these students would cope well with the laboratory work and be well trained for the assessment exercise.

For students in CHEM1001, however, the outcome was very different. The performance improved dramatically for those students that completed the online module. Students in CHEM1001 have a weak chemistry background and are unlikely to have much (if any) experience in titration technique. The *Concentration: Preparing a Standard Solution* module is closely related to the laboratory titration assessment. In addition to facilitating conceptual understanding, the module exposes students to the techniques involved in preparing a standard solution, helping them to understand the various steps involved before going to the lab. Animations and simulations incorporated in the module allow students to have a visual representation of the techniques involved (see Figure 3), such as quantitatively transferring the solution to the volumetric flask and mixing the solution thoroughly, without having the instructor perform demonstrations. When these students complete the module their prior knowledge improves by a large amount providing both a scaffold which new information can be linked to and minimising working memory overload which otherwise leads to information being discarded. Consequently these students are not confused by the many new concepts, techniques etc. and can instead focus on getting the practical work done with minimal error.

The improvement in the titration marks for CHEM1001 students is even more significant, given the amount of preparation all students undergo as well as the fact that all CHEM1001 students in semester 1, 2003 (when no additional online module was offered) achieved a mean mark of 1.63 (292 students).
The benefits of the module were apparent to a CHEM1101 student, Angela (pseudonym), who said:

*I also think that it is particularly good for people who hadn't done chemistry before. But because I have done it I found it relatively easy.*

This comment indicates that the module may be of more benefit to CHEM1001 students, as seen from the perspective of another student, and it also emphasises the fact that CHEM1101 students (and advanced students by inference) have previously encountered the concepts presented in the modules and do not necessarily perform better in the titration assessment as a consequence of completing the module (this student got 3/3 marks for the titration assessment).

**Conclusion**

This study investigated the effectiveness of a new online module as pre-laboratory work. Completing the module dramatically improved the performance of CHEM1001 students, who have a comparatively weak background in chemistry, in a laboratory titration assessment closely related to the module. These students are least familiar with the concepts of titrations, i.e. their improved performance indicates that completing the module improves their prior knowledge in a way that provides an effective scaffold which new information can be linked to and thereby reduces working memory overload during the laboratory sessions. Since the increase in performance can be attributed directly to completing the *Concentration: Preparing a Standard Solution* module, the regular implementation of modules of this kind would be expected to further improve learning in chemistry, albeit for students with a weaker background. For students with a stronger background modules need to be designed differently and targeted more towards areas with more difficult concepts rather than skills development, which is one of the main purposes of the titration exercises.
References


Copyright © 2005 Siegbert Schmid and Alexandra Yeung: The authors assign to HERDSA and educational non-profit institutions a non-exclusive licence to use this document for personal use and in courses of instruction provided that the article is used in full and this copyright statement is reproduced. The authors also grant a non-exclusive licence to HERDSA to publish this document in full on the World Wide Web (prime sites and mirrors) on CD-ROM and in printed form within the HERDSA 2005 conference proceedings. Any other usage is prohibited without the express permission of the authors.