# National Science Agency – University Collaboration Inspires an Inquiry-Oriented Experiment

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## Abstract

An initiative involving the University of Technology, Sydney (UTS) and Australia's premier science agency, the Commonwealth Scientific and Industrial Research Agency (CSIRO), connects first year students in a large enrolment physics service subject to research of national standing through a co-developed inquiry-oriented experiment. We describe the background to the initiative which we believe to be the first of its kind, how it was piloted, and our findings from the first running of the experiment with enrolled students. The initiative applies a previously published framework for designing and evaluating new and existing experiments with regard to student engagement and learning, laboratory logistics, and scale. Evidence from focus groups, student surveys, and classroom observations indicates that the experiment is regarded by students as: 1) a worthwhile, very valuable or outstanding learning experience; 2) engaging; and 3) benefitting their learning through group discussions. Student feedback during the development phase highlighted issues to be addressed, including allowing students greater time to design and carry out their own investigations, more explicit assistance for students in the use of supporting technology, and better guidance on the assessed component of the experiment.

## Background and Introduction: Connecting Undergraduates to National Research

Reports, papers, and authoritative commentaries over several decades have endorsed the benefits for student learning and engagement of actively participating in the processes of scientific inquiry through authentic, practical experiences (e.g., Boud, Dunne and Hegarty-Hazel 1989; Boyer Commission 1998).

Recently, institutional, national, and international drivers have aggregated to impart new impetus to the embedding of inquiry and research in the undergraduate science curriculum (Brew 2010). Renewed interest in laboratory-based inquiry in undergraduate science has emerged for several reasons, including:

- Recent nationally-funded projects have focussed on the need to reconceptualise the student experience of laboratory work and identified that 'recipe-style' experiments undermine the potential of the laboratory experience (Rice, Thomas and O'Toole 2009).

- Widespread recognition that traditional approaches to learning, especially in the laboratory, do not inspire or engage students (Luckie, Aubry, Marengo, Rivkin, Foos and Maleszewski 2012).
- The development of Threshold Learning Outcomes by the Australian higher education community (Jones, Yates and Kelder 2011) which have placed an emphasis on inquiry and problem solving in the undergraduate science curriculum (Kirkup and Johnson 2013).

The increased focus on active learning and inquiry is reflected in recent research into inquiry-oriented learning in Australian universities (see as examples Creagh and Parlevliet 2014; Rayner, Charlotte-Robb, Thompson and Hughes 2013; Pullen, Yates and Dicinoski 2014).

Another influential driver of curriculum reform is the increasing emphasis on providing undergraduate students with research experiences (Healey 2005). Research opportunities are not uncommon in the final year of a science degree, or in earlier years for a few students who are highly motivated and/or have outstanding academic records. However, there are relatively few examples of all first year students in large enrolment subjects being afforded similar opportunities (Sharma, Mendez, Sefton and Khachan 2014; Weaver, Wink, Varma-Nelson, Lytle, Morris, Fornes, Russell and Boone 2006). If research-inspired experiments for students in large enrolment first year classes are rare, then such experiments that connect students in those classes directly to research of national impact happening beyond their university are rarer still. Making this connection in order to integrate teaching and research and enhance student engagement and learning was a goal of the experiment described here.

Academics at UTS and senior scientists at CSIRO understood that the undergraduate science curriculum would be enhanced by consideration of, and direct contact with, research of national significance. We were also confident that awareness of the work of Australia's peak national science agency amongst large cohorts of undergraduate science would be enhanced through an experiment or activity which has CSIRO's research as its centerpiece. As a consequence, CSIRO and UTS have collaborated since 2012 on an initiative to co-develop an inquiry-oriented experiment based on research into organic solar cells. This research is led by CSIRO, with contributions from several universities, including UTS. Intentions of the collaboration were to:

- Integrate an experiment into the curriculum with a strong inquiry focus in order to engage first year students in a large enrolment physics subject;
- Develop students' inquiry skills;
- Connect first year students to research of national standing and influence;
- Raise students' awareness of the work of CSIRO.

This initiative with the CSIRO extends and complements other initiatives promoted and managed by the CSIRO, including the 'Scientists and Mathematicians in Schools' program (SMiS 2015). UTS and CSIRO committed to developing an inquiry-oriented experiment for large enrolment first year physics subjects that was in harmony with the undergraduate science curriculum and would impart some of the excitement and uncertainty associated with research carried out in the 'real world'.

## The Solar Cell Experiment and Context

This paper describes the development process of a new inquiry-based physics experiment which is intended to be scalable to large classes. This section describes the experiment while the following sections cover the multi-faceted evaluation process used to assess the value of the experiment during a pilot phase, prior to its release to all first year physics students.

The solar cell experiment described here takes place in a 150-minute laboratory session and forms part of a scaffolded inquiry-oriented laboratory program embedded in a first year physics service subject at UTS. Most students taking the service subject intend to major in the medical, biological or environmental sciences. The subject enrols around 750 students per year. There are typically 30 to 40 students in each laboratory class, working in pairs or groups of three supported by a principal and assistant demonstrator.

Solar cells, their physical principles, operation and applications address several areas of value in the undergraduate science curriculum, including promoting understanding of:

- The principles of conversion of energy from light to electricity;
- The properties of materials, such as semiconductors, that can be exploited in the conversion of energy for useful applications;
- The potential of solar cells to be a major enabler in the exploitation of renewable energy;
- The challenges that must be faced before solar cell technologies reach their full potential.

An overview of solar cells, their physical principles and application, are explored in a lecture immediately preceding the laboratory session.

The experiment is supported and supplemented by compulsory pre-work introducing students to equipment they will be using in the laboratory. The pre-work provides an overview of the experiment and requires students to practice calculations relating to the power generated by a typical solar cell. Such calculations feed into the hands-on stages of the experiment.

The laboratory session begins with a group discussion in which students identify and quantify sources of energy used in Australia. This reveals the overwhelming reliance in Australia on fossil fuels, which in turn leads to a consideration of solar energy and efforts being made nationally to exploit this renewable energy source through established and emerging solar cell technologies.

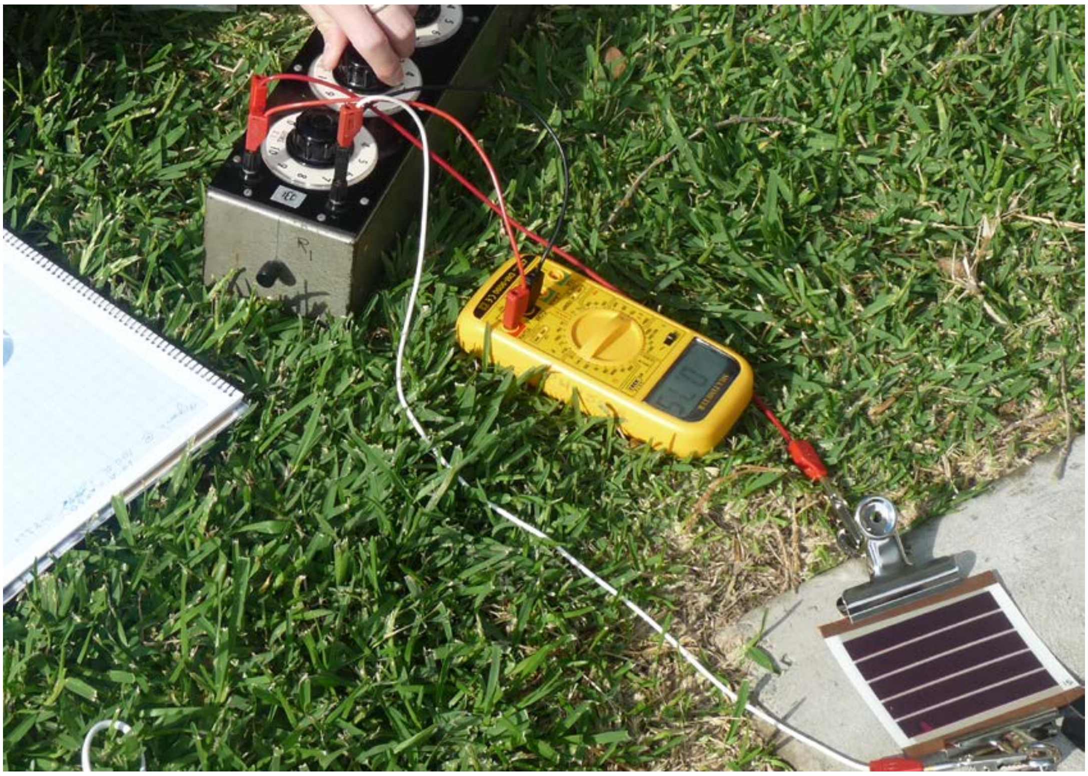

**Figure 1. The basic equipment used in the solar cell experiment. From top left to bottom right: a resistance box which acts as a load for the solar cell; a voltmeter used to measure the output of the solar cell; and a CSIRO organic solar cell**

In the first experimental stage, students undertake a guided inquiry in which they learn to measure the output power of a solar cell under illumination and determine its efficiency. Students establish the output power of two types of solar cell: a commercially available silicon solar cell, and an organic solar cell, the latter having been recently prepared in a CSIRO research laboratory. All students are supplied with some basic equipment including a solar cell, light source, voltmeter, and resistance box.

A short video featuring CSIRO scientist and co-author (SW) describing the background to the research and current status is shown during the laboratory session. After practicing the necessary measurement skills, students move onto the next stage where they are asked to devise an experiment to establish the influence of variables, such as the temperature of the cells, on the output power/efficiency of a solar cell. Here students have access to a range of other equipment allowing flexibility in the experiment they carry out. Students are advised that they do not need to confine themselves to the laboratory and may undertake the next stage of their experiment outside of the laboratory, as illustrated in Figure 1. While guidance at this investigation stage of the experiment is minimal, students are advised that they may consider:

- Varying the temperature of the cell;
- Changing the light source used to illuminate the cell;
- Tilting the cell or using a solar concentrator such as a lens.

At various points in their investigation (for example when the measurements on the silicon cells are complete) students report back their findings to the whole class. Students create a record of their experiment in a laboratory notebook, which is assessed, and produce a formal report of the experiment as the primary assessment artefact.

## Development of a New Experiment Using an Established Framework

The framework used to develop the experiment, and its application to the creation and evaluation of inquiry-oriented experiments for large enrolment classes, was developed through a National Fellowship, (Kirkup 2009) and has been published elsewhere (Kirkup, Pizzica, Waite and Srinivasan 2010). The framework was developed in part to reduce the risk of creating a new experiment of little educational value and/or relevance to the intended cohort, and the potentially significant costs in terms of materials and time in its implementation. When there are large student cohorts, with multiple laboratory demonstrators (also sometimes referred to teaching assistants in other tertiary institutions), the time and costs associated with professional development must be considered. The framework allows for input from many stakeholders within the development process, so that issues of feasibility, logistics and scalability are judged. The elements of the framework are:

- Identification of a topic that has meaning and value for students, and which can form the basis of the experiment;
- Development and trialling of the experiment by discipline experts;
- Review of the learning materials prepared for students by independent academics, in which they consider such questions as, '*Is there evidence that the experiment will foster deep approaches to learning*?';
- Trial of the experiment by a group of senior undergraduate students and demonstrators acting in the role of first year students;
- Roll-out of the experiment to students enrolled in the service subject.

Throughout the development process, feedback is obtained from the stakeholders using a number of methods including surveys, focus group interviews, and classroom observations.

## Use of the Framework to Evaluate the Experiment from Multiple Perspectives

In early 2012 feedback from discipline experts and independent academics trialling the experiment and reviewing the learning materials indicated the experiment was feasible within the human and physical resources available, and would form a worthwhile and valuable learning experience for students. One of the reviewers of the experiment, external to UTS, offered suggestions for extending the experiment:

> "*If [students] were measuring [the] temperature [of the cells] ... they might come to some conclusions as to some real-world limits on the system – i.e. why cooling is so important in solar concentrator systems*."

This feedback encouraged us to develop the experiment to the stage where it was trialled by a group consisting of senior students and demonstrators. The members of the group assumed the roles of undergraduate students and were surveyed on completion of the experiment.

## Pre-implementation Trial with Senior Students and Demonstrators

One of the authors, (LK), acted as the principal demonstrator during the trial of the experiment with the senior students and demonstrators (SS&D), and in the first presentation of the experiment to students enrolled in the physics service subject. In the development of the framework, we had found that senior students are able to provide valuable perspectives on the new experiment. In particular, they are able to compare the new experiment with the experiment it is targeted to replace. Demonstrators are able to provide feedback on potential laboratory logistics issues, and also benefit from developing their understanding of the goals of the experiment and enhancing their capabilities to present the experiment to students. This may be framed as "practical participatory evaluation" (Cousins and Whitmore 1998) as participants have a vested interest in the outcome.

Five senior students and five demonstrators trialled the experiment and completed the feedback survey at the end of the laboratory session. The SS&D were asked to rate the experiment as a learning experience. The respondents could choose from the following options: [The experiment is] of no value; of little value, worthwhile; very valuable, and; outstanding. All the SS&D rated the experiment as a positive learning experience, with 10% rating it outstanding, 80% very valuable, and 10% worthwhile.

The survey contained 12 statements to which the SS&D responded using a Likert scale, where 1 corresponds to strongly disagree with a statement, 3 to neutral, and 5 corresponds to strongly agree. The statements are shown in Figure 2 along with the SS&D responses.

The SS&D were also asked for open responses to questions: '*What are the strengths of this experiment?'* and '*In what way(s) could this experiment be improved?*' We consider mean scores and standard deviations (sd) of the responses of the SS&D to two of the statements:

> *Statement 5): The experiment is interesting*: mean score = 4.4/5 (sd = 0.5)
> *Statement 10): The experiment encourages the development of students' inquiry skills*: mean score = 4.3/5 (sd = 0.5)

Mean scores for both questions, which lie in the interval of agree to strongly agree, were supported by responses to the open ended question on the strengths of the experiment:

> "*encourages students to think about how to calculate efficiency. It is interesting and applicable to the real world,"* and "*freedom of looking at changing the experiment or choosing different paths of inquiry*."

Suggestions for improvement included:

> *"maybe [include more]... instructions [on how you] connect everything together",* and *"I felt pressed for time and was somewhat confused due to not planning my experiment. More time to think may be of value."*

In response to the first suggestion, demonstrators involved in the trial with real students were advised to deliver a general introduction which included guidance on how to connect together the solar cell and voltmeter. While we could not increase the duration of the experiment during the first semester as the laboratory schedule had already been determined, we resolved to assess how real students managed the time they had available, with a view to possibly extending the experiment over two laboratory sessions in following semesters.

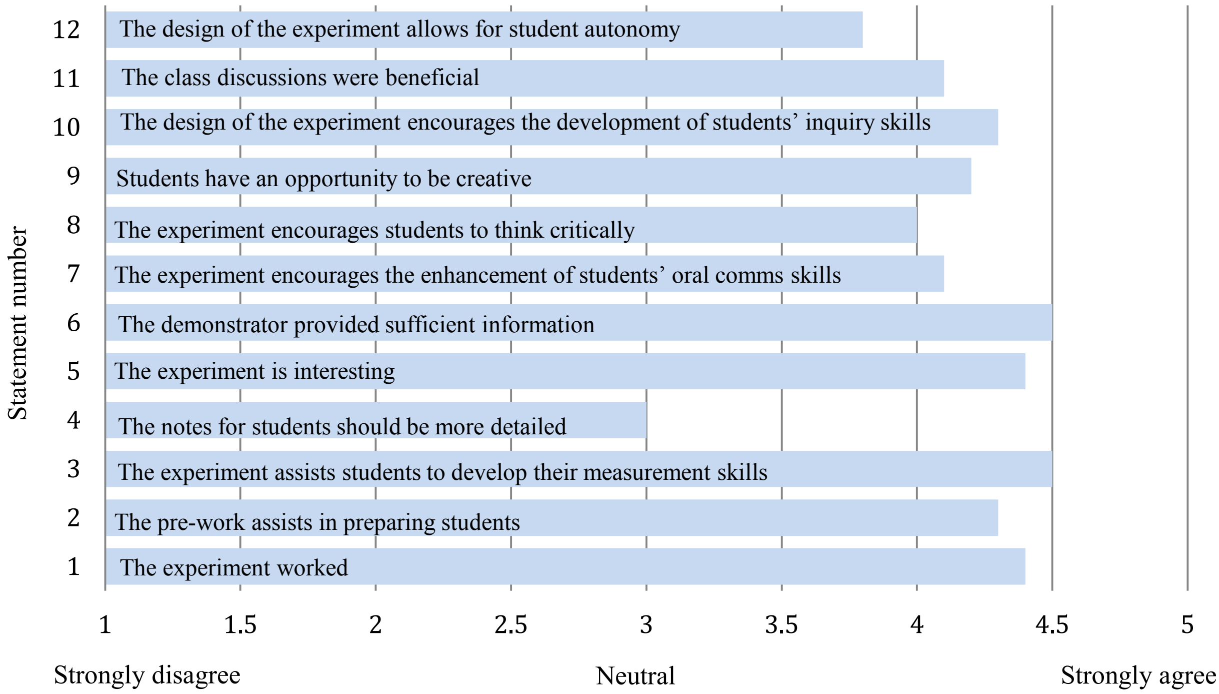


**Figure 2. SS&D responses to fixed response statements on anonymous survey**

## Scaling up: Enrolled Students Trial the Experiment

Following the trials with SS&D, and with the inclusion of the enhancements suggested during the pre-implementation trial, the experiment was run 'live' for the first time in Autumn semester 2013. Immediately after one of the laboratory sessions in which students carried out the solar cell experiment, 26 students (46%) completed an anonymous survey. All the enrolled students completing the survey rated the experiment a positive learning experience, with 23% rating it outstanding, 41% very valuable and 36% worthwhile. The survey distributed to the enrolled students contained statements requiring fixed responses on a Likert scale, and open-ended questions on the strengths of the experiment and suggestions for improvement.

Figure 3 contains the 14 statements students were asked to respond to. The mean score for most statements lies in the interval of agree to strongly agree. There was good agreement with statement 2) '*I had enough time to complete the experiment*' (mean = 4.5, sd = 0.6). The two parallel laboratory sessions were observed by two academic developers (JP and KW). Many students were observed to complete the core of the experiment (involving comparing the performance of two types of solar cells) which would explain the good agreement with statement 2). Approximately 70 % of students did not progress to designing and carrying out their own experiment. This might explain the response to the statement '*I had the opportunity to be creative*' with its comparatively low mean of 3.8 (sd = 0.7). In response to statement 6, students agreed that class discussions benefitted their learning (mean=4.4, sd = 0.6) but only two students specifically mentioned these discussions in the response to the open ended questions.

The response to statement 5) '*More details should be included in the notes'* gave an average response close to neutral and the largest variation between students (mean = 3.4, sd = 1.0). Closer inspection of the data reveals that 13/26 agreed or strongly agreed with the statement, and 12/26 were neutral, disagreed or strongly disagreed with the statement. The previous experience of many students of laboratory work may have led to an expectation that step by step instructions would be provided. We conjecture as this expectation was not realized, in line with the intentions of an inquiry based approach which eschews the inclusion of detailed instructions, this is partly responsible for half of the students agreeing or strongly agreeing with the statement.

The standard deviation of 0.9 in the score for the statement 14) '*The link to CSIRO research heightened my interest in the experiment'* indicates quite a large variation between students on how much their interest was increased by the link. Students' awareness of the link to CSIRO research and how it translates (or not) into interest in the experiment is an issue that was discussed further in the focus group sessions.

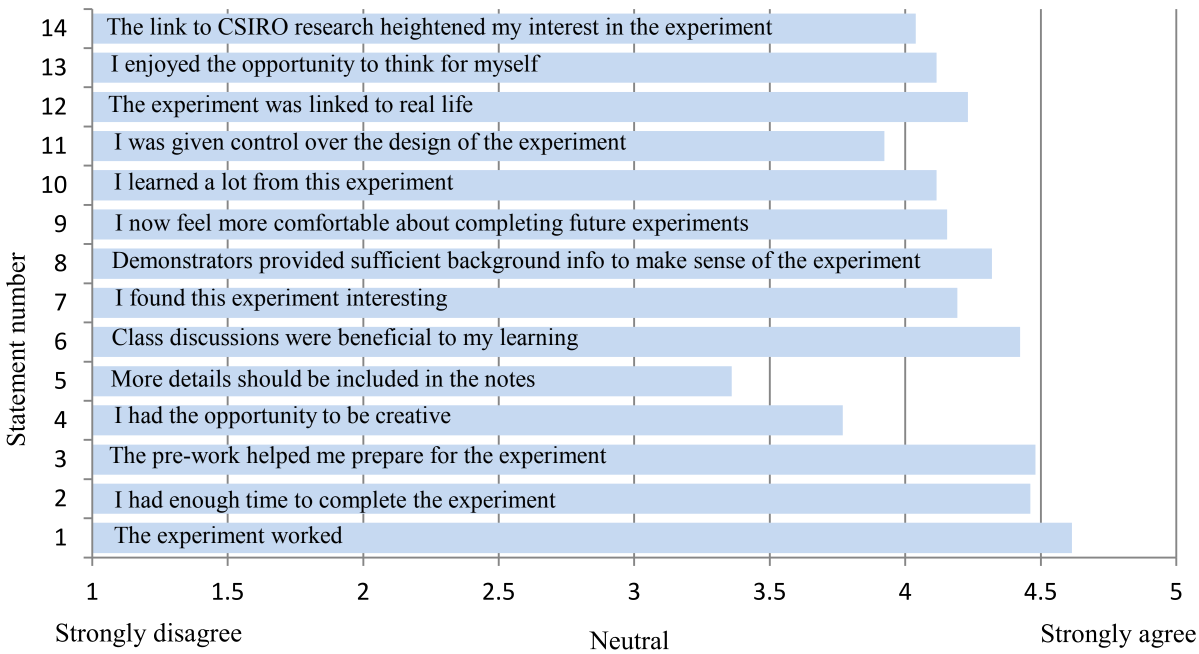


**Figure 3. Enrolled student responses to fixed response statements on anonymous survey**

Two themes emerged from student replies to the open response question on the strength(s) of the experiment to which 18/26 students responded: 5/18 students remarked on solar research and links to real life: "*Link to a real life research project. Relevant in terms of requiring new technologies for power"* and "*…applies to current research and quite interesting on development of CSIRO organic cells*." 5/18 students remarked positively on the use of computers to analyse and display data: "*the use of the computer allowed for quick calculations and quick representation of data*, and *develops understanding in using Excel"*.

Fewer students (11/26) responded to the question about improvements that could be made to the experiment. The most common suggestion (5/11) was to provide more background information and support: "[I'd like] *more of an explanation in relation to the formulas I used*, and; "*have instructions on Excel at beginning of prac"*.

## Observations of Enrolled Students Carrying Out the Experiment

Using an observation checklist adapted from the “New Perspectives on Service Teaching: Tapping into the Student Experience” framework (Kirkup, Pizzica, Waite and Mears 2012), two academic developers (JP and KW) observed the actions of the students and demonstrators in the laboratory environment in two separate laboratory classes. This was an opportunity to review how or whether the intended aims and inquiry-oriented approach of the experiment were being realised. Students were observed to be consistently and actively engaged in inquiry and problem solving during the class. They regularly asked questions, worked cooperatively, discussed and presented results and appeared involved and interested at each stage of the experiment. The demonstrators were also observed to be interacting with students in ways which supported and encouraged students’ participation in the processes of inquiry. This observation was also confirmed by the students’ comments in the focus groups on the nature of the student-demonstrator interactions: “*They (the demonstrators) don’t just say, “Here’s the answer”…they help”*.

It was observed that approximately 30% of students had enough time to progress to the final stage of the experiment, where they would have had greater control over the variables and been able to further exercise their creativity to design their own experiment. Students’ difficulties with *Excel* were observed, requiring both principal and assistant demonstrator to offer guidance to most groups on how to use the software.

## Positive Focus Group Findings – And the Unexpected

In a further evaluation framework activity, one of the observers facilitated a 30-minute focus group interview with students, immediately upon completion of the experiment. Eight students volunteered to be interviewed. All the volunteer students were female and were enrolled across a variety of science courses. The facilitator was an experienced academic developer, who had previously observed the session with the SS&D and understood the nature of the laboratory session and its goals. The focus group provided an opportunity to expand upon the feedback provided in the student survey.

A focus group script was developed relating to the aims of the experiment. This included open ended questions/prompts relating to the practical aspects of the experiment, student engagement and learning, and specifically the issue of relevance to their planned course majors, their future careers, and their everyday lives. The script also included a prompt which allowed students to raise any issues which had not already been raised in the discussion. The session was undertaken in a semi-structured conversational style, with the facilitator ensuring that contributions from all participants were included, by actively, and in a non-threatening way, inviting quieter students to contribute – with comments such as *“what about you?, any comments that you would like to add?”* The focus group session was recorded, and the facilitator also took notes during the session.

The student comments were analysed in relation to the focus of the questions. Students confirmed that this experiment had been an engaging and enjoyable learning experience, and highlighted a variety of ways in which the topic was relevant and meaningful to them, both during their course, and in their future careers. As the group included students intending to complete different majors, students were given the opportunity to comment on the relevance of the experiment to their major. Environmental science students regarded the topic of the experiment as directly related to their course. Students planning to major in chemistry were more interested in the chemical composition of the organic solar cells. Other students, such as those intending to major in biomedical science, noted that while they could not see a direct relevance to their intended major, they did find the topic interesting and meaningful due to their pre-existing familiarity with solar energy, finding it *"interesting because solar is in our houses"* and that *"solar energy is topical"*. All students commented that they had learned a great deal about solar energy through both the experiment, and the introductory framing components of the laboratory session.

Students commented on the connections of the experience with a potential research career. They stated that it was good *"to be doing an experiment people at CSIRO would have done themselves"; "Good, how we saw a man working in his career"; "Good to see how you can make a career on that"; "In a university of technology, it's good to be dealing with new technologies"*.

The response to the "any other issues" question highlights the value of the focus group evaluation. This question allows for the raising of issues that the experiment designer may not have previously considered, and as the focus group session was run by an academic developer who was not involved in teaching or grading the students, there were also opportunities to safely critique certain aspects of the experience and the approaches of teaching staff.

Students raised two concerns relating to their experiences in the laboratory. The students felt their inexperience with *Excel* software was a barrier to analysing their results. Whilst this issue was also raised in the student surveys, the focus group highlighted the extent of the problem, with 7 of the 8 interviewees reporting that they lacked the necessary software skills. One international student felt further disadvantaged as she explained that school students in her country did not have access to computers, so she felt challenged when the laboratory leader had assumed that students would be familiar with *Excel*. However, even for those who had some familiarity with *Excel*, the experiment required students to go beyond basic functions, as they were required to use formulae and produce graphs of the results.

An important and unexpected issue of focus was raised by the students. While the demonstrators appeared to be primarily concerned about the practical aspects of working with students, the students were very concerned about the assessment component of the task which was to be completed outside of class time. Students stated that they would have liked the principal demonstrator to spend time explaining how to write up the laboratory report, as this was the first report to be assessed in this subject, and they did not know the requirements for a laboratory report in this subject.

## Discussion

The multi-faceted evaluation of the laboratory session identified that the inquiry-oriented experiment was perceived to be an engaging learning opportunity by students and demonstrators. Responses from students in the focus group session highlighted how they were able to draw personal relevance and meaning from the topic of the research, allaying concerns that the solar cell research may have been perceived as irrelevant or of marginal interest to the large cohort of undergraduate students, being from diverse majors and educational backgrounds. As students felt they could meaningfully engage with the topic of the experiment, this assisted in creating an environment that could encourage them to take a deep approach to the tasks in the laboratory and make learning an interesting, challenging and positive experience (Biggs and Tang 2011). Relevance along multiple dimensions was an important element in the previous study using the development framework (Kirkup et al. 2010).

Areas for further fine-tuning of the experiment were highlighted from the evaluation. Feedback from demonstrators, senior students and enrolled students convinced us that one week devoted to the experiment is insufficient time for students to develop and carry out their own investigation, and simultaneously build their own inquiry skills. As a result, from Spring semester 2013 the experiment extended over two weeks, allowing more time for students to devise a hypothesis, and design and carry out their own investigation.

While the solar cell technology was of interest to all students, the level of technological skills they brought to the laboratory was uneven. For example, we assumed that students would be sufficiently familiar with *Excel* to allow for its seamless integration into the experiment. We were mistaken, and now, both pre-work and the first week of the experiment provides students practice in using *Excel*. In response to student concerns over guidance on report writing for their assessment, the pre-work for week two of the experiment now requires students to critique a sample student report.

The influence that demonstrators have on how laboratory-based activities are experienced by students is well-known (O'Toole 2012). In this instance, the principal demonstrator was one of the developers of the experiment and hence has a deep connection to the experiment and its design. Demonstrators are unlikely to be completely comfortable with the experiment until they have facilitated the session at least once – irrespective of the materials developed to support those demonstrators in the laboratory, or the briefings provided ahead of their laboratory sessions.

The framework used to develop and evaluate the experiment allowed us to observe the difficulties that diverse cohorts of first year students may have with inquiry-oriented laboratory work. Evidence we accumulated indicated that the students were highly engaged with the experiment due to the nature of the activity and the relevance of the topic across many dimensions - both disciplinary and personal. Students valued the links with 'real' research, through the video links, and appreciated they were working with cutting-edge technology.

Since the experiment reported in this paper was rolled out in Autumn 2013 it has been scaled such that in the Autumn and Spring semester of each year of the order of 150 and 600 first year students respectively engage in open-ended investigations utilising CSIRO organic solar cells. We have continued to develop the curriculum in which the experiment is embedded to take advantage of the unique opportunities that it and the collaboration with CSIRO offer for widening and deepening the student perceptions of the role of inquiry in the wider world. As an example, an innovation has been introduced in which a CSIRO, scientist intimately involved with the research and development of the cells, participates in a question and answer session with students over Skype. The Skype call occurs during a lecture, and after the students have completed the experiment. During the call the CSIRO scientist advises students of recent advances in the science and technology of organic solar cells and responds to student queries through a live and moderated Q&A session.

In conclusion, UTS and CSIRO have co-developed a scalable inquiry-oriented experiment for large classes of first year students enrolled in physics subjects. The approaches adopted, and the evaluation framework used, may serve as a model that can be adapted by others intent on integrating cutting-edge research into the first year curriculum. This initiative, which partners the university sector with a peak science agency to develop desirable skills within students, represents a concrete response to the call for the Australian higher education sector to connect more closely to industry in order to develop students' employability skills (BIHECC 2007).

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## References

BIHECC (2007). *Graduate employability skills*, Prepared by Precision Consultancy, Business, Industry and Higher Education Collaboration Council. Retrieved January 30, 2015, from http://aces.shu.ac.uk/employability/resources/graduateemployabilityskillsfinalreport1.pdf

Biggs, J., & Tang, C. (2011). *Teaching for Quality Learning at University* (4th ed.). New York, USA: Open University Press.

Boud, D., Dunn, J., & Hegarty-Hazel, E. (1989). *Teaching in laboratories.* Milton Keynes: Open University Press.

Boyer Commission (1998). *Reinventing Undergraduate Education: A Blueprint for America's Research Universities.* Retrieved January 31, 2015, from http://www.umass.edu/research/system/files/boyer_fromRussell.pdf

Brew, A. (2010). *Enhancing undergraduate engagement through research and inquiry.* Australian Government Office for Learning and Teaching. Retrieved on January 31, 2015, from http://www.olt.gov.au/resource-enhancing-undergraduate-engagement-research-enquiry-macquarie-2010

Cousins, J. B., & Whitmore, E. (1998). Framing Participatory Evaluation. *New Directions for Evaluation 80*, 5-23.

Creagh, C., & Parlevliet, D. (2014). Enhancing Student Engagement in Physics Using Inquiry Oriented Learning Activities. *International Journal of Innovation in Science and Mathematics Education*, *22*(1), 43-56.

Healey, M. (2005). Linking research and teaching: disciplinary spaces. In R. Barnett (Ed.), *Reshaping the university: new relationships between research, scholarship and teaching* (pp. 67-78). McGraw-Hill/Open University Press.

Jones, S. M., Yates, B. F., & Kelder, J-A. (2011). Learning and Teaching Academic Standards Project: Science Learning and Teaching Academic Standards Statement. Sydney, NSW: Australian Learning and Teaching Council.

Kirkup, L. (2009). *New Perspectives on Service Teaching: Tapping into the Student Experience*. Retrieved June 12, 2015, from http://www.olt.gov.au/resource-new-perspectives-student-teaching-uts-2009

Kirkup, L., & Johnson, E. (2013). Threshold Learning Outcome 3: Inquiry and Problem Solving. Sydney: Australian Learning and Teaching Council. Retrieved May 27, 2015 from http://www.acds.edu.au/tlcentre/wp-content/uploads/2014/02/Science-Good-Practice-Guide-2013_FINAL-TLO3.pdf

Kirkup, L., Pizzica, J., Waite, K. M., & Srinivasan, L. (2010). Realizing a framework for enhancing the laboratory experiences of non-physics majors: from pilot to large-scale implementation. *European Journal of Physics*, *31*(5), 1061-1070.

Kirkup, L., Pizzica, J., Waite, K. M., & Mears, A. (2012). *Adaptable Resource Kit (ARK) to assist in the development, trialling and evaluation of inquiry-oriented experiments.* Retrieved January 31, 2015, from http://www.iolinscience.com.au/wp-content/uploads/2011/11/ARK__June-10__2013.pdf

Luckie, D. B., Aubry, J. R., Marengo, B. J., Rivkin, A. M, Foos, L. A., & Maleszewski, J. J. (2012). Less teaching, more learning: 10-yr study supports increasing student learning through less coverage and more inquiry. *Advances in Physiology Education, 36*, 325-335.

O'Toole, P. (2012). *Demonstrator Development: Preparing for the Learning Lab.* Retrieved January 31, 2015, from http://www.academia.edu/2239775/Demonstrator_Development_Preparing_for_the_Learning_Lab

Pullen, R., Yates, B. F., & Dicinoski, G. W. (2014). A Preliminary Study: An Evaluation and Redevelopment of Current First Year Laboratory Practices. *International Journal of Innovation in Science and Mathematics Education*, *22*(7), 23-34.

Rayner, G., Charleton-Robb, K., Thompson, C., & Hughes, T. (2013). Interdisciplinary Collaboration to Integrate Inquiry-Oriented Learning in Undergraduate Science Practicals. *International Journal of Innovation in Science and Mathematics Education, 21*(5), 1-11.

Rice, J. W., Thomas, S. M., & O'Toole, P. (2009). *Tertiary science education in the 21st century*. Retrieved January 31, 2015, from http://www.olt.gov.au/Tertiary%20science%20education%20in%20the%2021st%20century%20-%20University%20of%20Canberra%20-%202009

Sharma, M. D., Mendez, A., Sefton, I. M., & Khachan, J. (2014). Student evaluation of research projects in a first-year physics laboratory. *European Journal of Physics*, *35*(2), 025004.

SMiS (2015). Scientists and Mathematicians in Schools. Retrieved 16 June, 2015, from http://www.scientistsinschools.edu.au/index.htm

Weaver, G. C., Wink, D., Varma-Nelson, P., Lytle, F., Morris, R., Fornes, W., Russell, C., & Boone, W. J. (2006). Developing a New Model to Provide First and Second-year Undergraduates with Chemistry Research Experience: Early Findings of the Center for Authentic Science Practice in Education (CASPiE). *The Chemical Educator 11*, 125-129.