Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL): a model for providing professional and personal development and facilitating improved student laboratory learning outcomes

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Abstract: The Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL) project aims to improve the quality of learning in undergraduate laboratories through two interlocking mechanisms. The first is to build a database of experiments that are both chemically and educationally sound by testing them in a third-party laboratory, usually through an ACELL workshop involving both academic staff and students, to ensure that they work. The second mechanism provides personal and professional development for staff and students through a workshop process, and reinforced through on-going engagement with the ACELL community via the project website and experiment assessment and evaluation. The ACELL workshops include discussion of educational issues, both in abstract (through discussing laboratory learning in general) and concrete (through debriefing of each experiment tested) terms. This paper discusses the design of the ACELL project, and illustrates some of the successes of the staff and student personal and professional development aims. [*Chem. Educ. Res. Pract.,* 2007, **8** (2), 232-254]

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Background and context

Chemistry is an ‘enabling science’ because its core concepts are essential for almost every area of science (White et al., 2003). Students study chemistry as a discipline in its own right and as a central component of other degree programs. Thirty-five Australian universities teach chemistry and over 20,000 students per year pass through these courses (Barrie et al., 2001a). Here, students learn about the microscopic and macroscopic world of molecules; the bonds that hold them together, how and why they react, and how to design molecules with properties that enhance our standard of living. Chemistry is highly conceptual, and students can find it difficult to relate the molecular level of explanation to macroscopic properties of everyday substances. Understanding the language and symbolism of chemistry is critical for students to be able to engage with the concepts of the discipline (Marais and Jordaan, 2000; Bucat, 2004). For example, Kozma et al. (2000) have reported on the contribution of symbolic representations and tools used in chemistry to the way students mediate between theoretical and material-world contexts, a topic that has also been examined by others (Treagust et al., 2003; Wu, 2003).

Laboratory work is integral to bridging the gap between the molecular and macroscopic levels of chemistry. Good laboratory programs provide a learning environment where students can forge links between theoretical concepts and experimental observations (Hegarty-Hazel, 1990). Moreover, learning goals that can be achieved through laboratory experiences include (Moore, 2006): subject-matter mastery; improved scientific reasoning; an appreciation that experimental work is complex and can be ambiguous; and an enhanced understanding of how science works. Skills that can be developed in high quality laboratory exercises include (Boud et al., 1986; Bennett and O'Neale, 1998): manipulation of equipment; experiment design; observation and interpretation; problem solving and critical thinking; communication and presentation; data collection, processing and analysis; laboratory 'know-how', including developing safe working practice and risk assessment skills; time management; ethical and professional behaviour; application of new technologies; and team work.

An extensive literature describes up-to-date chemistry laboratory exercises for students that extend beyond the traditional 'follow the recipe' format (Domin, 1999).[1] Bennett and O'Neale (1998, p. 59) have commented that students following a recipe, "*are not 'doing an experiment', but 'carrying out an exercise'*". They argue that 'recipe experiments' make limited intellectual demands on students, who "*often seem to go through the motions…with their minds in neutral*". By contrast, in a well designed laboratory exercise students can experiment and engage, both individually and collaboratively (Shibley Jr. and Zimmaro, 2002), in open-ended labs (Psillos and Niedderer, 2002) and inquiry-based learning activities (Green et al., 2004) that apply theoretical concepts to relevant, real life problems. Equally, pure discovery approaches can be ineffective (Mayer, 2004; Kirschner et al., 2006), in part because they can lack sufficient structure necessary to support student autonomy (Skinner and Belmont, 1993), and in part because they can foster behavioural rather than cognitive engagement (Byers, 2002).

In a well designed laboratory, students interact closely with teachers and peers, so learning can be enhanced, monitored and assessed effectively (Boud et al., 1986; Hegarty-Hazel, 1990; Vianna et al., 1999 ; Johnstone and Al-Shuaili, 2001; Psillos and Niedderer, 2002). It has been recognised that students find a well-designed laboratory program stimulating and motivating (George et al., 1985; Paris and Turner, 1994); moreover, they allow students to 'scaffold' each other's learning (Coe et al., 1999). Well designed laboratories can be a popular component of science courses (Hegarty-Hazel, 1990; Deters, 2005) and can promote quality learning (Teixeira-Dias et al., 2005). Poorly designed laboratory exercises have also been shown to result in working memory overload and can to push students towards a 'going through the motions' approach (Johnstone and Wham, 1982; Johnstone, 1984, 1997a, 1997b; Johnstone et al., 1994).

According to the recent *Future of Chemistry* report (Royal Australian Chemical Institute, 2005), 48% of student time is spent in laboratory work, and so it is imperative that the opportunities afforded by this substantial learning environment are realised. Notwithstanding an extensive literature describing the benefits of laboratory learning, the value of laboratory activities beyond developing technical skills (such as handling glassware) has been questioned, most recently by Hawkes (2004). Hawkes argues that laboratory activities are 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 (Baker, 2005; Morton, 2005; Sacks, 2005; Stephens, 2005), yet it reinforces the challenge to chemistry educators to provide compelling evidence that laboratory classes achieve more than Hawkes implies.

Concerns such as these are certainly not new – in fact, according to Lock (1988) and Hodson (1993), discussions of the value of laboratory work have been occurring since the late nineteenth century – and others who have recently raised concerns about the value of some laboratory work include Marthie et al. (1993) and Bennett (2000). Some research [such as Rigano and Ritchie (1994), Markow and Lonning (1998), and Hofstein et al. (2005)] has been undertaken in an attempt to address ways in which laboratory work can be made more effective for promoting student learning. Nevertheless, as Hofstein and Lunetta (1982, p. 212) note "*researchers have not comprehensively examined the effects of laboratory instruction on student learning and growth in contrast to other modes of instruction, and there is insufficient data to confirm or reject convincingly many of the statements that have been made about the importance and the effect of laboratory teaching*" and that there "*is a real need to pursue vigorously research on learning through laboratory activities to capitalize on the uniqueness of this mode of instruction*" (p. 213). Despite the progress that has been made in developing our knowledge of learning and instruction in the twenty-five years since these statements were made, these comments remain true today (Tobin, 1990; Hart et al., 2000; Nakhleh et al., 2002; Hofstein and Lunetta, 2004).

Promoting effective learning in the laboratory

The literature highlights the benefits to learning that should accrue when students engage actively in the discovery of knowledge through experimental investigation. However, this literature also notes that the potential for 'deep' learning is often not realised for reasons that include inappropriate experiments (Bennett and O'Neale, 1998), poor educational design (Boud et al., 1986; Hegarty-Hazel, 1990), and/or inadequate resources (Gibbs et al., 1997). Moreover, an undergraduate laboratory setting is one that can induce anxiety in students (Bowen, 1999) drawing undue attention to relatively simple activities, and reducing the available working memory needed for meaningful learning (Johnstone and Wham, 1982; Johnstone et al., 1994; Johnstone, 1997b) by introducing extraneous cognitive load (Chandler and Sweller, 1991; Paas and Van Merrienboer, 1994; Sweller, 1994; Kirschner, 2002). To some extent, such problems can be reduced by appropriate sequencing of activities (Wickman, 2004).

The challenge remains to provide students with laboratory programs that are relevant, engaging and offer effective learning outcomes. The Australian Physical Chemistry Enhanced Laboratory Learning (APCELL) project[2] (Barrie et al., 2001a, 2001b, 2001c) and its all-of-chemistry regional successor, the Australasian Chemistry Enhanced Laboratory Learning (ACELL) project[3] (Read, 2006a; Read et al., 2006a; Read et al., 2006b; Jamie et al., 2007) are examples of contemporary efforts designed to tackle this challenge. Very recently ACELL has undergone a change of name to Advancing Chemistry by Enhancing Learning in the Laboratory, motivated, in part, by a growing level of international interest in the project.

The APCELL project was developed when it became apparent to chemistry academics in Australia that no single institution had been successful at overcoming barriers to student engagement imposed by limitations on physical resources, specialist expertise, pedagogical expertise, and student involvement in laboratory exercise design. A collective effort involving the resources of multiple institutions offered an excellent chance to overcome these problems. In 2004 the APCELL concept expanded into the all-of-chemistry ACELL project. APCELL generated a range of tangible outcomes, including chemistry education research articles, a database of freely available peer- and student-reviewed experiments,[2, 3] workshops showcasing innovative experiments, and experiment development tools (all materials are available online in the Document Library on the ACELL website). These outcomes have contributed to academic staff development by, for example, providing educators with a framework to identify and integrate intended student learning outcomes from the outset of designing and/or reviewing a laboratory exercise.[4] Further staff development opportunities were initiated in APCELL through the active involvement of staff delegates as 'students' during the project workshops. This resulted in a new-found insight on the part of some staff delegates into the student perspective of learning. Nonetheless, limited data are available describing student views on the impact of APCELL on their learning; this became a priority for ACELL. Objective evidence is also required to support the putative notion that the A(P)CELL concept is of benefit to educators as they design and evaluate laboratory programs. Collection and evaluation of such empirical data is essential if the concerns raised by Hawkes (2004) and others are to be effectively addressed. In this paper we report on the views of staff and student delegates who participated in the ACELL Educational Workshop held in early 2006.

Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL)

The ACELL project has three principal aims: (*i*) to make available, via a public database, materials relating to undergraduate chemistry experiments which are educationally sound and have been evaluated by both students and academic staff. These materials consist of everything needed to introduce the experiment into another institution, as well as evaluation data relating to both the chemical and the educational aspects of the experiment (see, for example, the associated article by Read and Kable (2007) in this issue); (*ii*) to provide for the professional development of chemistry academic staff by expanding the understanding of issues surrounding student learning in the laboratory; and, (*iii*) to facilitate the development of a community of practice in chemistry education within the broader academic community.

A significant problem arising within the collaborative nature of ACELL is that at the teaching/learning interface, in the main, chemists are discipline experts, but not well read in educational research. Such research, like any other field of enquiry, has its own language and methodologies that are not always transparent to those outside the field, and is published in journals not usually accessed by chemists. ACELL, therefore, initially seeks to engage academics in reflecting on their own curriculum decisions about teaching and design of laboratory practice (Brew and Barrie, 1999), whilst simultaneously providing an accessible entry point or bridge into educational concepts (Read, 2006b; Buntine and Read, 2007).

The ACELL project methodology has identified the need, in the first instance, to engage academics from the participating universities at the level of their teaching and learning principles, rather than at the level of teaching behaviours. Processes that encourage academics to design student laboratory exercises from a learner-focussed perspective are used. This strategy has required that the project start with the participants' own concepts of teaching, even if these are teacher-focussed, then reflect on, and challenge these ideas in developing the parameters for the design of laboratory programs. An intensive workshop-style format, preceded by academics submitting what they consider to be exemplar experiments for peer and student feedback and comment, has been used to initiate this engagement and reflection process. The first APCELL workshop was held in February 2000. The first all-of-chemistry ACELL workshop was held in February 2006. Both events were held at the University of Sydney.

To assist academics in their reflective practice, ACELL modified an 'Educational Template'[4] originally developed under APCELL. The Educational Template serves several purposes, one of which is to act as a guide to submitters of an experiment for reflection on the learning objectives of their experiment. A second purpose is to provide users of the ACELL database with evidence that the experiments are high quality learning resources. The Template is divided into four sections, which present (*i*) a general summary, (*ii*) an analysis of the educational objectives, (*iii*) empirical data relating to student experiences, and (*iv*) relevant documentation. All four sections are rigorously reviewed prior to acceptance of an experiment into the database. The focus of this report is not to discuss the Educational Template in any detail. However, part of the review process undertaken at the ACELL workshop includes feedback to submitters on how their Template content can be improved to better serve ACELL's second purpose described above. This feedback plays a critical role in the academic reflective cycle and is relevant to the workshop analysis that is the focus of the current report.

The ACELL workshop format involves an early morning discussion session focussing on a particular educational theme, with mid-morning and early-afternoon laboratory sessions. Each day concludes with a focussed debrief and discussion session where delegates critically evaluate the experiments they undertook in both the morning and afternoon sessions. At the February 2006 workshop, delegates (staff and students alike) worked with different people in each laboratory session, providing the opportunity for delegates to work with colleagues and students from a range of sub-discipline areas of expertise, geographic locale, and/or university contexts. This format provided valuable delegate networking opportunities, furthering the ACELL 'community of practice' (Wenger, 1998) aims. Academic staff delegates were deliberately assigned to test experiments in areas both inside and outside their fields of sub-discipline expertise, forcing them to move beyond their comfort zone. In this way, the evaluation of each experiment drew on the specialist expertise of staff, whilst still allowing them plenty of opportunity to experience other experiments from the perspective of a student. Likewise, student delegates were mixed so that they were able to undertake experiments across a broad range of chemistry sub-discipline areas and undergraduate year levels. In general, each experiment was tested in both sessions on a particular day, with mixed student/staff teams used in one session, and student/student or staff/staff teams used in the other.

A design feature of the ACELL workshop format was to promote the stated academic staff professional development aims through (*i*) the formal panel discussions of educational issues, (*ii*) developing insight into the student's perspective afforded by participating in the laboratory sessions with student delegates as equals, together with undertaking experiments outside of their area of specialist expertise, and (*iii*) encouraging reflection on the Educational Template submissions of other delegates as a means of developing skills to self-evaluate critically a staff member's own submission. It was intended that this involvement also provided students with a rare opportunity to interact with staff from multiple institutions over several days, providing them with intensive networking opportunities and offering them some insight into the staff members' perspectives. Delegate evaluations were undertaken to determine the extent to which the ACELL project objectives were met through this educational workshop format.

Evaluation Methods

The February 2006 Workshop was held over 3 days[5] and involved thirty-three academic staff (excluding the eight Project Directors) and thirty-one student delegates from twenty-seven tertiary institutions across Australia and New Zealand, supported by three technical staff. All delegates were surveyed extensively during the workshop for their views on the chemical and educational aspects of the experiments they undertook, and again at the very end of the workshop where their evaluation of the workshop as a whole was sought.

In this final survey, staff delegates were asked to respond to eleven 5-point Likert scale items while student delegates were asked to respond to six 5-point Likert scale items, the first four being in common with the staff. All delegates were also asked for responses to four additional open-ended items. The distributions of delegate responses to the Likert-scale items have been compared using non-parametric χ^2 hypothesis testing where appropriate, and also by assigning each response a value (Strongly Agree = +2, Agree = +1, Neutral = 0, Disagree = -1, Strongly Disagree = -2) and using the resulting means for comparative purposes. If delegates were unsure of their attitudes to any particular item they were asked not to make any response, ensuring that the 'neutral' midpoint is not used in cases where the respondent is 'unsure'. This approach is in line with standard ACELL practice described in our 'Guidelines' document (ACELL, 2007), and reflects the belief (as described by Andrich (1978) and others) that the probative insight provided by the use of means for comparative purposes justifies the careful use of interval scale analysis methods (Michell, 1986), notwithstanding the near-interval (but technically ordinal) nature of this Likert scale.

In addition to the Likert-scale items, the survey solicited delegate responses to the following four open-ended items:

- What did you find to be the most valuable aspect of the ACELL workshop? Why?
- What area of the workshop do you think most needs to be improved? What improvements would you suggest?
- What was the thing at the workshop you found most surprising?
- Please provide any additional comments on the workshop here.

Delegate responses were entered into a database as thematically distinct comments prior to being subject to a content analysis; the first part of this analysis involved coding the comments following the general approach described by Miles and Huberman (1994). According to this approach, there are two types of coding reliability: inter-coder reliability, where two investigators independently code a section of the data set [a process also known as investigator triangulation (Sidell, 1993)], and intra-coder (or code-recode) reliability. In each case, reliability can be defined as the proportion of the total number of comments which are coded consistently, and it is expected that coding is not complete until reliability exceeds 90%. In this work, inter-coder reliability was initially low due to inconsistent coding approaches having been taken, although there was immediate agreement on the six broad categories or themes that emerged from the data. Once a common coding approach had been agreed, both inter-coder and intra-coder reliability rapidly exceeded 90% as recommended by Miles and Huberman (1994, p. 64). Every comment was coded; most comments were allocated to one category only, and on occasion a given comment was included in, at most, two categories. The relative scarcity of dual-coded comments provides indirect evidence that the themes identified are indeed non-overlapping. Whilst not being definitive evidence for the validity of the analysis, this fact, coupled with the concordance found during the investigator triangulation phase of coding, does provide credibility for the analysis approach taken. In fact, different types of triangulation are widely used in part because the can contribute to establishing credibility for methodological and analytical choices made (Moschkovich and Brenner, 2000).

Once categorised, all comments were identified as being either a 'positive' or a 'negative' response, allowing statistical analysis in addition to the qualitative analysis from the content analysis of the comments in each category. Together, the delegate responses from the two parts of the survey provide a rich vein of both quantitative and qualitative data against which to assess the efficacy of the ACELL workshop format in achieving the project's aims. The six broad categories, together with their coding type, and number of positive and negative delegate responses are listed in Table 1.

Table 1: Broad coding categories (or themes) emerging from a content analysis of delegate responses to open-ended items in the 2006 ACELL workshop evaluation survey, together with the number of staff/student positive/negative responses in each category.

Category	**Staff Comments**			**Student Comments**			**Total Comments**
	Pos.	**Neg.**	**Total**	**Pos.**	**Neg.**	**Total**	
Delegate Interactions	14	2	16	18	1	19	**35**
Educational Aspects	33	3	36	34	8	42	**78**
Workshop Design	7	17	24	12	22	34	**58**
Project Design	2	6	8	3	4	7	**15**
Project Impact	16	0	16	7	0	7	**23**
Miscellaneous	4	2	6	3	0	3	**9**

The workshop survey data have been augmented with interviews of both staff and student workshop delegates held after the workshop had concluded. A total of six interviews have been undertaken, involving four staff (pseudonyms: James, Kate, Stephanie, and Ted) and two student (pseudonyms: Dace and Luke) delegates (both student delegates interviewed are male). The structure of each interview allowed for in-depth investigation of issues which arose, whilst remaining consistent with an overall semi-structured framework (Minichiello, 1995; Mason, 2002), in accord with Burgess's (1984) description 'conversations with a purpose'. An examination of the interview data related to ACELL processes in general, and to the workshop in particular, shows that most comments fall comfortably within the broad coding categories shown in Table 1, providing further evidence for the robustness of this coding scheme. The interviews have been drawn upon to augment the workshop survey data: They also include substantial material relating to individual experiments and to issues of laboratory design; these data have been disregarded as going beyond the scope of the workshop evaluation that is the focus of the current report.

Methodological triangulation can be defined as "*the use of a combination of methods to explore one set of research questions*" (Mason, 2002, p. 190), and can provide for a more comprehensive understanding of a phenomenon, provided it is used with care (Silverman, 2005). In social contexts, it is common for meaning to be context-dependant and to vary between individuals, so that there is no single 'truth' to be discovered (Jaffe and Miller, 1994), and for that reason triangulation should not be used in a search for truth (Sidell, 1993; Silverman, 2005), nor as a means to judge the efficacy or validity of different methods (Mason, 2002). In this work, the qualitative and quantitative approaches described above arise from different methodological frameworks, and yield a mixture of hard (quantitative), medium-textured (coded qualitative), and soft (interview) data. Each data source illuminates different aspects of the workshop process and the delegates' experiences, and no single data source should be viewed as having primacy over any other. Triangulation of these differently textured data has been used solely to provide a more holistic view of the actual experiences of the delegates, providing a deeper understanding than would be possible from either source individually, and thus a more detailed and comprehensive answer to the research questions (Sidell, 1993; Denzin and Lincoln, 1994).

Results and discussion

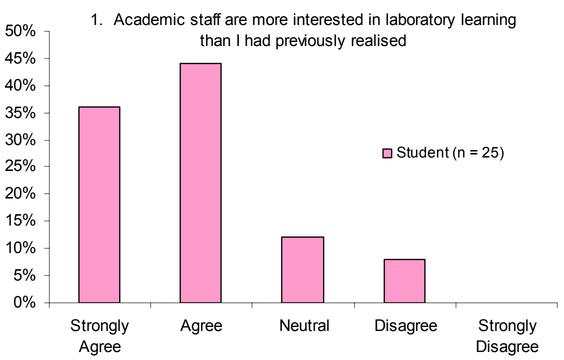
A discussion of the results obtained from this study is presented for each of the broad thematic categories listed in Table 1, with the exception of the 'Miscellaneous' category.

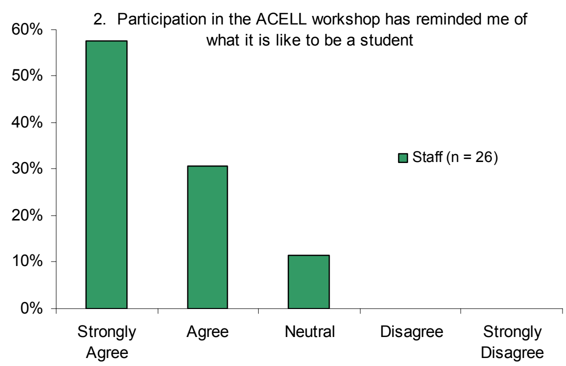
Delegate interactions (DI)

Delegate responses to the open-ended survey items in the DI category include comments on themes including: 'delegates' perceptions of one another', 'personal/professional development and networking', and issues of 'discussion, collaboration and feedback'. In particular, student delegates developed an awareness of the extent to which the participating academic staff were genuinely interested in their laboratory learning experiences, whilst staff delegates found that participating in the workshop reminded them of what it is like to be a student in the lab. As shown in Table 1, both students and staff provided significantly more positive than negative responses in this category ($\chi^2 = 24.2$, df = 1, $p = 8.64\times10^{-7}$). However, there is insufficient data to carry out a valid statistical test to ascertain whether there is any difference in the pattern of positive responses between the two cohorts.

Staff and student delegates were each asked one Likert-scale item relevant to the DI category. In Figure 1 the delegate responses to these items are presented, which were designed to determine how each cohort's perceptions of the other had changed as a result of participating in the workshop. Consistent with the thematic data discussed above, the quantitative data highlight strong positive responses to the questions posed: Responses to Question 1 highlight an increased student-delegate awareness of the academic staff commitment to improving student learning. These data also imply a significant improvement in the personal development and attitudes to learning of student delegates as a result of participating in the workshop, and suggest that their greater awareness of staff commitment to improving laboratory learning can enhance the quality of the student feedback and review of experiments submitted to the project.

Figure 1: Delegate responses to the respective Likert-scale items on 'Delegate Interactions' posed in the ACELL workshop evaluation survey.





Question 2 was specifically designed to gauge the level of impact of the workshop on staff-delegate professional practice. Responses to this question highlight that staff were reminded of what it is like to be a student, suggesting prior difficulty for them in judging the quality and effectiveness of experiments from the student perspective. This renewed awareness of the student learning perspective for staff delegates at the ACELL workshop partly explains an anecdotal observation from the earlier APCELL project where post-workshop revisions to Section 2 (Educational Objectives) of the APCELL Educational Template include descriptions of 'indicators of student learning outcomes' that are more clearly written from the student perspective.

The value of delegate interactions and being reminded of what it is to be a student was highlighted in interviews conducted with staff delegates Ted and Kate. Ted found that being reminded of the student perspective was a particular highlight of the workshop:

> It certainly was a bit of an eye-opening experience to actually be in the lab again, and think from a student perspective again, which is… no matter how hard you try, it gets harder and harder as the years go by to recall what it was like. So, yeah, that was certainly enjoyable, for the most part – maybe I experienced a bit of frustration with not clicking in to some of the experiments as quickly as I thought I should have, but that's good in and of itself as a learning experience.

These views were reinforced by Kate:

> And because of the way the workshop was run, you got to know people – I went over there knowing very few people because I don't network, but I came away thinking that I was quite happy to talk to anyone there. … It was very collegial, so, that's what I'll take away … [and it] reminded me of what it was like to be a student doing an experiment.

Staff and student feedback within the DI category also highlight the 'discussion' and 'networking' aspects mentioned earlier. For example, the following comments from staff and students (in response to the open-ended survey item asking them to identify the most valuable aspect of the workshop) illustrate the positive impact the workshop in this regard:

> *Staff:* "Participation with other academics from other institutes and being able to work with students. Why? It gave me insight into the working of other universities and students opinion of things."
>
> *Student:* "Being able to give feedback on the labs as a student. It was a rare opportunity and I did not realise how interested the demonstrators were in student opinion."

The quality of delegate interactions, particularly those between staff and students was found to improve significantly as the workshop progressed. The workshop format was designed to break down staff-student barriers from the outset. Interviews with student delegates Dace and Luke highlighted that the workshop structure (including staff and students working together to undertake experiments, and daily debrief sessions at a local hotel) engendered professional and social interactions that promoted to staff-student discussions of educational issues, which, in turn, had a particular positive impact on student perceptions of academic staff as educators. For example Luke stated:

> Actually I was quite surprised with some of the staff. I would always assume, like, most Professors and what not – they're not into teaching at all. They're just there because they have to teach so they can conduct their research, and… but, that wasn't the case at all. Like, all the staff that I met at ACELL, they are actually interested in teaching chemistry. That was a… bit of a revelation for me, actually.

Luke suggested that the debriefing sessions were not long enough (it is noteworthy that Luke was just about to begin his final (Honours) year at the time of the workshop); these sentiments are reinforced by Dace, who, when asked about any particular highlights from attending the workshop, commented:

> There was the social aspect – I think that was very well organised, high fives all around. Because, nobody really knew each other on the first day but by the third day, everyone knew everyone, and was… I think that made the labs easier on the third day than the first day, because you're more than happy to go 'oi, such-and-such, chuck me a beaker of this' instead of going over and getting it yourself, or whatever. Umm, and that camaraderie, and the development thereof early in the program – I think is something that should be continued.

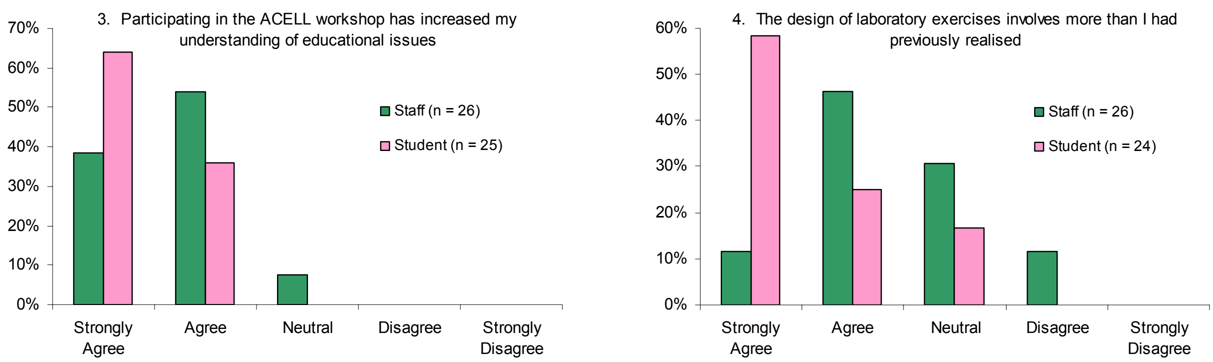
Overall, the survey and interview data illustrate the effectiveness of the ACELL workshop format as an effective mechanism for improving academic staff and student perceptions of each other in terms of (*i*) the former's appreciation of what it is like to be a student in the undergraduate laboratory, and (*ii*) the latter's appreciation of staff commitment to providing quality laboratory exercises. As we will present in following sections, the in-depth staff-student interactions promoted throughout the workshop have a demonstrable positive impact on the quality of the student laboratory learning experience.

Educational aspects (EA)

Delegate responses to the open-ended items in the EA category include comments on 'delegate educational awareness', 'the quality/effectiveness of laboratory exercises for improved student learning', and 'delegate reflection and reflective practice'. Again, as evidenced by the data contained within Table 1, both students and staff provided responses in the EA thematic category that are significantly more positive than negative ($\chi^2 = 41.1$, df = 1, $p = 1.45\times10^{-10}$). Interestingly, there is no difference between the response patterns of the staff and student delegates in this category ($\chi^2 = 1.84$, df = 1, $p = 0.175$).

In Figure 2 we present delegate responses to two Likert-scale items designed to inquire into development of educational awareness as a result of participating in the ACELL workshop. Both staff and students report an overwhelmingly positive attitude to their understanding of educational issues (Question 3), with any difference between the groups being borderline in terms of reaching significance. The mean staff delegate response to Question 3 is 1.31 ($\sigma = 0.62$) and the mean student response to this item is 1.64 ($\sigma = 0.49$) on the +2 to -2 scale. Student responses to Question 4 (concerning the amount of effort involved in the design of laboratory exercises) shows a significantly more positive response pattern ($\chi^2 = 12.3$, df = 2, $p = 2.11\times10^{-3}$), suggesting that the student cohort has gained an increased awareness compared to the staff delegates. Indeed, the stronger level of agreement amongst the students is indicated by a response mean of 1.42 ($\sigma = 0.78$) compared with that of 0.58 ($\sigma = 0.86$) for staff on the +2 to -2 scale. This minor divergence of views is not surprising and is most likely attributable to the considerable lack of prior exposure of students to issues surrounding educational awareness, also seen in an increased student awareness of the teaching content of laboratory exercises – more than 80% of student delegates agreed or strongly agreed that laboratory exercises are intended to teach more than they had previously realised.

Figure 2: Delegate responses to the Likert-scale items on 'Educational Aspects' posed in the ACELL workshop evaluation survey.

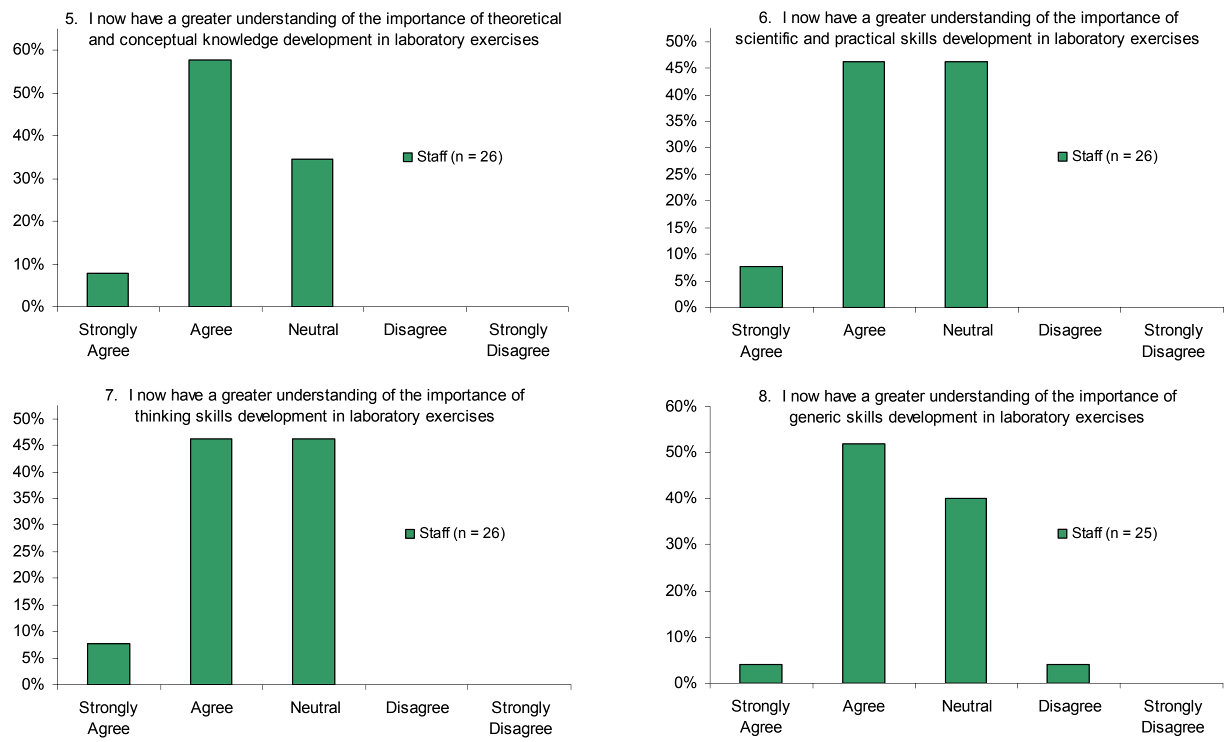


The previous APCELL participation of some staff delegates may also contribute to the difference in staff and student responses to Question 4 (Figure 2). In this context a staff response of 'disagree' with the item does not necessarily imply that the design of laboratory exercises is easy or straightforward. Rather, staff members could hold the view that laboratory exercise design is difficult, but they already knew this. For example, Stephanie was interviewed as a staff delegate who attended both the APCELL and ACELL workshops. Stephanie commented on the continuing value of the workshops:

> I have to say…I liked the idea – it was something different that people were interested in, and initially it was physical chemistry, so I liked the idea that somebody was going to try and do something about physical chemistry experiments, probably because I had some bad experiences. Also, at that stage, I was involved in running physical chemistry labs. So, it was timely. It was something I was interested in. That was my initial reason for involvement [and continuing, as] it gives me an opportunity – it forces me to develop some good experiments.

In Figure 3 we present the staff-only responses to the Likert-scale items on educational awareness posed in the workshop evaluation survey. These items were included in the survey instrument because they had been designated as the learning outcome areas for consideration in the version of the Educational Template used at the ACELL workshop. In other words, having been asked to consider these issues prior to the workshop when completing the Template, staff delegates were subsequently surveyed on their attitudes after participating in the intensive workshop process.

Figure 3: Delegate responses to the staff-only Likert-scale items on 'Educational Aspects' posed in the ACELL workshop evaluation survey.



The data in Figure 3 highlight a range of staff opinions inclined towards an overall positive sentiment, providing further evidence that the workshop is a useful professional development format in the quest to seek ways in which to improve student laboratory learning outcomes. The data in Figure 3 are not as positive as the student responses discussed earlier, where a more positive improvement in student educational awareness is demonstrated. We again attribute this minor difference in views to the lack of prior educational awareness of the student delegates.

The positive delegate sentiment towards educational aspects of the ACELL workshop evident in the quantitative data is reflected in the open-ended responses provided in the workshop survey. Examples of positive comments (in response to the open-ended item asking them to identify the most valuable aspect of the workshop) include:

Staff: "It made me sit down and think carefully about what I wanted my students to get out of my experiment, and how I could judge if they had been successful."

Staff: "Educational issues – as a scientist, I felt lacking in educational knowledge."

Student: "Most of all though, I was shocked to find that the academics at the universities really want to make our laboratory experience as worthwhile as possible."

Student: "That was one of the best chemistry experiences I have had in the last 4 years – knowing that there are people that are concerned with teaching in labs and what makes a great lab and how they can be improved has given me ideas that I can take back when I demonstrate [to] students."

Within the EA category, staff and student comments of a negative nature were in a remarkable degree of agreement as exemplified by the following comments on the size of the workshop's discussion forums (made in response to the question asking to identify ways in which the workshop could have been improved):

Student: "Smaller groups facilitating an open discussion."

Staff: "It would be great to have a session, very earlier in the program, to sit down with a small group of people to discuss why laboratory lessons are not living up to their potential. One would feel more comfortable in a small group setting to air their opinions, and this would lead to fruitful discussion."

In her interview, Stephanie comments on how, in going about designing a new experiment she draws upon the APCELL/ACELL approach as a framework for ensuring quality and validity in terms of educational outcomes:

Well, for me, first of all: being able to write a – what I, well what other people as well, view as a quality experiment. I certainly never went through that process, I knew, you know, I think I've always known what's a good experiment, what a good experiment should have – you know demonstrator notes and technical notes, and so on, and educational background and objectives and so on. [But,] I didn't know how to put it all together, didn't have a template, I didn't have time. So, for me, having reached a quality experiment which has been tested by students, peer reviewed, and so on, that I feel confident…

Thus far we have contrasted staff and student delegate attitudes within the EA category in terms of students having a less well developed educational awareness. However, as illustrated in the following interview extract with Dace, students have a quite well-developed sense of when and how they actually learn:

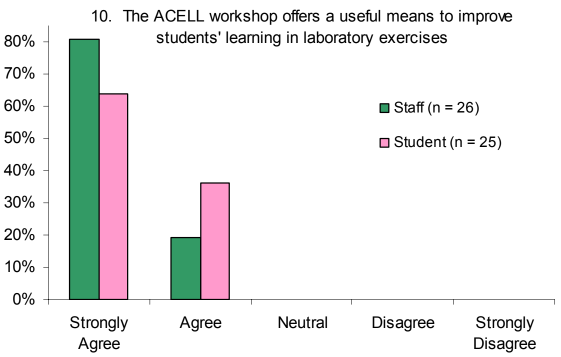
You don't learn in the lab – you learn before the lab, and you learn after the lab, but you don't learn in the lab. You 'do' in the lab. If you're learning in the lab, it's a top experiment.

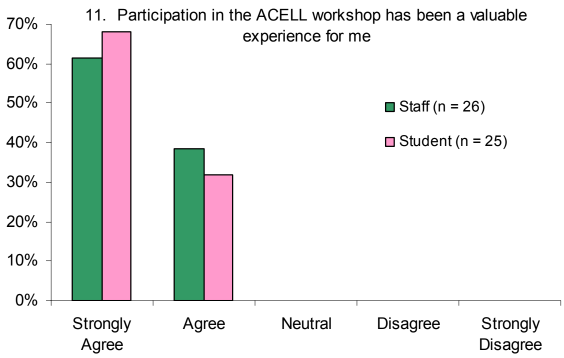
In conclusion, the survey and interview data illustrate the effectiveness of the ACELL workshop format as an effective mechanism for improving academic staff and student educational awareness, thereby contributing to the professional and personal development of all delegates.

Workshop design (WD)

In Figure 4 we present delegate responses to two Likert-scale items designed to determine delegate views on the structure and design of the ACELL workshop. Both staff and students report an overwhelmingly positive attitude to the design of the workshop, with no statistical difference evident in the response patterns of the two groups for either question (Question 10: $\chi^2 = 1.80$, df = 1, $p = 0.180$, Question 11: $\chi^2 = 0.233$, df = 1, $p = 0.629$). The mean staff delegate response to Question 10 is 1.81 ($\sigma = 0.40$) while the mean student response to this item is 1.64 (σ = 0.49) on the +2 to -2 scale. Similar response patterns are seen for Question 11, with the mean staff response being 1.62 (σ = 0.62) with a mean student response of 1.68 (σ = 0.48).

Figure 4: Delegate responses to the Likert-scale items on 'Workshop Design' posed in the ACELL workshop evaluation survey.





In terms of the open-ended items, the WD category includes responses that comment on the 'workshop program: format, timing and impact on delegates', 'venue and facilities', 'delegate laboratory exercise allocations', and 'laboratory exercise time allocations'. In contrast to the quantitative data presented above, the qualitative responses of both students and staff are significantly more negative than positive (χ^2 = 7.11, df = 1, p = 7.67×10^{-3}). Again, there is no difference between the response patterns of the staff and student delegates in this category (χ^2 = 0.24, df = 1, p = 0.624).

The negative commentary of issues relating to workshop design might, at first glance, seem at odds with the quantitative data. However, most of the negative comments relate to infrastructure matters including the quality of the budget college accommodation used by delegates and the lack of air conditioning and other environmental controls during a humid summer period. Constructive negative comments relating to educational aspects of the workshop design focus on the non-stop intensity of the three-day program. Several staff delegates commented on how tired they were and suggested a less dense program in future. In her interview, when asked about the merit of allowing for 'visiting' of other experiments, Stephanie suggested:

> Yeah, I was thinking about that. Yes and no. Yes, because then I would get – I would choose the ones that would be appropriate for my units, probably. But, no, because, I may be biased – I'm interested in those anyway. So, I may not be as critical maybe of the actual experiment. So, maybe it was good that you gave – and like you said, putting people out of their comfort zone was very, very useful

In contrast to staff feedback which focussed on the conduct of the laboratory sessions, most negative student comments related to the format of the morning and evening discussion sessions that bracketed each day's laboratory program. By and large, student delegates expressed a desire for smaller, more focussed, discussion groups, and some variation in the discussion forums, including the possibility of including 'student only' discussion sessions on occasion. The constructive nature of the negative comments can be interpreted in terms of positive level of delegate engagement with the workshop process; delegates enjoyed the workshop, and the feedback given is offered in terms of making subsequent activities even better educational experiences. From the six interviews conducted, all interviewees have said that they would recommend future ACELL activities to colleagues and peers.

Representative delegate comments highlighting the views expressed in terms of suggesting improvements to the workshop format include:

Staff: "Not enough time to look at other experiments – could staff be "students" for only 2 half-days instead of 2 full days?"

Student: "More discussion time i.e. the panel discussions in the morning – perhaps break into groups (half size) – one morning session, one afternoon."

Student: "Apart from doing the labs themselves, there should be a brief discussion prior to this about the context of the lab and the theory that surrounds it."

As stated earlier, a key objective of the ACELL project is to build a community of practice amongst staff and students. A deliberate design feature of the 2006 workshop was to quickly establish and promote an informal, collegial atmosphere in which staff and student delegates could learn to appreciate each other's points of view without focusing on each other's rank and station in the education hierarchy. The earlier discussion regarding Delegate Interactions highlighted the success of the workshop format in contributing to this objective. The following student comment in response to being asked to identify the most surprising aspect of the workshop is indicative of delegate attitudes:

I was surprised at how relaxed the atmosphere was. I had expected the 3 days to be stressful and put my skills to the test. I was glad that I was able to analyse the experiments in the relaxed atmosphere.

A further aspect of informality designed to promote the ACELL community of practice and delegate equality objectives was to integrate social aspects into the educational deliberations. For example, the evening discussion and evaluation sessions were held in a local hotel, with food and drinks provided throughout the discussion periods. A relatively small number of delegates commented negatively on this aspect of the workshop, but interestingly the comments offered were almost all in terms of the inappropriateness of the venue's acoustics for simultaneous small-group discussions of the day's experiments rather than the use of a hotel *per se*. As before, these 'negative' comments can be interpreted as constructive feedback, and are indicative of the high level of delegate engagement in the educational process; delegates were commenting on the inappropriate acoustics in the hotel because it prevented them from fully participating in the discussions at hand! Positive delegate attitudes towards the hotel-based discussions are best summarised by the following comments:

Student: "The half-hour discussions at the end of the day at the pub – I believe this is where the majority of good feedback to the demonstrators occurs, as 'students' could bounce ideas off each other." (In response to what was most valuable about the workshop).

Staff: "How engaged staff and students were, even over the beer sessions" (In response to what was most surprising about the workshop).

In her interview, Kate made several references to how the ACELL workshop format has reinforced her motivation for pursuing educational excellence, by providing her with the confidence, via the ACELL instruments in general, and constructive peer and student criticism in particular, that her design and sequencing of laboratory exercises is of a very high standard, with clear objectives:

The Template – that is a way of trying to remind – continually reminding academics: why are you doing this? What is the pedagogy? What are the learning outcomes? There's always a sense that we stick in labs just for the sake of sticking in labs and to fill space. And, I've seen it, I've seen academics saying I've got to find another lab – and really, that's not what we should be looking at. If there's no lab – if you don't think you need another lab, why run another lab?

The survey and interview data illustrate that the design of the intensive ACELL workshop, including the aspects of (*i*) staff and students working on experiments together as equals, (*ii*) the informality of daily discussion, evaluation and review sessions, and (*iii*) the social program all contributed to establishing a friendly and supportive environment in which constructive educational criticism and feedback was given and received positively.

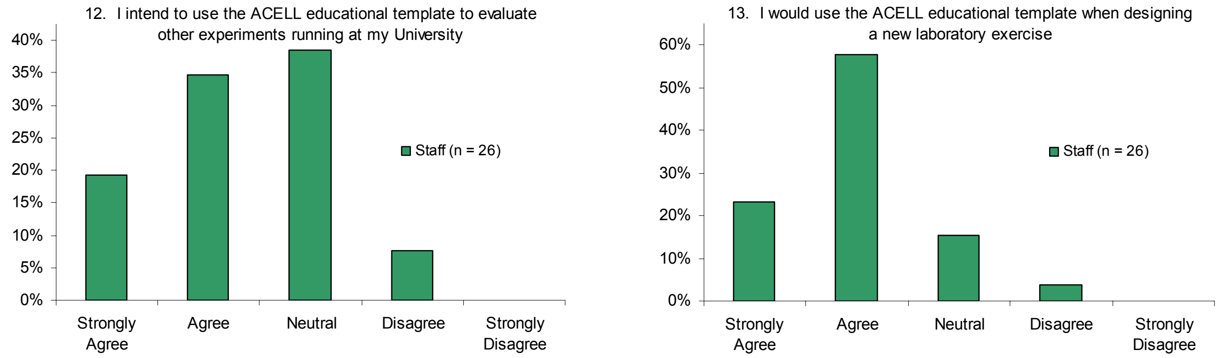
Project design (PD)

Delegate responses to the open-ended survey items in the PD category include comments on themes including the 'Educational Template: effectiveness, scope and purpose', and 'quality of submissions'. As shown in Table 1, only 15 responses were allocated to this category and there is insufficient data to comment on separate staff and student response patterns. When all delegate responses are combined, there is a balanced positive and negative response distribution ($\chi^2 = 1.66$, df = 1, $p = 0.197$), suggesting a plurality of positive and negative views.

One aspect of the ACELL project to receive considerable attention is the Educational Template. The Template is an instrument originally developed during the APCELL project to assist team members in identifying and articulating the key learning aspects of their submitted experiment. Based upon APCELL participant feedback, the Template was modified somewhat for the ACELL workshop, but retained its key characteristics designed to elicit reflective practice from the workshop staff delegates. In Figure 5 we present the staff-only delegate responses to the Likert-scale items on the educational template posed in the workshop evaluation survey. These data highlight a range of opinions clustered around generally positive sentiments, which suggests that the development and use of the Educational Template is a useful tool for educators to reflect upon and ultimately articulate the educational benefits of any given experiment. The survey data indicate that ~80% of workshop delegates intend to use the Template when designing a new laboratory exercise, and over half intend to use the Template to evaluate existing experiments at their institution. Nonetheless, support for using the Template is not unanimous. We intend for the Template to continue to evolve with ACELL participant needs, and in this vein delegate feedback from the 2006 workshop has resulted in minor changes. However, we have (as yet) no feedback on whether these changes are seen by users to have addressed their areas of concern.

The quantitative data presented in Figure 5 expresses a consistently more positive sentiment than the open-ended response data. One possible interpretation of this difference is that delegates expressing some negative feeling can see the value in using the Educational Template, but are having some difficulty with using the Template with confidence, mostly attributable to a lack of familiarity with what is being asked of them. The intensive workshop format required staff delegates to submit their completed Template describing their experiment in advance of the workshop itself. As a result, delegates did not have the benefit of the workshop discussions to inform their completion these initial submissions.

Figure 5: Delegate responses to the Likert-scale items on 'Project Design' posed in the ACELL workshop evaluation survey.



From a constructivist perspective (Bodner, 1986; Phillips, 1995; Palinscar, 1998; Windschitl, 2002), the ACELL project design requiring submitters to complete the Template prior to attending the workshop, with all workshop delegates participating in that given experiment's review commenting on the clarity and usefulness of the Template, is pedagogically sound. Learning-by-doing allows delegates to make mistakes and learn from them, and leads to a much more developed understanding, albeit personalised.

To assist submitters in their reflection, a written 'how to' guide for filling in the Template was provided prior to the workshop, but it is clear that some submitters didn't fully appreciate its implications. Consideration was given to the possibility of providing more guidance, such as by including more reference to the literature of education, but this idea was discarded. The ACELL project is designed to encourage participants to engage with educational issues surrounding effective student laboratory learning – if delegates were asked to immerse themselves too deeply in educational theory prior to attending the workshop an unnecessary barrier to engagement might have been introduced.

Some delegates turned to published Templates from the earlier APCELL experiment database for guidance on completing the ACELL Template. In his interview, Ted mentioned looking for such guidance as he first wrote his Template draft and then went on to say that he felt that the Template is a useful instrument to promote the difficult task of reflection around educational issues:

> [The completed Template is] certainly something I would look at again with my particular experiment, and probably want to modify. But, yes, it's useful to be concrete about things and, try to target the various learning areas and think about the practical side, but also how the theoretical side is tying in to that. [Also], how we are assessing that is, of course, the hard part.

Positive survey feedback about the Template was also offered, by staff and student alike, in the context of a new-found educational awareness. Experience from the preceding APCELL project is that the quality of the Educational Template submissions markedly improved following the experiment critical review process at the workshop. These improved Template submissions form the basis of the public database of APCELL experiments.[2, 3] It is expected that a similar improvement in the quality of the ACELL Template submissions will result from the ACELL workshop experience. Indeed, the most comprehensive ACELL Template submissions for the 2006 workshop were provided by staff delegates who had previously participated in the APCELL project. As discussed previously, the very fact that these staff chose to participate in ACELL, having previously contributed to APCELL, attests to the value of these initiatives in providing on-going and lasting professional development value.

Representative delegate comments on the ACELL Educational Template, expressed in terms of suggesting improvements to the project design, include:

> *Staff:* "Template. The Template is good for developing an experiment as a check list, but not as good for communicating choices for aims and basis. Could be improved – but need to think about it. Templates may be a good way of disseminating info in labs."

> *Student:* "Perhaps outlining the Educational Template a bit better BEFORE the workshop so delegates understand what they are critiquing/analysing."

Unlike the staff delegates who had to prepare an experiment for submission to the workshop, most student delegates attended with no prior knowledge of what to expect. Although the blank Template and associated guide were provided to student delegates prior to the workshop, the absence of any concrete example appears to have made this hard to understand. Therefore, most students only appreciated the significance of the Template at the workshop itself, and the student comment above should be interpreted in this context. Interestingly, a small number of staff delegates chose to get the student delegate(s) from their institution involved in the workshop preparations, and anecdote suggests that these students adapted to the workshop environment more readily. Involving students in workshop preparation in future endeavours is well worth considering.

Project impact (PI)

Delegate responses to the open-ended survey items in the PI category address issues including 'delegate motivation, inspiration and new ideas' and 'views as to the lasting impact of the project'. No quantitative items concerning project impact were included in the evaluation survey form. With only 23 open-ended responses allocated to this category, there is insufficient data to comment on separate staff and student response patterns. When all delegate responses are combined, the pattern of responses is uniformly positive. Most delegates offered comments relating to Project Impact in response to the item asking about what they found to be the most valuable aspect of the workshop. Example comments include:

> Staff: "Ways to improve more variables into our lab to make them more 'enquiry driven'."

> Student: "Learning lab skills from more experienced lab partners. I am looking forward to utilising those new-found skills when I get back to Uni."

The most compelling evidence relating to the impact of the ACELL project on the quality of Australasian undergraduate laboratory programs comes from the interview data. Supporting ACELL's 'community of practice' aims, student delegate Luke commented on how attending the workshop has provided him with on-going contact with other staff and student delegates he met:

> I was a bit intimidated because I thought everyone would be really super smart, and everything, but, yeah just a bunch people who just loved chemistry – just really, really good. I wasn't really familiar with ACELL at all, before – I know they had it for physical chemistry in previous years.

Staff delegate Ted commented that attending the workshop has had an impact in terms of reinforcing his view that undergraduate laboratories are not simply 'assembly' lines that you pass students though:

> …thinking about the lab again from an educational standpoint, which, unfortunately, we often see it as a timeframe that has to be filled, and getting students in and out, sort of like an assembly line, sometimes, which…comes from the redundancy, I guess, of doing it every year, that sometimes you lose perspective on the teaching dynamic in the lab and being able to troubleshoot new problems that you really haven't encountered, as opposed to just funnelling students through the system.

Stephanie, a participant in both the APCELL and ACELL workshops, identified the project impact in terms of improving the quality of individual laboratory exercises, as well as her personal and institutional attitudes towards assessment, staffing and resourcing models for undergraduate labs:

> [ACELL] also [offers] a quality control [mechanism] that I can say to my students that the experiment that they're doing is going to provide them with a good laboratory experience. Personally, I think that that's – that's very important. I think it's fantastic that finally laboratories are being viewed as an important learning environment. I say that because, when I went through University, many, many years ago – but not too many, because I do remember – I really don't think that the lecturers viewed the laboratories as being that important. And I went through some labs that were ancient – the way they were written, the quality wasn't there – just the way the assessment was. I didn't see that it was certainly such an important learning environment, and I don't think the lecturers viewed it that way. That was my view, and – that's changing… [ACELL] is saying 'no, laboratories are important, you need to spend time designing the labs, you need to have a good demonstrator, it is a place where students are learning. … [T]he whole ACELL experience has given me the tools to create new labs, and whenever I do design a new experiment – or fix the old ones – I do it now according to the ACELL way, because I want – in future, I would like all my experiments to be ACELL experiments, that's the goal.

Apart from influencing their broader educational awareness, during their interviews, staff delegates also discussed how the ACELL project has impacted on the way that they implement new experiments and/or identify aspects of experiments that are suitable to their educational context. All staff delegates highlighted particular experiments showcased at the workshop that they would like to introduce to their institutions. All these showcased experiments are fully documented in the ACELL workshop manual, and each staff member interviewed wishes to adapt their experiment of interest to suit the specific conditions found in their institution. Nonetheless, this willingness to adopt experiments from other universities illustrates the ACELL project's impact, in that workshop delegates have the resources at hand to 'fast track' such experiment adoption. All experiments that pass through ACELL's rigorous review process will become publicly available on the project's website[3] to allow ready adaptation and adoption by all interested parties.

The February 2006 ACELL workshop involved 64 staff and student delegates, not including the 8 project Directors. One measure of the broader interest that the project is having in the higher education community can be found from the number of visits to the project's website. In the period since the website was launched near the start of June 2006, an average of over 1000 visitors to the web site each month has been recorded, with the number of *unique* web site visitors each month steadily increasing, to approximately 500 unique visitors per month over the period October 2006 – February 2007.

All the evidence presented supports the conclusion that the ACELL project is having a significant impact on the professional development of the participants in the workshops. Preliminary evidence suggests that the project's impact is extending well beyond the flagship workshop held in February 2006. The interview data, in particular, suggests that the A(P)CELL projects have, together, contributed fundamentally to the educational awareness in terms of student learning in the laboratory of academic staff who have been involved. The explicit incorporation of student commentary in the anonymous peer review of experiments that are revised following feedback provided at ACELL workshops, which is an essential component for publication of the educational aspects of an experiment (see the ACELL website for a comprehensive discussion of the entire ACELL process), is designed to ensure a student focus at every stage. Our hope is that the ACELL initiative will have lasting impact in the sector. The recent ACELL change of name, designed to accommodate a growing level of interest in the project outside of Australasia, augurs well for the future.

Conclusion

The A(P)CELL model has proved effective at engaging academic staff and students collaboratively in evaluating undergraduate chemistry laboratory exercises. The project is a practical example of how to sustain a community of practice in chemistry education. The immersive workshop approach has been demonstrated to allow both pedagogy and discipline content to be discussed; it engages staff in a scholarly approach to curriculum development, and provides a practical way for student feedback to be used in designing resource-intensive components of an undergraduate program.

Apart from the obvious academic staff professional development benefits, student involvement demonstrates and reinforces the commitment of the Australasian chemistry educational community to be inclusive, and to work collaboratively with stakeholders. Student participants benefit from tangible personal development opportunities, and have provided positive feedback that the ACELL workshops enhance their ability to 'learn how to learn'. In short, the A(P)CELL model has strong potential to provide similar benefits to other chemistry education communities, and to other laboratory-based disciplines in the science, technology and engineering fields.

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Notes

1. Also, see, for example, any recent issue of *J. Chem. Educ.* for examples of modern undergraduate and high school experiments that promote problem solving over recipe following.
2. See http://www.apcell.org .
3. See http://acell.chem.usyd.edu.au .
4. As evaluating the educational design aspects of a laboratory exercise is new territory for many academic staff, an important feature of A(P)CELL has been the development of an "Educational Template" to guide this assessment. 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.
5. Time associated with travel to and from the Workshop meant that delegates invested up to 5 contiguous days to the project, which itself is a strong indicator of their perceived worth of the activity.

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