The Australian Chemistry Enhanced Laboratory Learning project

Justin Read discusses the educational basis for learning in the laboratory, and the Australian Chemistry Enhanced Laboratory Learning project.

Laboratory-based learning activities are an integral part of education in chemistry. According to the recent report from the RACI's *Future of Chemistry Study*,[1] students of chemistry spend about 48% of their time in the laboratory. It is therefore extremely important that this time be spent engaged in educationally sound activities, and not be lost in unproductive activities. The Australian Chemistry Enhanced Laboratory Learning (ACELL) project aims to build a database of educationally sound, peer-reviewed and student-tested undergraduate laboratory exercises. These exercises will be available to everyone on the internet, and should help to promote effective laboratory learning in universities in Australia, New Zealand and throughout the world.

The APCELL project was the physical chemistry predecessor of ACELL, and has been previously described.[2–4] APCELL was a great success: its database of quality physical chemistry experiments now contains 12 experiments, the majority of which have also been published in the *Australian Journal of Education in Chemistry*. In addition, APCELL raised awareness in the academic community of the importance of evaluating the educational aspects as well as the chemical aspects of laboratory activities. Because carrying out such an educational assessment is new territory for many academic staff, an important feature of APCELL was the development of a guiding educational template. This template can be used beyond the confines of the project to evaluate any existing experiment, as well as being a useful tool to use when developing new experiments.

It is not the purpose of this article to review the research literature on educational design. There are many issues that need to be considered when evaluating a learning activity from an educational perspective, of which three will be briefly discussed below. The APCELL educational template provides a framework that can be used to guide an educational analysis, and is one of the reasons that participants in the APCELL project reported an increased awareness of educational issues surrounding teaching practice.[2]

Developing non-technical skills

Despite the large amount of time students spend engaged in laboratory activities, the value of such activities beyond the development of technical skills (such as handling of glassware) has been questioned, most recently by Hawkes in the *Journal of Chemical Education*.[5] Hawkes argues that laboratory activities are both expensive and time-consuming, and that the costs involved are not justified (particularly for non-science majors) by the technical skills developed. This position has been criticised,[6,7] and poses a challenge to chemistry educators – to prove that laboratory classes achieve more than Hawkes implies. Laboratory exercises should have educational benefits for students who undertake them and these benefits should be demonstrable, and it is also true that some are ineffective learning activities. However, this does not mean that the laboratory environment cannot be an effective one in which to learn non-technical skills; rather, it means that careful consideration must be given to the laboratory as a learning environment if laboratory activities are to lead to meaningful outcomes.

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Issues surrounding the effectiveness of learning environments have been extensively discussed in the education literature, and these discussions should be used to guide the design of laboratory exercises.

Influence of the learning environment

Wickman[8] examined the interaction between teaching practices and the resulting learning approaches taken by university students engaged in laboratory work. This study showed that the activity sequence was an important factor in determining content learnt, in part because sequencing can be a signal to the student of what is important.

The underlying structure of the laboratory exercise also has important consequences, both in terms of its impact on the learning environment and students' experience. Expository labs follow the traditional verification approach – students follow a pre-set procedure to a known outcome – and have been heavily criticised for producing virtually no meaningful learning.[9] By contrast, guided-inquiry approaches allow more student control of the learning activity, and have been shown to promote deep learning approaches.[10] A recently reported study[11] directly compared a single experiment presented in expository and inquiry formats, finding that the inquiry version led to more positive outcomes, both in terms of student learning and student perception of the exercise.

Design of the laboratory exercise

Another important consideration in laboratory activity design is ensuring that demands on working memory are not excessive, thereby allowing students to focus on the implications of what they are doing.[12] It is well established that, in any learning activity, cognitive engagement and activity are critical if meaningful learning is to occur, and that physical activity alone is not a sufficient condition for learning.[13] This is a finding of particular importance to laboratory activities, where the potential for students to be physically active, but not cognitively engaged, is high. It is also important that cognitive activity be directed towards educationally useful ends. There is significant potential for student anxiety in laboratory settings, with five distinct sources of anxiety having been identified.[14] Although such anxiety may have some benefits for students, in that it may make them more aware of safety issues, it can also interfere with learning by diverting attention from important aspects of the activity. By taking steps in the design of an activity to minimise potential sources of anxiety, an instructor can reduce the cognitive load associated with the exercise, and thereby promote meaningful learning.

ACELL

The ACELL project extends the APCELL approach to all areas and levels of undergraduate chemistry. Experiments submitted to ACELL are currently in use at an Australian or New Zealand university, or are newly developed and will be run for the first time in 2006. Such submissions include the new ACELL educational template (a refinement of the APCELL template), as well as student, demonstrator and technical notes. For an experiment to be accepted, it must pass through a rigorous evaluation process involving testing by both students and academic staff and evaluation of both the chemical and educational merit of the exercise.

Staff who wish to submit an experiment to the database are not expected to complete the educational analysis in isolation. In addition to guidance provided with the template itself, the ACELL Associate Director has responsibility for providing support and feedback during this process. There are also plans for some findings from the education research literature to be recast into the language of practising chemists, and made available through the ACELL website. This will hopefully not only increase awareness of educational issues, but also make the education literature more accessible, by reducing the language barrier presently dividing the academic communities in education and chemistry.

The purpose of the first stage of the submission process is to demonstrate that the experiment will work in a setting outside the one in which it was developed, and to evaluate its chemical and educational merit. A workshop will be run for this purpose in the School of Chemistry at the University of Sydney in February 2006. Interest in this workshop has been high, with more than 30 experiments already submitted from universities in Australia and New Zealand. Institutions participating in this workshop will be represented by both academic staff members and by undergraduate students, who will work together in the laboratories to test the submitted experiments. Student participation is an integral part of the ACELL approach, because it allows not only feedback to be collected, but also interaction of staff and students as equals, thereby gaining insight into each other's perspectives.

Feedback collected at the workshop will cover both the experiment itself and the educational template; this will be provided to the staff member who submitted the experiment. There will then be an opportunity for the experiment to be modified prior to it being run during semester at the submitting institution, at which time a voluntary survey of all students who complete the experiment will be conducted by ACELL. The final submission will then be peer-reviewed by both staff and student reviewers, before the experiment is added to the ACELL database and the educational analysis is published in the literature.

In conclusion, ACELL aims to utilise and extend the methods developed in the APCELL project to laboratory exercises in all areas of undergraduate chemistry. The result will be a database of student-tested and educationally sound laboratory exercises, which will be available to all. It is hoped that the project will help to raise awareness of educational issues within the chemistry academic community, and will help to make more accessible the findings of the research literature in education, by recasting some important findings into the language of the practising chemist.

For further information, visit the APCELL website at www.apcell.org, where a link to the ACELL website is provided.

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References

1 *The Future of Chemistry Study: Supply and Demand of Chemists*. Royal Australian Chemical Institute, Melbourne, 2005, viewed 3 December 2005, http://www.raci.org.au/future/futureofchemistry.html.

2 Barrie S., Buntine M., Jamie I., Kable S. Physical chemistry in the lab. *Chem. Aust.* 2001, **68**(2), 37–8.

3 Barrie S.C., Buntine M.A., Jamie I.M., Kable S.H. APCELL: The Australian Physical Chemistry Enhanced Laboratory Learning Project. *Aust. J. Educ. Chem.* 2001, **57**, 6–12.

4 Barrie S.C., Buntine M.A., Jamie I., Kable S.H. APCELL: developing better ways of teaching in the laboratory. In A. Fernandez (ed.) *Proceedings of the Research and Development into University Science Teaching and Learning Workshop*. UniServe Science, Sydney, 2001, pp. 23–8.

5 Hawkes S.J. Chemistry is *not* a laboratory science. *J. Chem. Educ.* 2004, **81**(9), 1257.

6 Morton S.D. Response to 'Chemistry is Not a Laboratory Science'; Sacks L.J. Reaction to 'Chemistry Is *Not* a Laboratory Science'; Stephens C.E. Taking issue with 'Chemistry Is *Not* a Laboratory Science'. *J. Chem. Educ.* 2005, **82**(7), 997–8.

7 Baker A.T. Chemistry: laboratory science or not? *Chem. Aust.* 2005, **72**(3), 12–13.

8 Wickman P.O. The practical epistemologies of the classroom: a study of laboratory work. *Sci. Educ.* 2004, **88**(3), 325–44.

9 Domin D.S. A review of laboratory instructional styles. *J. Chem. Educ.* 1999, **76**(4), 543–7.

10 Teixeira-Dias J.J., de Jesus H.P., de Souza F.N., Watts M. Teaching for quality learning in chemistry. *Int. J. Sci. Educ.* 2005, **27**(9), 1123–37.

11 Berg C.A.R., Christina V., Bergendahl B., Lundberg B.K.S. Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *Int. J. Sci. Educ.* 2003, **25**(3), 351–72.

12 Vianna J.F., Sleet R.J., Johnstone A.H. Designing an undergraduate laboratory course in general chemistry. *Quimica Nova* 1999, **22**(2), 280–8.

13 Mayer R.E. Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *Am. Psychol.* 2004, **59**(1), 14–19.

14 Bowen C.W. Developing and score validation of a chemistry laboratory anxiety instrument (CLAI) for college chemistry students. *Educ. Psychol. Meas.* 1999, **59**(1), 171–85.