Improving Undergraduate Laboratory Work in Physics: Outcomes of the ‘Forging new directions in physics education in Australian universities’ Project.

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Abstract
The current Australian Learning and Teaching Council (ALTC) funded project ‘Forging new directions in physics education in Australian universities’ includes a working party examining learning in undergraduate physics laboratories. This group has focussed in particular on two concerns: sharing of resources and evaluation of experiments. Recognition of our various goals for laboratory has underpinned both of these initiatives. Sharing of resources has occurred at workshops held during 2008 and late in 2007, and is being facilitated by material on the project website. These resources include higher year level experiments, which are recognised as an issue across many departments and which have not previously received detailed consideration in physics education research.

Evaluation of laboratory experiments, particularly in terms of student learning outcomes, is more problematic. One approach that has been trialled is the ACELL (Advancing Chemistry by Enhancing Learning in the Laboratory) process. Some ways in which this approach may be modified to better suit the physics context and streamlined so that it can be applied more quickly will be presented. This evaluation will lead to confidence in sharing resources due to the fact that they have been peer and student evaluated.

Keywords: physics education, undergraduate laboratory teaching

Introduction
Most physicists consider laboratory work an important component of an undergraduate physics degree. However there has been a recent trend towards the erosion of time spent by undergraduates doing laboratory work. This has occurred for a number of reasons, including the decrease in resources to maintain undergraduate laboratory programs and the increasing use of computer simulations to replace hands-on laboratory activities. Nonetheless, there is evidence that laboratory work supports the teaching and learning of undergraduate science in general (Khoon & Othman, 2004) and in physics in particular (AAPT, 1997 and Feteris, 2007). The aim of undergraduate laboratory work stream of the current ALTC (formerly Carrick) funded project is to assist physics departments in Australian universities to maintain and improve their laboratory programs by assisting in sharing of resources and promoting communication between physics educators (particularly those with an interest in laboratory work) and developing tools to evaluate laboratory exercises. By the evaluation of resources and the sharing of high quality resources that have been through an evaluation and testing process we hope to improve the laboratory experience of Australian undergraduate physics students, without placing a significant additional burden on physics departments and educators.

A workshop held in September 2007 identified these needs for sharing and evaluating of shared resources. At this workshop project participants were introduced to the ACELL (Advancing Chemistry by Enhancing Learning in the Laboratory) process of evaluating chemistry experiments (see for example Buntine et al, 2007) which was developed by the chemistry education community in Australia. The ACELL process can also act to serve the second aim of the current project – the sharing of resources. This sharing of resources occurs at three stages in the ACELL process, first through the workshops at which experiments are tested, then through the website on which draft experiments are placed and finally through the publication of fully evaluated experiments. The application of the ACELL process to physics experiments was explored, and an evaluation of the process is presented.

At a subsequent workshop at Monash University in June 2008 a particular need for the sharing of laboratory resources for higher year courses was identified. We have been working to meet this need by creating an online information resource on the experiments currently used in second and third year courses at Australian universities. The development of this resource is described.
Evaluating the ACELL evaluation process

The ACELL process of evaluating experiments has several stages (see Buntine et al, 2007). In the initial or preliminary stage the authors or proponents of an experiment complete a template which deals with educational and practical issues; the experiment script, demonstrator notes, technical notes, notes on OHS issues or risk assessment and education notes. The education notes require a summary of the experiment including its place within the course, which year it fits into, students requisite prior knowledge, the purpose of the experiment and its desired outcome. The proposer of the experiment must clarify learning objectives, the processes by which these are to be learnt and indicators by which the learning may be assessed. At the next stage the experiments are presented at a workshop where “students” (some actual undergraduates and some academics) undertake the experiment and then provide feedback on them using surveys and facilitated feedback sessions. Experiments may then be placed on the ACELL database as ‘experiments under review’. In the next stage authors or proponents respond to recommendations from the preliminary evaluation and extensive student data in an authentic learning environment is gathered. If the experiment passes this review then it becomes an ‘ACELL experiment’ on the ACELL website and the authors can pursue publishing their work in one of the journals with which ACELL has a publication agreement (twelve such published experiments are listed on the ACELL website, see for example Wajrak and Rummey, 2004).

The first two stages of this process have been trialled for physics experiments. A workshop was run at UTS in November 2007 in the manner of an ACELL workshop but on a smaller scale. It was a single day workshop in which eight experiments were presented in two sessions (morning and afternoon). The experiments covered a range of topics including thermal physics, AC and DC electronics and waves and oscillations. The academics who put forward the experiments completed the ACELL education templates for their experiments in advance of the workshop and a booklet containing this information was printed and made available to all attendees on the day. The experiments were then undertaken by groups of “students”. The “students” were a mixture of academics, including lecturers and some deans of science, and undergraduate students from 19 different universities.

At the completion of the experiments the “students” evaluated the experiments and the educational templates by completing feedback surveys. Further feedback on the experiments was provided in discussion sessions at the end of the day. Much useful feedback was provided by the “students”, and it also provided an opportunity for the academic who acted as demonstrator to better explain the educational context of the experiment. Following the workshop, a survey was sent to all participants asking for their views on the day, including how they found the experience as students, and in particular asking how useful the event and the feedback had been to those presenting experiments and whether they would support such an approach to evaluating physics experiments or participate again in such a workshop.

The feedback from the discussion sessions at the UTS workshop and from the subsequent survey was generally very positive. The most positive aspect reported by the majority of survey respondents (12 out of 18), and mentioned several times in discussions on the day, was the opportunity to network with other people interested in learning in laboratories. Academics also mentioned that they appreciated the chance to consider pedagogical outcomes of their experiments, this opportunity largely coming from completing the educational template in advance of the workshop, and then reinforced in discussions with the students in the feedback sessions following the experiments.

Concerns raised in discussions and later echoed on the surveys included the lack of understanding of the context in which experiments are undertaken, particularly in terms of how they fit into course context and the prior knowledge, experience and skills of students doing the experiments in their usual setting. Some experiments presented had substantial pre-laboratory work and preceding experiments designed to prepare students for the experiment. This preparatory work could not be presented at the workshop. The ACELL workshop process and templates as used did not provide for participants to do this preparation.

An additional concern is the inapplicability of the ACELL process to extended laboratory experiments, such as higher year experiments which may take many hours over more than one day, or mini-projects whether student designed or otherwise. Such projects are becoming an increasingly important feature of undergraduate laboratory courses from first year onwards in Australia (Learning Outcomes and Curriculum Development in Physics Project, 2005) and elsewhere (the May 2007 issue of European Journal of Physics has a special section dedicated to undergraduate laboratory and project work).
Despite concerns, most participants indicated that the ACELL approach, either in its current form or with some modifications, would be suitable to apply to physics experiments. There was concern that the amount of time required by the people preparing and presenting experiments at an extended workshop was unrealistic, and could not be done on a regular basis, unless the process was supported by funding, and by recognition of its value in departmental workload models. The prospect of a publication associated with the evaluation process was a definite positive for some participants, and would provide incentive to participate as proponents of experiments. Suitable places for such publications are currently being explored.

A tangible outcome of the trial “ACELL for physics” workshop is that three experiments have passed the first review criteria and are going forward to evaluation by students at their own institutions. Two academics have already adopted experiments which they saw at the trial workshop in their own departments, with some modifications to suit the courses at those institutions. Hence we may conclude that the ACELL process can be applied to physics experiments, and has already resulted in valuable sharing of resources. The question now is how to proceed with the process at the conclusion of the current project.

Sharing of higher year resources

At a project workshop held at Monash University in June 2008 (and attended by representatives from nine physics departments) it became apparent that many departments are looking to redevelop their higher year laboratory programs or overhaul individual sets of experiments. This is a difficult process to undertake from scratch and currently there is no convenient way for academics to gather ideas and information about the laboratory programs at other departments across Australia, other than through personal contacts. The workshop participants felt that there is a need for a readily accessible, centralised depository, housing a comprehensive listing of second and third year experiments currently in use. Each entry would contain the experiment’s name, a short description of its aims and a contact person’s details, allowing interested parties to seek further information if required. The displayed information, being minimal, could never be used by anyone to appropriate an experiment, and any taking up of that experiment would require contact with, and permission from, the originating institution. Initially this depository will be hosted on the project’s website but due to the anticipated ongoing nature of this enterprise a more permanent and easily updateable home is to be identified in the near future.

A total of 26 physics departments involved in the project were contacted about the possibility of contributing to this endeavour. Of these, a small number of departments informed us that they would not be able to participate due to the fact that they do not provide a physics laboratory program beyond the first year. Up to the present date, we have received data on higher year experiments from 15 physics departments. We expect to gather data from various other departments, either in the near future or once the website is activated, and people can better appreciate the value of such a depository. An example of an entry is given below.

<table>
<thead>
<tr>
<th>Table 1: An example of an experiment listing in the higher year laboratory database</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
</tr>
<tr>
<td><strong>Level</strong></td>
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<tr>
<td><strong>Field of physics</strong></td>
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<tr>
<td><strong>Key Words</strong></td>
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<tr>
<td><strong>Short description / aim</strong></td>
</tr>
<tr>
<td><strong>Contact person</strong></td>
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</tbody>
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At present we have collected data concerning 208 second year and 123 third year experiments. The topic areas covered include: astronomy, atomic physics, electromagnetism, electronics, fluids, mechanics, nuclear physics, waves, optics and photonics, quantum physics, condensed matter physics and thermodynamics.

The initial home on the project’s website is currently under development.
Future Directions
We have investigated the ACELL process and found that within limitations it is suitable for evaluating physics experiments, particularly those that are short and relatively self contained. It is recognised that the resources required to run an ACELL workshop are significant, including particularly the time taken to organise one. This could be overcome by having such workshops as regular events associated with conferences such as the UniServe conference and the AIP congress. The next evaluation stage where experiments are submitted for review and publication, initially online and then in a journal, would need an ongoing host and appropriate people to manage the process and review experiments. This is somewhat more problematic, and the process would either need to be funded to employ a project officer (as is the case with ACELL) or “adopted” by an existing organisation. The ACELL project group are currently investigating the possibility of extending the ACELL project to include other sciences, so this may be an excellent and very timely opportunity for the physics education community to collaborate with the ACELL group.

The collection of data on higher year experiments will be available at the project website but will also need an ongoing host for it to be a useful resource in the longer term. It will need to be updated regularly, in particular to keep the contact details of the people who can provide more specific information on particular experiments up to date. Again, this will require an ongoing commitment of time.

Conclusions
As part of an ALTC funded project to improve physics education we have investigated the ACELL process for evaluating undergraduate chemistry experiments and evaluated its applicability to physics experiments. The process is suitable for evaluating physics experiments, however has limitations in that it can not easily take into account the overall course context in which an experiment is used, and it cannot be applied to lengthy activities such as experiments which take more than a single laboratory session or student projects.

A need for sharing of higher year laboratory resources has been identified, and we are beginning to meet this need by collecting data on second and third year experiments and making it available via the current project website. At this time there is information available on more than 300 experiments on a wide range of topics.

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References