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Matching the background of demonstrators with those of their students: does it make a difference?

Final report 2016

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List of abbrevations used

ACDS	Australian Council of Deans of Science
EJP	European Journal of Physics
FNDPEAU	Forging New Directions in Physics Education in Australian Universities
HOD	Head of Department
HREC	Human Research Ethics Committee
IJISME	International Journal of Innovation in Science and Mathematics Education
IBL	Inquiry-Based Learning
IOL	Inquiry-Oriented Learning
OLT	Office for Learning and Teaching
PAN	Physical Aspects of Nature
PQU	Planning and Quality Unit
SFS	Student feedback surveys
SMaPS	School of Mathematical and Physical Sciences
SPAM	School of Physics and Advanced Materials
STARS	Student Transitions Achievement Retention and Success
UCT	University of Cape Town
UQ	University of Queensland
UTS	University of Technology Sydney

In this report we make reference to subjects which are taught components of one semester duration within an undergraduate degree. In other institutions such subjects might be referred to as courses, modules, or units of study.

Executive summary

Project Context

Well-conceived and well-delivered undergraduate science laboratory programs encourage students to develop and enhance their inquiry, experimental and communication skills and urge deeper insights into scientific principles. The laboratory is a setting in which authentic scientific inquiry can occur (Hume and Coll, 2008).

Despite the promise of the laboratory as an inspiring and effective learning environment, concern has been expressed over many years about the benefits of the undergraduate science laboratory to students (Hegarty, 1978). There is regular criticism, expressed by students, of their learning experiences in undergraduate physics laboratories (Kirkup, 2015). This is particularly true of students for whom physics is a service subject (Kirkup, Johnson, Hazel, Cheary, Green, Swift and Holliday, 1998). [1]

The reasons for widespread student dissatisfaction with the first year physics laboratory experience remain unclear. However, there is little doubt that the demonstrator (sometimes referred to as a teaching assistant) plays a pivotal role in creating and maintaining a positive and productive learning environment especially where which student-centred learning is promoted. Rice, Thomas and O'Toole (2009) found that for many students, '*demonstrators had the power to make a lab a great or a miserable experience'* and called for a project to be undertaken to '*promote change in the system of laboratory demonstrating*'. This seed project is an answer to that call.

Aim of project

By examining student and demonstrator experiences and perceptions of the undergraduate physics laboratory we wished to enhance the value to students of undergraduate physics laboratories. More specifically, our aims were to:

- examine the influence of alignment between the background, ambitions, and views on teaching and learning of students and their demonstrators on student engagement and satisfaction.
- explore students' and demonstrators' views about learning and teaching in the physics laboratory and how these views manifest themselves in student-demonstrator interactions.
- investigate aspects of student-demonstrator interactions students consider helpful in increasing their engagement with laboratory work.

As an outcome of this work, we intend to advise on demonstrators' recruitment, induction and professional development as well as offer commentary on issues impacting on student experiences in the undergraduate laboratory.

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[1] A physics service subject is a physics subject enrolling only non-physics majors (Kirkup, Scott and Sharma, 2007). An example would be a physics subject enrolling only bioscience or engineering majors (and designed specifically with these majors in mind).

Project approach

Stimulated by work begun at the University of Cape Town, this project adopted several methods of exploring and examining student and demonstrator experiences and perceptions of an undergraduate physics laboratory for a large-enrolment first-year physics service subject at UTS. The methods included, but were not limited to:

- centrally administered student feedback surveys gathered longitudinally over several years.
- paper-based surveys of students and demonstrators comprising closed and open-items to probe student and demonstrator experiences and expectations of the laboratory.
- semi-structured interviews of students and demonstrators (at UTS) as well as students, demonstrators, subject convenors and the head of department (at UCT) in order to validate the data from the surveys and to examine more directly stakeholders' values, beliefs, concerns, experiences and attitudes towards laboratory work.
- Observations carried out in undergraduate laboratories using a 'fly on the wall' approach. An unobtrusive video camera was used to capture events, activities and incidents that may have been raised or commented upon during the semi-structured interviews.

We took the opportunity to engage in action research at UTS in response to student and demonstrator experiences as evaluated through the surveys and interviews. Upon completion of an intervention stimulated by findings from spring 2014, we surveyed students in autumn 2015 semester and compared student perceptions with those expressed in spring 2014.

Project outputs and deliverables

Project outputs include: student and demonstrator survey designs adaptable to other contexts and disciplines which support the exploration of student and demonstrator perceptions, expectations and experiences of laboratories and; semi-structured interview questions allowing for more detailed examination of student and demonstrators beliefs about laboratories. These resources, along with details of the project aim, methodology, findings and details of dissemination, can be found at http://www.iolinscience.com.au/demonstrators-students/participants-method/

Presentations and workshop:

STARS conference presentations, Melbourne, 3rd July, 2015, *Matching the background of demonstrators with those of their students: does it make a difference?* Authors: Les Kirkup, Meera Varadharajan, Michael Braun, Andy Buffler and Fred Lubben.

ACDS T&L Conference presentation, Brisbane, 16th July, 2015, *OLT Seed Project: Matching the background of demonstrators with those of their students: does it make a difference?* Presenter: Les Kirkup.

STARS workshop, Melbourne, 1st July, 2015, *A hands-on exploration of learning through inquiry.* Authors: Les Kirkup, Meera Varadharajan and Michael Braun.

Papers

Kirkup L., Varadharajan M., Braun M., Buffler A. and Lubben F. (2015). Matching the background of demonstrators with those of their students: does it make a difference? STARS conference, Melbourne 2015: available from: http://www.unistars.org/papers/STARS2015/13F.pdf

Braun, M. and Kirkup, L. (2016). Non-physics peer demonstrators in undergraduate laboratories: a study of students' perceptions *European Journal of Physics* vol 37, 015703.

Kirkup, L., Varadharajan, M. and Braun, M. (2016). A Comparison of Student and Demonstrator Perceptions of Laboratory-Based, Inquiry-Oriented Learning Experiences *International journal of innovation in science and mathematics education* (in press).

Key findings from UTS data

From the longitudinal survey administered at UTS we found there was a negative correlation between students' perceptions of the help and encouragement they received to think deeply about the experiment and the number of years of post-school physics experience of the demonstrators. In brief, those demonstrators with only a year or so post-high school physics, including peer demonstrators drawn from the same disciplines as the students, were seen to be more helpful and encouraging of deep thinking than those with seven or more years of post-high school study of physics. The analysis showed that the difference was statistically significant at the 0.05 significance level. Peer demonstrators were perceived to be at least as effective as more senior demonstrators at assisting students to think deeply about the experiments. This is evidence validating the introduction of peers into the first year laboratory and may be one of the most significant findings of this study.

From the custom surveys administered to students at UTS, we found significant differences between students' and demonstrators' perceptions of interactions in the laboratory. Overall, the demonstrators appear to adhere to the principles of an inquiry-oriented model of learning, though there are indications that several demonstrators may be uncomfortable with some of the consequences flowing from the adoption of the model. On the other hand, the model adopted by many students is that of direct instruction even though they may recognise that inquiry-type experiments encourage deeper level engagement in their interactions with the demonstrators. There appear to be several reasons for students' adherence to the direct instruction model, including: ineffectively managed student expectations; lack of conviction in the validity of the inquiry model, and; prevalence of the direct instruction model in students' prior and concurrent laboratory experiences.

Semi-structured interviews carried out at UTS were successful at probing the students' and demonstrators' expectations, experiences, and views on the role of the laboratory and examining student reliance on demonstrators. The interviews revealed two conceptions of the laboratory, held concurrently in some measure by all students and demonstrators, but their relative importance varied from student to student, and demonstrator to demonstrator. One conception could be described as functional and was held most strongly by those most comfortable with recipe-based experiments and adoption of a direct instruction model where a) what has to be done is spelled out in detail by the demonstrator or the laboratory manual and, b) more emphasis is expressed by the student on technical matters, such graph plotting, or set up and use of equipment. The other conception, more aligned to learning through inquiry, emphasises activities and interactions which have as their goals students developing their own approaches to problem solving and the enhancement of concepts, applications of physics or exploration of phenomena.

More details of the findings from the UTS surveys and interviews given in chapter 3 of this report and in a paper to be published in the International Journal of Innovation in Science and Mathematics Education (Kirkup et al., 2016). A draft of the paper is attached as an appendix to this report.

Observations captured by video of students and demonstrators in the laboratory remain to be analysed, however we offer one comment based on viewing students working in a conventional physics laboratory at UTS in 2014 and other students working in UTS' new 'superlab' in 2015 (which accommodates up to 220 students simultaneously). In the 2014 laboratories which were smaller but with more space per student, there was a greater flow of students around the laboratory and more student/demonstrator interactions than in the superlab.

In response to student and demonstrator data gathered through this project, aspects of the PAN laboratory program at UTS and its delivery were modified for the autumn semester 2015. The intervention was correlated with gains in student engagement and perceptions of the value of the laboratory. As an example, in autumn 2015, 87% of students agreed that the experiments increased their understanding of physics compared to 59% in spring 2014.

That this short study was able to identify issues impacting student and demonstrator experiences and perceptions which in turn inspired a successful intervention, is an endorsement of the methods adopted during the project.

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Chapter 1: Project context, drivers and aim

The importance of the laboratory in the science curriculum

The undergraduate science laboratory is a potentially rich learning space prompting and encouraging students to develop and enhance their experimental skills (Boud, Dunn and Hegarty-Hazel, 1989; Hazel and Baillie, 1998; Psillos and Niedderer, 2002) and where authentic scientific inquiry can occur (Hume and Coll, 2008). The laboratory is able to offer students opportunities to enhance their capacities in such areas as critical thinking, written and oral communication skills, working productively in groups and behaving ethically and responsibly (Hanif, Sneddon, Al-Ahmadi and Reid, 2009). The laboratory plays a major role in the undergraduate science curriculum, both for students destined to major in physics and others for whom interest, circumstance or career trajectory takes them along other paths. Students recognise the value of their experiences in laboratories, especially with respect to their exposure to research and inquiry. When asked in a recent study 'What do you value most from your background in science?' students placed skills in observation, experimentation and quantitation high on their list (Harris, 2012).

Shifts in students' undergraduate laboratory experiences

We are witnessing a substantial shift in the type of laboratory experience offered to science students. This may be traced to institutional, national and international pressures for change arising from:

- increasing student numbers (Australian Broadcasting Corporation, 2013; Norton, 2013).
- reconsideration of pedagogies adopted in undergraduate laboratories, with an increasing emphasis on inquiry (Kirkup, Pizzica, Waite and Srinivasan, 2010; Cobern, Schuster, Adams, Applegate, Skjold, Undreiu, Loving and Gobert, 2010).
- Australia's ex-Chief Scientist purposefully advocating students be given insights into processes by which scientific knowledge is created and challenged (Office of the Chief Scientist, 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).
- recognition of the potential of inquiry to engage students, thereby arresting student attrition prevalent in science courses (Pitkethly and Prosser, 2001).
- the emergence of 'superlabs' in science faculties in Australia and around the world, in which many students operate simultaneously in a high-technology learning space (Hinton, Yeoman, Carvalho, Parisio, Day, Byrne, Bell, Donohoe, Radford, Tregloan, Poronnik and Goodyear, 2014).
- changes in the Australian Science Curriculum from K–12 (National Curriculum Board, 2009), which have an increased emphasis on science inquiry skills.

Challenges for student learning in the laboratory

Despite the promise of the laboratory as an inspiring and effective learning environment, there is a history of criticism of what it delivers (Bless, 1933; White, 1996). For example, there is evidence that student experiences in the laboratory fail to live up to their expectations. The national significance of this problem was highlighted in an ALTC-funded report (Kirkup and Mendez, 2009) 'Forging New Directions in Physics Education in Australian Universities' (FNDPEAU), which showed the quality of the students' experiences at almost all of the 22 universities in the FNDPEAU collaboration fell significantly below student expectations, prompting the recommendation that[2] [the physics community] '*Recognise that the laboratory experience of students in first year physics subjects … across the majority of the tertiary physics institutions in Australia is a matter of concern, demanding urgent action'.*

The reasons for widespread student dissatisfaction with the first year physics laboratory experience remain unclear and are likely to vary from course to course and institution to institution. However, there is little doubt that the demonstrator plays a pivotal role in creating and maintaining a positive and productive learning environment. Rice et al. (2009) found that for many students, '*demonstrators had the power to make a lab a great or a miserable experience'* and recommended a project be undertaken to '*promote change in the system of laboratory demonstrating*'. Herrington and Nakhleh (2003) expressed the view that '*assessing students' and [demonstrators] perceptions of effective laboratory instruction is important in expanding definitions of teaching effectiveness to encompass different types of instructional contexts'*.

More recently, a report (O'Toole, 2012) commissioned by the Australian Council of Deans of Science (ACDS) recognised the importance of the laboratory for promoting authentic, inquiry-based learning persistently advocated by Australia's Chief Scientist (2012). The report states: '*The impact of the challenges posed [by promoting inquiry based learning] justifies investment in the development of demonstrators' competencies, both at the individual and group level, to realise the potential of science teaching laboratories'.*

Institutional driver for this project

In the first year physics laboratories at UTS there is an emphasis on learning through inquiry (Kirkup, 2015). A demonstrator supporting experiments with an inquiry focus is expected to assume the role of a facilitator rather than that of a teacher who provides student with detailed instructions on how to carry out an experiment (Roehrig, Luft, Kurdziel and Turner, 2003). Recognising this, and acknowledging the positive impact that students can have on the learning of their peers (Dawson, van der Meer, Skalicky and Cowley, 2014), the School of Physics and Advanced Materials (SPAM) at UTS introduced peer-demonstrators into the first year physics laboratories. Student perceptions of the comparative effectiveness of peer and non-peer demonstrators, for example in promoting deep learning was tracked (Braun and Kirkup, 2016). The work revealed a systematic trend indicating that peer demonstrators are perceived by students as more helpful and more effective at promoting deep learning than non-peers. This finding was a driver for this project.

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[2] http://www.physics.usyd.edu.au/super/ALTC/documents/ALTC-Report.pdf

The physics department at the University of Cape Town was also keen to explore student/demonstrator interaction, with a view to understanding and enhancing engagement to the benefit of student learning, and had already initiated a study in this area prior to this project beginning[3]. The fact that the laboratory learning environments and philosophies underpinning the laboratory programs are quite different at UTS and UCT was expected to lead to findings that would be applicable beyond the two institutions. The two institutions have this in common: both UTS and UCT have large numbers of students underprepared for physics-based tertiary study, with many students taking physics as a service subject.

Our premise is that improved understanding of the factors affecting student-demonstrator interactions will lead naturally to improved strategies for recruitment and professional development of demonstrators. This in turn will enhance student engagement and satisfaction with laboratory work, facilitating a reduction in student attrition in the first year of university, which can typically exceed 20-30% (see for example Hinton, 2007).

Aim

By examining student and demonstrator experiences and perceptions of the undergraduate physics laboratory, we wished to enhance the value of undergraduate physics laboratories to students. More specifically, our aims were to:

- examine the effect of alignment between the background, ambitions, and views on teaching and learning of students and their demonstrators on student engagement and satisfaction.
- explore students' and demonstrators' views about learning and teaching in the physics laboratory and how these views manifest themselves in student-demonstrator interactions.
- investigate aspects of student-demonstrator interactions students consider helpful in increasing their engagement with laboratory work.

As a result of the examination, we intend to advise on demonstrators' recruitment, induction and professional development as well as offer commentary on issues impacting on student experiences in the undergraduate laboratory.

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[3] Curtin University was also a partner in the original application for funding from the OLT. Before this project began, the team member from Curtin left the university. As a consequence, Curtin's involvement in this project came to an end.

Deliverables

The intended deliverables of this project included:

- a final report which will be made available in several forms including on the Inquiry Oriented Learning in Science website http://www.iolinscience.com.au/demonstrators-students/ .
- dissemination of the project, its methodology and findings through established national teaching and learning networks.
- promotion of project findings on the ACDS Teaching and Learning Centre website.
- delivery of a national workshop.
- presentations of the work and its findings at national and international conferences including the STARS conference and the ACDS Teaching and Learning Conference.
- a paper in an international peer-reviewed physics education journal detailing aspects of the project.
- a paper in an international peer-reviewed science education journal describing findings of the project.

Chapter 2: Approach and methodology

Overview

Central to this project is the exploration of student/demonstrator experiences. This exploration comprised three phases.

1. Survey/interview design and ethics approval
2. Data collection phase
3. Analysis, review and development phase

Project dissemination occurred mainly in the second half of the project through various modes including presentations at conferences, papers in international journals and a website.

Survey/Interview design

Ahead of this project, UCT physics carried out open-ended interviews with demonstrators and students of different backgrounds about their experiences in the laboratory sessions. The approach adopted in the interviews, and the questions posed to students were adapted for use at UTS. Other questions explored the views of subject coordinators and senior academics and formed part of semi-structured interviews carried out at UCT.

In order to explore and compare student and demonstrator experiences, perceptions and interactions in first year laboratories at UTS we employed several complementary methods: electronically administered UTS students feedback surveys which we adapted in 2011 to investigate student perceptions of their demonstrators; paper-based surveys of students and demonstrators; structured interviews and; observations, captured through video of students and demonstrators working together in the laboratory.

Ethics approval for this work was sought from the UTS Human Research Ethics Committee (HREC). Approval was granted in August 2014 (HREC REF NO. 2014000443).

Centrally administered student feedback surveys

In common with other institutions, UTS administers online student feedback surveys (SFS) at the end of each semester. Survey items relating to the study of student perceptions of demonstrators, with responses recorded on a Likert scale from *strongly disagree to strongly agree*, comprised:

- *The [principal/assistant] demonstrator was well prepared to help me with my work.*
- *The [principal/assistant] demonstrator encouraged me to think deeply about the experiments*.
- *The principal demonstrator gave me good feedback on my work.*

These extra survey questions were developed in 2011 and were administered to first-year students including those majoring in the medical, biological and environmental sciences who enrolled in the subject, Physical Aspects of Nature (PAN) at UTS each semester from 2011 onwards, including the period of this seed project.

Paper-based surveys of students and demonstrators

Surveys are used to probe students' perceptions of their learning experiences and provide valuable feedback to practitioners and researchers (Barrie, Bucat, Buntine, Burke da Silva, Crisp, George, Jamie, Kable, Lim, Pyke, Read, Sharma and Yeung, 2015). A short paper-based survey exploring the processes undertaken in the laboratory as well as aspects of the laboratory experiences was administered to all students enrolled in the first year physics subject. A paper-based, in-class survey was chosen so as to maximise the response rate.

Closed items were responded to on the Likert scale of strongly disagree to strongly agree. Other items on the survey allowed for free response.

Similar and complementary items to those on the student survey were included on a paper-based survey administered to demonstrators. Table 1 contains some items from the student and demonstrator surveys. The complete surveys for students and demonstrators can be found at http://www.iolinscience.com.au/demonstrators-students/

Table 1: Sample items from student and demonstrator surveys

Type	Students	Demonstrators
Closed	I was comfortable asking the Principal/Assistant demonstrator questions about the experiment	Generally, I was comfortable answering questions about the experiment
Closed	Overall, the demonstrator made an important contribution to my learning in PAN labs	Overall, I think I made an important contribution to enhancing students' learning experience in PAN labs
Open	Please write a few words on how the demonstrator most helped you in your learning	Please write a few words on what you see as the most important thing you did to help students learn in PAN labs

The School of Mathematical and Physical Sciences (SMaPS) at UTS employs principal and assistant demonstrators who assume different roles in supporting students in the laboratory. The differences are relevant to this project. The principal demonstrator either possesses a PhD in physics or is working towards one. She or he has primary responsibility for managing the laboratory, introducing experiments to the class, assessing the students' laboratory-based work and assisting students throughout the laboratory session. The assistant demonstrator is generally a senior undergraduate following a major of students in the class or a physics honours student, with a more limited physics background than the principal demonstrator. The assistant demonstrator supports students throughout the laboratory session, but has no assessment or organisational responsibilities. The student survey included questions specific to each category of demonstrator.

Semi-structured interviews

While surveys are able explore the students' experiences and perceptions (Kuh, 2003), the project team judged the surveys would be complemented, and the findings of the surveys validated, by a more nuanced approach to this exploration. Also, it was regarded as essential that the student voice be heard directly in order to examine more thoroughly their beliefs, concerns, experiences and attitudes. It was anticipated that the interviews would be a rich source of insight into the experience and touch on matters that we had overlooked or given insufficient attention to, but that were prominent in the minds of students and/or demonstrators.

Informed by work that had been carried out at UCT, semi-structured one-on-one interviews were designed and conducted with students and demonstrators in PAN at UTS. Through the analysis of the interviews we wished to establish how the participants conceptualised the role of the laboratory and that of the demonstrator. There was an ambition to build a bigger picture of the range of these conceptions held collectively by students and demonstrators. The approach adopted has some similarity with phenomenographic methods (Akerlind, 2005). These methods strive to establish, often through semi-structured interviews in which a particular catalyst for conversation is focussed upon (Wilson, Åkerlind, Francis, Kirkup, McKenzie, Pearce, and Sharma, 2010; Kirkup et al., 2010), the variation in conceptions, understanding or ways of experiencing some phenomenon (Marton and Booth, 1997). It should be emphasised that, though our approach is similar to that adopted in phenomenography, there was no attempt to adopt that methodology rigorously.

The aims of the student interviews were to: understand what students perceived to be the purpose of laboratory work and how they learnt in the environment and; to gather student views and perceptions of the demonstrators and the support they offered in the laboratory. Students had the opportunity to discuss the challenges faced in learning and doing laboratory work and to suggest ways to improve their learning experience. A similar line of questioning was adopted for the demonstrators to determine their views on student learning and what could be done to enhance students' and demonstrators' experiences of the physics laboratory.

Examples of interview questions addressed to students included '*What are your views on the role and relevance of physics to your degree and career?'*; '*What are your learning influences in laboratory work?'* and; '*What in your view is the role of demonstrators and what kind of qualities should they possess*?' Students were prompted to explain their learning process. Questions such as '*Could you briefly describe a recent experiment or procedure followed in PAN labs'* were used to gather further insight into ways they understood, approached and learnt from their laboratory experiences. Conversational style interviews allowed for probing more deeply into participants' views and perceptions through prompts such as '*Can you describe that a bit* more' or '*Please tell me why you feel this way*'.

Laboratory observations

It is likely that self-reporting by students and demonstrators of their laboratory activities does not capture all the dimensions of their activities and interactions. The project team determined that a 'fly on the wall' approach using an unobtrusive camera would capture events and activities that may not emerge during the interviews. Students and demonstrators gave informed consent for the videoing. Further, they were advised that the video would be used for research purposes only.

A video camera was placed at a discrete vantage point within the laboratory to capture the movements of those in the room for the duration of the whole laboratory session. Our intent was to observe the frequency and length of interactions between students and demonstrators, student engagement while performing experiments and generally identify critical incidences that take place in student learning and demonstrator teaching.

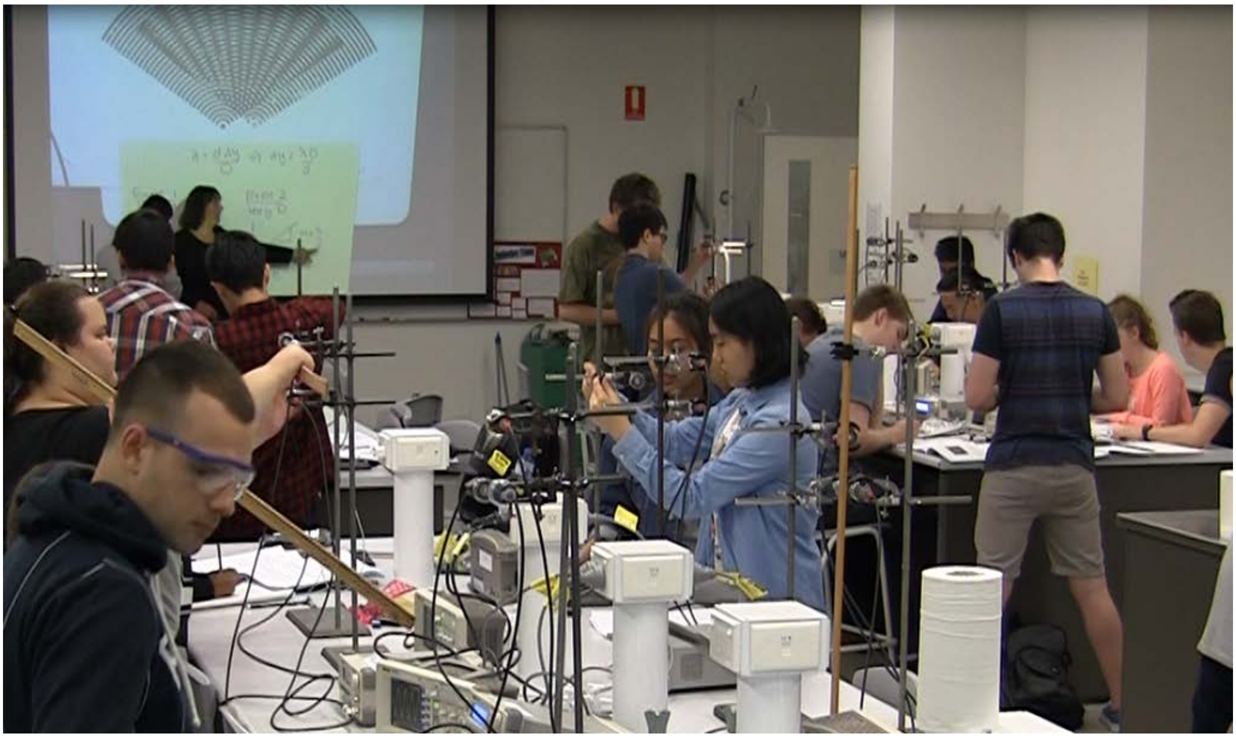

Figure 1: A still from PAN laboratory session videoed in spring semester 2014 at UTS.

A total of 5 PAN laboratory sessions were recorded each of duration two and half hours in spring semester 2014. The recording took place during the final experiment in the laboratory program. Figure 1 shows a still from one of the video recordings.

Data collection

The data collection protocols are described in this section.

University administered surveys: Online surveys were administered and analysed by the Planning and Quality Unit (PQU) at UTS at the end of spring semester. Response rate was approximately 30%.

Project focussed surveys: Paper-based surveys of students and demonstrators took place at UTS in the final week of the laboratory program. All students were asked to complete a consent form before they completed the survey (and were given the option not to hand in the survey); 417 (76% of all students enrolled in PAN) students and 18 demonstrators (82% of all PAN demonstrators) completed the survey. Out of the 18 demonstrators, 9 were principal demonstrators, and nine were assistant demonstrators.

Interviews at UTS: The interviews took place at UTS at the end of teaching in the spring semester 2014, but before students took their end of semester examinations. 15 students took part in the interviews and 11 demonstrators (6 principal demonstrators and 5 assistant demonstrators). Potential participants were informed about the nature of project and asked for consent to being interviewed. The interviews were recorded and transcribed for analysis. Each interview was between 20 and 60 minutes in duration, with the demonstrator interviews generally longer than those of the students.

The interview began by putting participants at ease by asking general questions (for example, what was the degree being undertaken by the student) before proceeding to questions of a specific nature. For example, the following questions were put to student participants which gave them opportunity to open up and provide critical information of value to the study: '*What do you think is the role and relevance of physics to the degree you are undertaking?' ;* '*Before you started the course, I am curious about what you expected the course to be like?',* and*;* '*How did you feel once you had started the course?'*

Questions on participants' perceptions on laboratories and how they learn were probed before moving on to questions about demonstrators. Participants were given the opportunity to describe their learning process ('how they learn') in various ways. Examples could be participants describing the procedure they followed while conducting an experiment (in steps) or describing what happens in a typical laboratory session from the beginning to the end.

Interviews at UCT: Student and demonstrator interviews were carried out at UCT in April 2015 by the project leader. Five demonstrators and five students were interviewed. The same interview structure and questions were adopted as for the UTS interviews. Opportunistically, and because we believed we were missing important voices of stakeholders impacting on the student experience and student/demonstrator interaction, interviews were carried out with the head of department and 3 other developers/convenors of the first year physics laboratories at UCT.

Questions asked of the HoD and developers/convenors included; In what way are laboratory programs valuable to students, and: what are the most important traits of demonstrators?

Videoing laboratory classes: Five PAN laboratory classes were videoed during their final experiment. The videos were of approximately 2.5 hours duration.

Analysis methods

University administered surveys: Basic statistical methods were applied to establish the impact of several factors including the influence of demonstrator background (number years of formal study of physics of the demonstrator) and the gender of the demonstrator on mean student responses to the survey items.

Project focussed surveys: Each response to a closed item on the survey was scored using a 5-point Likert scale, where: 1=*Strongly disagree*, 2 = *Disagree,* 3 = *Neutral,* 4 = *Agree*, and 5=*Strongly agree*. To compare student and demonstrator responses to complementary items on the survey, for example *I relied on the demonstrator to tell me how to do the experiments* (item on student survey) and *Most students relied on me to tell them how to do the experiments* a two-tailed t-test was applied to test a null hypothesis that the means of samples were drawn from the same population at the 0.05 significance level. Analysis of the open-ended questions involved a qualitative approach. A process of constant comparison for recurring words and emerging patterns (Lincoln and Guba, 1985) and open coding (Strauss and Corbin, 1990; Wiersma and Jurs, 2005) was used to categorise the data. The responses for each item were analysed, following a process of data organisation, data reduction, coding and categorisation. The results of the analysis were used to relate the open- to the closed-ended responses.

Interviews: Student and demonstrator interview transcripts were examined for commonalities and variations in their respective expectations and perceptions with respect to the laboratory and the factors that impacted on those perceptions. Responses to the interviews question were compiled to identify significant features. In addition, similar responses were grouped or categorised to understand how participants described their perceptions. The groupings were supported by extracts from the transcriptions (Booth and Ingerman, 2002).

Video observations: Observations of students and demonstrators have yet to be analysed. The intention is to adapt a protocol for analysing student-demonstrator interactions in the laboratory developed through an ALTC fellowship awarded to the project leader (Kirkup et al., 2011).

Chapter 3: Findings, outputs and dissemination

Findings

A statistically significant finding from the centrally administered SFS surveys at UTS was that the mean student scores (out of 5) for the items *The [principal/assistant] demonstrator was well prepared to help me with my work, The [principal demonstrator/assistant] encouraged me to think deeply about the experiments* **decreased** as the years of formal study of the demonstrators increased[4]. That is, demonstrators with a modest background in physics scored well in the SFS surveys compared to those with many years of experience. Another statistically significant finding was that the mean score awarded to assistant demonstrators for the level of help they provided to students and their preparedness to help was greater than that of the principal demonstrators, as shown in Figure 2.

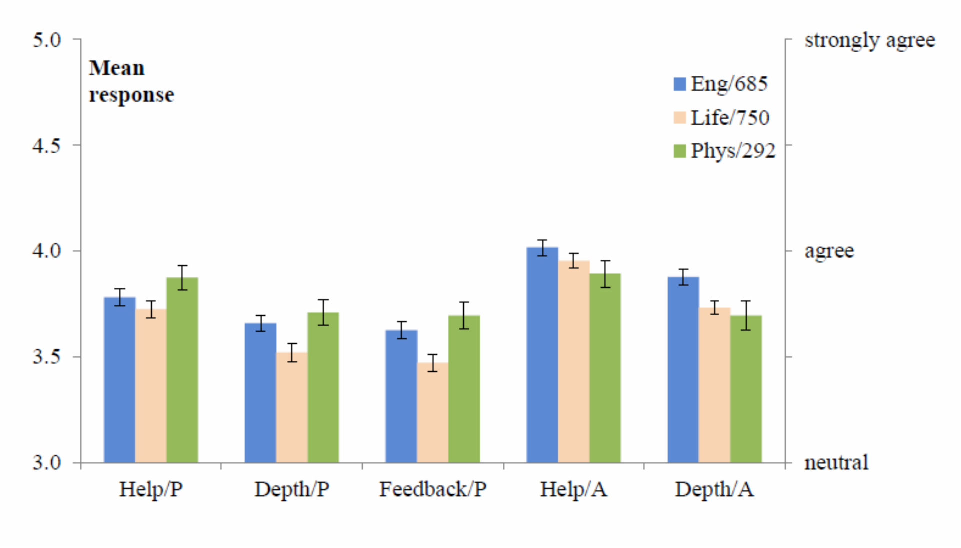

Figure 2: Mean response of students studying first year physics for engineers (Eng), physics for physical science students (Phys) and physics for life science students (Life). The categories have the following meanings: Help/[P/A] is help provided by principal/assistant demonstrators, Depth/[P/A] is encouragement to think deeply about experiments by principal/assistant demonstrators and Feedback/P is feedback given to student by the principal demonstrator.

The pink bars in Figure 2 relate to PAN student responses. For comparison, the blue and green bars represent responses for cohorts of students enrolling in two other subjects at UTS: physics for engineering (Eng) students, and physics for physical science (Phys) students respectively. Though not part of this study, it is worth remarking that similar statistical differences between student responses to assistant and principal demonstrators apply to these cohorts, suggesting that findings with respect to PAN students and their relationships with demonstrators are widely applicable.

The custom designed student survey for this project comprised 14 closed statements and 3 open-ended questions. Closed statements included:

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[4] More detailed information on the findings can be found in Braun and Kirkup, 2016.

I was encouraged to think deeply about the experiments by the Principal/Assistant demonstrator, and; I was comfortable asking the Principal/Assistant demonstrator questions about the experiments.

Responses to the open-ended questions in the demonstrator surveys reveal that more assistant demonstrators (than principal demonstrators) describe helping students at a deep/conceptual and higher order thinking level. Examples of such responses are:

- ✓ *'[I get the students to]* discuss *the underlying physics and … to think deeply about the experiment'.*
- ✓ *'[I] encourage them to go beyond what was stated in the experimental protocol'.*
- ✓ *'[I] explain the significance of the experiments and how it related to applications/fields'.*

In support of this finding, when students in the open-ended responses reported that they were encouraged to think deeply about the experiment, they referred to the assistant demonstrator more often than to the principal demonstrator.

With regard to the demonstrator's contribution to student learning, a large proportion of students praised the attributes and inter-personal skills of their assistant demonstrators. For example, the students described the assistant demonstrators as being '*more approachable and helpful'* and possessing an '*awesome personality'.*

These qualitative findings support the analysis of the university-administered SFS surveys that found the assistant demonstrators to be more highly rated than the principal demonstrators in terms of readiness to help and encouragement of deep learning. These findings have been published (Braun and Kirkup, 2016).

Further analysis of the surveys revealed two major issues with respect to students' views about the work they did in the laboratory: the written material provided to students, and student dependency on demonstrators. With respect to the former, the nature of the inquiry-oriented experiments meant that the designers provide a skeleton description of the experiment. The surveys and the interviews revealed that neither the students nor the demonstrators were comfortable with a sparsely-scripted laboratory manual and were quite critical of its clarity and the support it gave.

Analysis of the surveys revealed that demonstrators believed students relied on them to tell them how to proceed with experiments. This is indicative of students' expectations of a direct instruction model in their interactions with the demonstrators (Boud et al., 1989).

Most demonstrators referred to encouraging the students to '*think deeply'* about the experiments, '*encouraging* [students] *to go beyond what was stated'*, and were happy to '*discuss the underlying physics'*. Such views were as prevalent among the assistant demonstrators as among the principal demonstrators despite the former having had a typically shorter exposure to the physics discipline. Details of the survey results have been submitted for publication (Kirkup, Varadharajan and Braun, 2016).

There was consistency expressed by students (S) and principal (P) and assistant (A) demonstrators through the semi-structured interviews on the purpose of the laboratory. In broad terms, the purposes can be categorised as:

> Demonstrating some important physics phenomenon (linked to lectures) eg *'to reinforce the theories we learn in the lectures'* (S) , '*practically showing how concepts work'*....(A).
>
> Developing skills (such as communication, manipulative and analysis skills) for example, '*develop skills (eg report writing, inter-personal)'* (S) '*experimental skills...graphing, being able to write down all measurement and collate into a report'* (A).
>
> Going deeper into their learning '*So we get a better understanding of the concepts'*(P), '*to promote inquiry based learning'* (P).

These views are well aligned with the literature (for example Boud et al., 1989, Hazel and Baillie, 1998).

The interviews also allowed for the exploration of the factors that influenced student learning including their interaction with demonstrators: '*Demonstrators have the influence on how you take an approach to the prac...really does influence your learning, the demonstrator can have a large impact because the amount of information you can get out of them is obviously going to impact how much you learn, If they are approachable and friendly, it makes a lot easier'*.

Insight into student/demonstrators interactions and their experiences in the laboratory will form the core of a paper to be prepared for publication in an international journal.

The outputs of this project include conference papers, peer-reviewed papers, conference presentations and resources developed for this project. These resources, along with details of the project aim, methodology, findings and details of dissemination, can be found at http://www.iolinscience.com.au/demonstrators-students/resources/ . Details of other modes of presentation which also supported project dissemination can be found in Chapter 4.

Data from the UCT interviews remain to be analysed in detail. However, a preliminary analysis reveals a difference in interactions between students and demonstrators with respect to asking and answering questions posed in the laboratory: at UTS, students consistently referred to asking questions and having demonstrators answering them. By contrast at UCT, the interviewees (both demonstrators and students) spoke of demonstrators asking questions that probed student understanding and reasoning skills. In short, the interactions were largely student-initiated at UTS and demonstrator initiated at UCT. It is possible that this occurred due to advice given in training sessions at UCT for demonstrators to employ Socratic questioning during their interactions with students in laboratories.

How the project used and advanced existing knowledge

Laboratories remain a vital component of the undergraduate science curriculum. With student numbers increasing in many universities and the increasing influence on the curriculum of standards and prescriptions of learning outcomes, there has been a new impetus to reconceptualise the role of the laboratory in learning. We have been influenced by existing knowledge in this area built up over several decades, including monographs, such a 'Teaching in laboratories' by Boud, D., Dunn, J. & Hegarty-Hazel, E. (1989) and 'Improving teaching and learning in laboratories' by Hazel and Baillie, (1998).

This project utilised the evidence and extended findings of student experiences in laboratories acquired through Carrick and ALTC fellowships awarded to the project leader (Kirkup, 2009; Kirkup, 2013). Survey items developed as part of the 2013 fellowship were adapted for use in this project. This project is promoting and contributing to the reconceptualisation of the role of the laboratory, and in particular, the role of the demonstrator, in part through building on work carried out nationally, for example the influential ALTC funded study by Rice et al. (2009) which focussed on 'Tertiary Science Education in the 21st Century'.

This project supports and adds weight to findings and recommendations of an ACDS-funded study 'Demonstrator development: Preparing for the Learning Lab' by O'Toole (2012) for example that 'demonstrators should encompass a wider range of experience than university research' and subject coordinators/convenors should 'encourage feedback from demonstrators'. O'Toole emphasised that the pool of demonstrators should be broadened to include 'experienced science professionals'. The study indicates that demonstrators close in age and disciplinary persuasion are also deserving of consideration for inclusion in the pool of demonstrators as they are recognised by students as encouraging deep learning.

The methods adopted in this project were informed and in some cases underpinned by the work of others who have devoted time and energy to maximising the value of laboratories to students. As examples,

- The review of the value of peer-instruction by Dawson et al. (2014). Our study points to peer-instruction being valuable within the context of the laboratory.
- The challenge of encouraging students and instructors to embrace learning through inquiry in the laboratory, as described by Hume and Coll (2008). The instructors in Hume and Coll's study were teachers. We found in this project that, although inquiry has been built into and throughout a laboratory program, unless the right messages are sent to students and demonstrators in a persuasive, coherent and timely manner, the perceptions of the purpose of the laboratory and its effectiveness may be compromised.
- Bruck and Towns (2009) considered how to prepare students to benefit from inquiry-based activities and recommended that demonstrators adopt a more facilitative role. This study supports that suggestion (which also has been made elsewhere many times, see Roehrig et al. (2003)). What we have learned through this seed project is that it is the whole laboratory program that must be reviewed and in some cases reconceptualised if that program is to be successful. This might

include rigorously reviewing materials prepared for student and demonstrators, making persistent links to other facets of the curriculum, such as to the lectures, emphasising the relevance of the laboratory activities to the student current studies and possible future career trajectories, and giving demonstrators just-in-time advice regarding the experiments and their purpose. This study showed that accomplishing these things may improve student perception of the value of the laboratory.

Disciplinary and interdisciplinary linkages

Through conference attendance, OLT events, academic networks, and contacts with academics at UTS linkages have been forged with groups and individuals including:

Kelly Matthews, Senior Lecturer, Curriculum**,** Institute for Teaching and Learning Innovation UQ. Kelly's OLT fellowship is reconceptualising the role of students in science degree programme curriculum. Kelly is eager to explore with the project team the role that students can have in developing and co-delivering laboratory programs.

Georgina Barratt-See, Manager, U:PASS, Higher Education Language & Presentation Support, UTS It is timely for the role of peer support in laboratory to be placed front and centre. The project team is linking with Georgina to progress peer support in the laboratories at UTS.

Mauro Morcerino, Associate Professor, Department of Chemistry, Curtin University. Mauro's OLT fellowship '*Enhancing learning in the laboratory: identifying and promoting best practice in the professional development of demonstrators* has much in common with this project. The sharing of finding between his fellowship and this seed project will bring emphasis to the importance of demonstrators as facilitators of student learning.

Australian Council of Deans of Science. Through contact with the Director of ACDS TL centre, Professor Liz Johnson, details of this project have been placed on the ACDS website. We anticipate that future developments will also be reported on this website.

Factors contributing to the success of the project

Recruiting Meera Varadharajan as a part-time project officer with skills that complement those of the principal investigators has been particularly advantageous to the project. Meera brought much-valued expertise and a skill set well-matched to this project.

Being able to utilise the existing infrastructure of survey collection and analysis (in our case, the University's Planning and Quality Unit) has allowed us to focus on the content of the evaluation tools rather than the mechanics of survey production and data gathering.
It is particularly important in projects of a short duration that interventions and evaluations occur on a short time scale. Achieving tight timelines is made easier if a principal investigator has a substantial teaching role in a suitable subject (in our case, one of us was the subject coordinator and lecturer).

Events can, and often do, occur that require the project plan to be revised. In our case, two changes that initially appeared to be impediments to the project's progress, were turned into opportunities. One of our overseas principal investigators was appointed into a senior management position and was no longer in a position to run a planned student survey. We adjusted our approach and implemented interviews with laboratory teaching staff with one of the UTS investigators travelling to Cape Town to run the interviews with students and demonstrators. The other change was a move from a conventional laboratory space accommodating 40 students to a 'superlab' accommodating up to 220 students. While the different physical environment of the superlab makes it more difficult to carry out longitudinal comparisons, we took the opportunity to evaluate the impact of the superlab on the delivery of practical classes by adding a superlab-related open-ended question to the student survey. Our preliminary work will be useful to us in adapting our classes to the new environment.

Dissemination

Formal dissemination of the project and its findings has occurred through a range of modes targeting different audiences as shown in Table 2.

Table 2: Modes of dissemination and the corresponding target audience.

Mode	Target
Posting of project background, aim, methodology, findings on the IOLinscience Website. http://www.iolinscience.com.au/demonstrators-students/	University academics, learning developers and designers in Australia and worldwide with an interest in enhancing student/demonstrator interactions, particularly in inquiry-oriented laboratory programs.
Presentation and workshop at the STARS workshop http://unistars.org/docs/STARS_2015-Program.pdf	The broad academic community (i.e. broader than the science community within universities), including academic developers and those that support student transition to university .
Paper at the STARS conference http://www.unistars.org/papers/STARS2015/13F.pdf	University academics, learning developers and designers in Australia and worldwide.
Paper in the European Journal of Physics	The international physics community committed to supporting student learning in universities
Presentation at the ACDS Teaching and Learning Conference (Brisbane, July 2015)	Associate Deans, Teaching and Learning (and equivalent) from science faculties around Australia.
Description of Seed project on the ACDS Teaching and Learning Centre website http://www.acds-tlcc.edu.au/	Academics designing and teaching the undergraduate science curriculum in Australia
Project Fliers	Associate Deans Teaching and Learning
Final project report	Science academics.
Invitations to present in 2015/2016 on the project from Kelly Matthews (University of Queensland), Mauro Morcerino (Curtin University) and Karen Burke da Silva (Flinders University)	Front line full time and casual academics with responsibilities for delivering laboratory programs.

Chapter 4: Lessons learned and future directions

A successful implementation of an inquiry-oriented model of learning in a laboratory requires the experiment designers, demonstrators and students to be ‘on the same page’. Our results indicate that this is not necessarily the case. Students, guided by prior experience and perhaps laboratory classes in concurrent subjects that follow a direct instruction model, do not recognise, or are confused about, the expectations placed on their work and interactions with demonstrators. Demonstrators, either by virtue of personal preference or, more likely, in response to the pressure of keeping to the timelines, deviate from the inquiry model. The laboratory program designers may not be involved in reviewing and modifying the practical class to better fit in with the learning objectives. In overcoming these difficulties, an ongoing practical development process is needed that involves all three parties. Professional development of demonstrators needs to incorporate better communication of the learning objectives and processes consistent with the inquiry-oriented learning. Students’ expectations need to be better managed by involving both the lecturing and the demonstrating staff in the processes of communicating those experiences.

Our study of the effect of the separation (measured in the number of years of formal study) between the demonstrators and the students indicates that, in terms of helpfulness and engendering deeper engagement with the subject matter, the demonstrators with minimum separation (and therefore greater proximity to students in age, background, and academic aspirations) did no worse, and often better, than their more experienced colleagues. The study validates in particular the use of non-physics major peer demonstrators in laboratories for non-physics students. This approach to recruitment offers the potential for improved engagement in such classes, where student motivation tends to be a common concern.

Giving students a role in the design and co-delivery of the curriculum provides exciting opportunities likely to have growing impact on the teaching and learning landscape. It is timely for partnerships between students and academics/curriculum designer of the laboratory curriculum to be engendered and nurtured in higher education. This project has shown that peer demonstrators can effectively support the delivery of the curriculum, but it is time to expand student input and influence. We propose a follow-on project provisionally entitled ‘Students as learners, leaders and architects: reconceptualising curriculum design, development and delivery of student-centred, laboratory-based, activities’. The goal of the project would be to effect systemic enhancement of the student laboratory experience and learning by adapting and expanding existing and emerging work on student-centred curriculum design and delivery, learning outcomes, and the design of new laboratory learning spaces.

Many universities are introducing or are considering introducing large-capacity, multidisciplinary, computer-equipped and internet-enabled science laboratories (sometimes referred to as ‘superlabs’). Because the laboratory classes we studied moved from a traditional laboratory space to the superlab, we have acquired data that allow a preliminary comparison. The superlab cohort is much smaller than the traditional laboratory cohort, reducing the statistical power of the survey instrument. Nevertheless, initial indications are that the transition to the superlab (a) has not adversely affected the indicators of student engagement in an inquiry-based laboratory experience, and (b) students' open-ended responses to a survey item on the "learning experience in the superlab" were generally positive although students commented on difficulties arising from the constraints of the physical architecture of the laboratory. This is an area requiring work in assessing the impact of the superlab architecture on the inquiry model of learning. More generally, a better understanding is required of how to optimise student learning in a superlab, as well as identifying factors that reduce the effectiveness of learning in such a space.

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Appendix A

Certification by Deputy Vice-Chancellor (or equivalent)

I certify that all parts of the final report for this OLT grant provide an accurate representation of the implementation, impact and findings of the project, and that the report is of publishable quality.

Name: ....Date: 17/8/15

Appendix B

Draft of paper in press (February 2016) with the International Journal of Innovation in Science and Mathematics Education (IJISME).

A Comparison of Student and Demonstrator Perceptions of Laboratory-Based, Inquiry-Oriented Learning Experiences

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Keywords: Inquiry-oriented learning, laboratory class, student-demonstrator interactions, contingent instructors, service teaching

Abstract

Effective student-demonstrator interactions attend successful laboratory programs which engage students with the processes and products of science. We report a study on student and demonstrator experiences and perceptions of a physics laboratory program delivered to first year students in a large-enrolment subject for non-physics majors at the University of Technology Sydney. The program comprises experiments promoting learning through inquiry. Neither students nor demonstrators were completely comfortable with the open-ended nature of such experiments. Students expected instructions from demonstrators on how the experiments should be performed, and both students and demonstrators presumed the laboratory manual to offer more detailed instructions on each experiment than it provided. There was a significant and discouraging difference between student and demonstrator perceptions of a) the extent to which the skills developed in the laboratory assisted students in their future career, and b) the contribution that the experiments made to students' understanding of physics.

Implications for practice emerging from this study include the need for academics to better communicate the reasons for an inquiry-oriented approach being adopted and clearer articulation of the expectations of student and demonstrators. Careful scaffolding of activities is necessary if students are to transition from recipe-type experiments to inquiry-oriented experiments. Aligning demonstrator professional training with the underlying philosophy of an inquiry-oriented laboratory program is not sufficient to ensure demonstrators are comfortable with that philosophy, suggesting a deeper consideration of the epistemologies influencing their actions is warranted. It is evident that the materials developed to support both students and demonstrators must undergo regular and critical review.

Introduction

Hands-on, laboratory-based activities are regarded by many science academics as essential elements of an undergraduate degree in science (Kirchner & Meester, 1988; Hofstein & Lunetta, 2003). The nature of those activities has come under scrutiny in recent years, with renewed interest in the place of inquiry-oriented experiments in the undergraduate science curriculum (Cobern, Schuster, Adams, Applegate, Skjold, Undreiu, Loving, & Gobert, 2010; Alkaher & Dolan, 2011; Rayner, Charlotte-Robb, Thompson, & Hughes, 2013).

Through inquiry-oriented experiments, students: engage with scientific questions that have no predetermined answer; develop and implement approaches to address those questions; refine their approaches in order to enhance the quality of their data; gather evidence, and; communicate explanations and conclusions based on that evidence (adapted from Olson & Loucks-Horsley, 2000). Such experiments contrast with the recipe-type experiments that have dominated science curricula for decades (Bless, 1933; Menzie, 1970; Cheary, Gosper, Hazel, & Kirkup, 1995; Kirkup, 2015). A recent revision of the K-12 school science curriculum in Australia has resulted in greater emphasis on scientific inquiry skills (National Curriculum Board, 2009), suggesting students choosing to study science will enter university better prepared to engage in inquiry-oriented experiments, and that the undergraduate science curriculum should be ready to build on this foundation.

Those entering university to study science will likely find themselves in large enrolment subjects in which the diversity of students and the disparities in their readiness for university study has never been greater (Alauddin & Ashman, 2014). Enrolments have been rising in many Australian universities (Norton, 2013) at a time when a greater emphasis on research in these institutions has reduced the involvement of full-time academics in teaching (Lama & Joullie, 2015). One outcome of this is that the support for student learning in science laboratories falls largely, and in some instances wholly, to demonstrators (equivalent to graduate teaching assistants in North America).

Demonstrators are known to have a significant impact on the student experience in the laboratory. Rice, Thomas, & O'Toole (2009; p.65) found that, for many students, '*demonstrators had the power to make a lab. a great or a miserable experience'.* Almost three decades ago it was argued that the lack of progress in laboratory teaching was largely due to the neglect of the human dimension of the undergraduate laboratory, as embodied in student-demonstrator interactions (Pickering, 1988). Despite the importance of demonstrators, little has been written on their influence on the student experience in undergraduate laboratories where the experiments have an inquiry focus (Wyse, Long & Ebert-May, 2014).

A report commissioned by the Australian Council of the Deans of Science (O'Toole, 2012) recognised the importance of the laboratory for promoting authentic, inquiry-oriented learning purposefully advocated by Australia's Chief Scientist (Office of the Chief Scientist, 2012). The report (O'Toole, 2012; p.5) states:

> *The impact of the challenges posed [by inquiry-based learning] justifies investment in the development of demonstrators' competencies, both at the individual and group level, to realise the potential of science teaching laboratories.*

The laboratory may be the only place in the first year of a degree where one-on-one interactions occur between students and their instructors, further accenting the influence laboratory-based activities can have on student attitudes and experiences (French & Russell, 2002).

Background and motivation for this study

The School of Mathematical and Physical Sciences at the University of Technology Sydney (UTS) delivers a first-year physics service subject named Physical Aspects of Nature (PAN) to students enrolling in medical, biological and environmental science degrees at UTS. Total enrolment in PAN in 2014 was close to 700 students. PAN consists of, on average, 3.5 hours of lectures/tutorials each week for 12 weeks, and 2.5 hours a week of laboratory work for 9 weeks. Students work together on experiments in groups of two or three and there are typically 40 students and two demonstrators in each laboratory class. The two demonstrators play significantly different roles in the laboratory. A *principal demonstrator*, who either possesses a PhD in physics or is working towards one, has primary responsibility for managing the laboratory, introducing experiments to the class, assessing students' laboratory-based work and assisting students throughout the laboratory session. An *assistant demonstrator*, who is generally a senior undergraduate or honours student with a more limited physics background than the principal demonstrator, assists students throughout the laboratory session, but has no assessment or organisational responsibilities. Both principal and assistant demonstrator attend a demonstrator training day before the start of the semester where they are advised on the philosophy underpinning the laboratory program, issues to do with each experiment, the assistance available in the laboratory, any safety matters as well as their respective roles and responsibilities. Demonstrators are also supplied with a demonstrator manual giving details of the design and philosophy of the laboratory program, how it links to the subject as a whole, and general advice on running each experiment.

Inquiry-oriented experiments, in which students engage with scientific questions that have no predetermined answer, and take on responsibility for designing an approach to addressing those questions, have been incorporated into PAN since 2001 (Kirkup, Pizzica, Waite, & Srinivasan, 2010). This is reflected in the PAN laboratory manual which advises students:

> *As a result of this laboratory program you will be able to actively participate in scientific activities, experiencing science as a relevant part of your life as opposed to a series of isolated events that happen in a laboratory….. you will be encouraged to think independently and creatively, and develop self confidence in your ability to tackle scientific problems.*
>
> *An inquiry-oriented approach, which is adopted in this laboratory program, opens opportunities for you to obtain first-hand experiences of doing science like practicing*

> *scientists and to develop much sought-after skills to identify and define a problem, formulate a hypothesis, design an experiment, and collect, analyse and interpret data. Learning by inquiry will also allow you to relate and combine information (for example that which you will encounter during lectures) in a way that makes sense to you.*
>
> PAN laboratory manual, UTS, spring 2014

Demonstrators translate and operationalise the intentions of the designers of a laboratory program and communicate those intentions to students (French & Russell, 2002; p. 1040). Inquiry-oriented experiments in which students are given a large measure of control over how they perform an experiment present demonstrators with challenges absent when supervising recipe-type experiments. For example, demonstrators may be required to manage several groups simultaneously taking quite different approaches to carrying out an experiment (Cheary et al. 1995). While much has been written on the design of inquiry-oriented experiments (see, for example, Luckie, Maleszewski, Loznak, & Krha, 2004), less has been written on student and demonstrator views or experiences of such experiments (Wyse et al., 2014).

The research question we wished to explore through this study was: what are the students and demonstrator perceptions and experiences of the PAN laboratory program, and how do the perceptions and experiences compare? We also wished to explore how well PAN students prepare themselves for the inquiry-oriented experiments; the students' and the demonstrators' perceptions of the quality of teaching materials provided to support their learning, and the extent to which students rely on the demonstrators to assist them in carrying out the experiments.

We describe the methods adopted to explore these questions, report on findings of significance, and discuss the implications of the findings for the delivery of an inquiry-oriented laboratory program, the materials to support student learning, and improvements in preparing the demonstrators to work with students carrying out inquiry-oriented experiments.

Method

In spring semester 2014, we surveyed PAN students (N=417 representing 76 % of those enrolled) and their demonstrators (N=18 representing 82 % of all PAN demonstrators). Participants completed a survey consisting of open- and closed-ended statements and questions. The survey items were adapted from previous work (Kirkup, Pizzica, Waite & Mears, 2011) in line with the aims and focus of this study. The student and demonstrator surveys were similar in structure and most survey items were equivalent in order to facilitate comparative analysis. Table 1 lists the survey items. The first 15 items were closed-ended and the last 3 were open-ended. Participants responded to the closed-ended items using a 5-point Likert scale, where: 1=*Strongly disagree*, 2 = *Disagree,* 3 = *Neutral,* 4 = *Agree*, and 5=*Strongly agree*. For item Q1, students were asked to select a frequency from *Never* to *Always* which was reported on a scale of 1 to 5.

Recognizing the different roles of the demonstrators, some items in the survey gave students the opportunity to respond separately with reference to the principal and the assistant demonstrator. The open-ended questions encouraged a short response from students on their views on the demonstrators and on how the PAN laboratory program could be improved. The closed-ended items were clustered into two groups: items 1-10 broadly canvassed the *processes* undertaken in or before the laboratory class whereas the remaining items dealt with *outcomes.*

Table 1: Items presented in the student and demonstrator surveys.

Code	Students	Demonstrators
Q1	Before each lab session, did you read the PAN lab manual?	Most students had read the relevant section of the lab manual before coming to the lab
Q2	The PAN lab manual should contain more detailed instructions for each experiment	The PAN lab manual should contain more detailed instructions for each experiment
Q3	The demonstrators took steps to explain the purpose of the experiments	I took steps to explain the purpose of the experiments
Q4	I was comfortable asking the Principal/ Assistant demonstrator questions about the experiments	Generally, I was comfortable answering questions about the experiment
Q5	The demonstrators were knowledgeable about the experiments	I took the time to prepare for each experiment
Q6	I relied on the demonstrator to tell me how to do the experiments	Most students relied on me to tell them how to do the experiments
Q7	In answering my queries, I found the Principal/Assistant demonstrator to be helpful	
Q8		I explained my role as demonstrator to the PAN students
Q9	I was encouraged to think deeply about the experiments by the Principal/Assistant demonstrator	I asked students questions to encourage them to think deeply about the experiments
Q10	Overall, the demonstrators made an important contribution to my learning in PAN labs	Overall, I think I make an important contribution to enhancing students' learning experience in PAN labs
Q11	PAN experiments increased my understanding of physics	PAN experiments increased the student's understanding of physics
Q12	Physics is an important part of my undergraduate education	Physics is an important part of a PAN student's undergraduate education
Q13	The practical skills I developed in the PAN laboratory will assist me in my future career	The practical skills students developed in the PAN laboratory will assist them in their future careers
Q14		I was able to explain to students the relevance of PAN experiments to their majors
Q15		Generally, students had a positive attitude towards the PAN labs

Q16	Please write a few words on how the demonstrators most helped you in your learning	Please write a few words on what you see as the most important thing you did to help students learn in PAN labs
Q17	In what way(s) could the PAN demonstrators have better supported you in the lab?	In what way(s) could support for students in the PAN lab program be improved?
Q18	Please let us know how the PAN lab program can be improved	Please let us know how the PAN lab program can be improved

Data analysis involved both quantitative and qualitative approaches. A two-tailed t-test was applied to test a null hypothesis that the means of samples were drawn from the same population at the 0.05 significance level (de Winter & Dodou, 2010).

Results and discussion

Of the 417 students and 18 demonstrators surveyed, the response rate was 100 % for the closed-ended questions and over 70 % and 80 % respectively for students and demonstrators to the open-ended items in the survey.

Table 2 provides the mean score (out of a maximum mean score of 5) and the associated standard error for each of the closed-ended survey items. Where the students were asked questions relating separately to the principal (P) and the assistant (A) demonstrator, the mean scores are specified separately. The last column in Table 2 shows the outcome of the t-testing of the null hypothesis.

Table 2: Mean score and standard error for closed-ended items in Table 1.

Item Code	Students (N=417)	Demonstrators (N=18)	Agreement ($p<0.05$)
Q1	3.40±0.07	3.06±0.24	N
Q2	3.91±0.05	3.88±0.19	Y
Q3	3.92±0.04	4.33±0.11	N
Q4	4.08±0.05 (P)	4.17±0.15	Y
	4.21±0.04 (A)		Y
Q5	4.17±0.04	4.33±0.14	Y
Q6	3.37±0.05	3.78±0.19	Y
Q7	3.96±0.05 (P)		
	4.02±0.05 (A)		
Q8		3.89±0.14	
Q9	3.58±0.05 (P)	4.22±0.13	N
	3.56±0.05 (A)		N
Q10	3.92±0.04	4.00±0.16	Y
Q11	3.55±0.05	4.00±0.08	N
Q12	3.13±0.05	4.33±0.14	N
Q13	3.21±0.05	4.28±0.16	N
Q14		3.67±0.19	
Q15		3.44±0.23	

Analysis of the open-ended questions involved a qualitative approach. A process of constant comparison for recurring words and emerging patterns (Lincoln & Guba, 1985) and open coding (Strauss & Corbin, 1990; Wiersma & Jurs, 2005) was used to categorise the data. The responses for each item were analysed, following a process of data organisation, data reduction, coding and categorisation. The results of the analysis were used to relate the open- to the closed-ended responses.

Examining the pattern of agreement between the student and demonstrator mean responses of Table 2, agreement is greatest for the process-related items (1-10). By contrast, disagreement occurs consistently for the outcome items (11-13).

With regard to the outcome items, the demonstrators as a group were more positive about the value of the laboratory class to the students than the students themselves. Demonstrators strongly supported the proposition that students’ understanding of physics was enhanced (Q11), that the practical skills learned in the laboratory would assist the students in the future (Q13) and that physics formed an important part of a student’s education (Q12). Students’ mean responses to the same items were significantly lower, tending towards the neutral response. Only 39 % of students surveyed agreed or strongly agreed that physics was an important part of their undergraduate education (Q12) and a similar percentage (43 %) of students agreed or strongly agreed that the practical skills developed in the laboratory would help them in their future career (Q13).

Some degree of bias on the part of the demonstrators as the active agents of the laboratory program may be anticipated. Their responses might have been informed by factors possibly not known to, or appreciated by, the students. For example, the demonstrators might have a greater awareness of where and how the knowledge and skills acquired in the laboratory class would fit into a student’s later studies. Additionally, the demonstrators did not believe that students regarded the laboratories highly (Q15) with only 45 % agreeing or strongly agreeing that ‘generally, students had a positive attitude towards the PAN labs’.

With reference to the process-related questions, it is worth reiterating that the laboratory program emphasised learning through inquiry (Kirkup et al., 2010). On the scale of the inquiry continuum, much of the experimental work falls into the ’guided inquiry’’ level (Boud, Dunne, & Hegarty-Hazel, 1989; Banchi & Bell, 2008), where the research question is posed to students but neither the procedure nor the outcome are specified. This contrasts with the `verification inquiry’ or ‘recipe-type’ experiments where the procedure is specified and the outcome (for example, the value of the gravitational acceleration) is known in advance (or can be ascertained easily).

Two major issues emerged from the survey: one relates to the laboratory manual, the other to students’ dependency on the demonstrators.

Laboratory manual: expectations and experiences

Consistent with learning through inquiry, the PAN laboratory manual does not provide detailed descriptions of experimental procedures. This was seen as a deficiency. As shown

in Table 2, the demonstrators and the students on average agreed that the laboratory manual ‘should contain more detailed instructions’ (Q2). This shared view was also confirmed in the open-ended responses to Q18, which sought ideas for improvements to the PAN laboratory program. Of those who responded to Q18, 20 % of the students and over 50 % of demonstrators made reference to the laboratory manual. Students remarked that “*instructions* (were*) very unclear”* and referred to *“confusion and ambiguity in the manual”,* while demonstrators described the manual as “*vague”,* causing the students to become *“frustrated with the experiments”.* Demonstrators suggested that, in future versions, the laboratory manual should have the instructions “*clearly set out”* and should specify a “*clear aim for each experiment”*.
Student-demonstrator agreement about shortcomings of the laboratory manual implies that neither the students nor the demonstrators were comfortable with sparsely-scripted laboratory instructions. The perception of lack of detail and clarity in the laboratory manual can also have a bearing on whether the manual was read or not before each class (response to Q1) though there is some level of disagreement between student and demonstrators, with the latter of the opinion that students did not read the manual before each class. Challenges pertaining to the laboratory manual may also have contributed to the type of help sought by students from their demonstrators, as noted by some students in their responses “*[demonstrators should] run through each experiment more thoroughly*”.

Students’ dependency on demonstrators

Demonstrators’ response to Q6 (3.78 ± 0.19) suggest that they believe students rely on them to tell them how to proceed with experiments, which is indicative of students’ expectation of a direct instruction model in their interactions with the demonstrators (Boud et al., 1989). About 30 % of students who responded to the open-ended item (Q16) described the practical ways in which demonstrators helped them by outlining the steps involved in the process. Students were “*assisted in simplifying the experiment”*, “*helped with calculations”,* shown *“how to set up graphs”,* and instructed on *“what to do with data in the end”.* They relied on their demonstrators for “*explaining things when stuck with experiments”* and acknowledged that the demonstrators were “*helpful in explaining and demonstrating experiments”*.

Requesting assistance on how to ‘set up graphs’ is not inconsistent with students engaging in inquiry, as plotting graphs is a skill demanded in both recipe-type and inquiry-oriented experiments. On the other hand, where students describe demonstrator’s assistance as *“demonstrating experiments”*, this is more indicative of direct intervention by the demonstrator to assist students to reach a specific endpoint characteristic of recipe-type experiments.

Demonstrators, too, noted that they helped students to complete their tasks, taught them “*improvement in lab techniques”, “plotting”, “graphs”,* and (the meaning of technical) *“terms”.* Such assistance suggests that demonstrators are adopting a direct instruction approach rather than a facilitative approach favoured when learning through inquiry (Kirkup, Johnson, Hazel, Cheary, Green, Swift, & Holliday, 1998). Most demonstrators referred to encouraging the students to “*think deeply”* about the experiments, “*encouraging* [students] *to go beyond what was stated”*, and were happy to “*discuss the underlying physics”*. Such views were as prevalent among the assistant demonstrators as among the principal demonstrators despite the former having had a typically shorter exposure to the physics discipline. The open-ended responses are consistent with the demonstrators' response to the closed-ended item Q9 (4.22 ± 0.13), with all demonstrators but one agreeing with the statement 'I asked students questions to encourage them to think deeply about the experiments'. The student mean score for Q9 was much less (3.56 ± 0.05 for assistants and 3.58 ± 0.05 for principal demonstrators), with just over half the respondents agreeing or strongly agreeing with the statement 'I was encouraged to think deeply about the experiments by the (principal/assistant) demonstrator'. In response to Q16, some students appear to have accepted the proposition of deeper engagement, with 23 % commenting that demonstrators helped them *"understand the reasoning behind the experiment"* or acting to *"challenge my methods"*.

The data suggest a dichotomy between the learning model implicitly assumed by the students and that adopted by the demonstrators. The relatively low score for Q8 (3.89±0.14), which examines whether the demonstrators explained their role in the class, suggests that in many cases students were not appraised in advance of what the mode of learning and interaction with the demonstrators would be, thus contributing to the dichotomy. Students' prior experience with experimental work at school, and in the concurrent subjects, might well have followed the verification or structured model of learning. Managing students' expectations in an inquiry-oriented experiment emerges therefore as an important prerequisite for an effective learning experience.

The demonstrators were perceived as approachable (Q4), which is a precursor to deeper interaction with the students (Kendall & Schussler, 2012). This is also reiterated in the open ended response (Q16) where 31% of students chose to describe the attributes or qualities of their demonstrators and how this helped them in their learning. For example, students referred to the demonstrators as being "*easily approachable"*, "*able to communicate well"* and had "*different ways of explaining"* that "*helped make the subject more comfortable"*. Furthermore, both the students and the demonstrators agreed with the proposition that the latter enhanced students' learning experience (Q10). The student response to Q4 differentiated between the principal and assistant demonstrators, with the latter being perceived to be more approachable (at the 0.05 significance level). A comparison of students' perceptions of different categories of demonstrators is examined elsewhere (Braun & Kirkup, 2016).

Preparedness for inquiry-oriented experimentation

Depending on the nature of a particular inquiry-oriented experiment and its educational purpose, students may require a firm grasp of the principles underpinning the phenomena they are investigating particularly if they are required to reconcile and compare their experimental findings with theoretical predictions (Etkina, Karelina, Ruibal-Villsenor, Rosengrant, Jordan, & Hmelo-Silver, 2010). Background preparation of students to carry out their experiments is canvassed in Q1. The average rate with which the students admitted to have prepared for the class by reading the laboratory manual corresponded most closely to *often*. The demonstrators, however, tended not to rate the students' preparation highly, as evidenced by a score of (3.06±0.24) for item Q1. In the open-ended responses to Q17, students stated they would like the demonstrators to "*expand on the theoretical understanding"* and provide a "*clearer discussion of what the results are meant to show in* *relation to physics theory"*. Depending on the breadth and depth of the "*discussion"*, this suggests that the students expect the demonstrators to cover the theoretical background to the experiments thus supplanting students' own preparation. Almost 30 % of respondents wanted "*more explanation"* and "*more detail"* regarding the experiment and about 18 % expressed the need for "*effective communication"* of the laboratory's aims by the demonstrators.

The demonstrators asserted that they prepared for each class and as a result, we conjecture, were perceived by students to be knowledgeable about the experiments, with a score for item Q5 of (4.17±0.04). Where students, with the assistance of demonstrators, better appreciate the relevance of the activity to their major area of study, this leads to deeper students' motivation and engagement (Bruck & Towns, 2009). An ambivalent demonstrators' response to Q14 signifies that the students were not necessarily introduced by the demonstrators to the broader context and relevance of the experiments. There may be a variety of factors responsible, including some demonstrators' lesser familiarity with the students' majors, the notion that this is dealt with elsewhere (for example in the prework or in lectures leading up to an experiment) and varying personal beliefs about the value of such relevance.

Differences between corresponding responses from the students and the demonstrators have parallels in the literature. Herrington & Nakhleh (2003) found that while students and teaching assistants (TAs) agreed on what made for an effective TA, there were differences. For example, with regard to TAs 'encouraging students to ask question or express opinions', students ranked this 17th, out of 17 characteristics, while TAs ranked this as 10th out of 17. This was attributed to students placing greater value on a demonstrator's knowledge of the experiment as exemplified by "*[the TA] explains and demonstrates the experiment"* than on a TA's affective domain qualities, such as "*[the TA] motivates students to do their best in the lab"*.

Teacher-student response differences to aspects of engagement were recently investigated by Zepke et al., (2014). The differences may be ascribed to different backgrounds and, more specifically, to different epistemological approaches (Roth, 1994). In the context of a laboratory, such discrepancies were noted by Kirkup et al., (2010). The effect of the background of the demonstrators on student-demonstrator interaction has been the subject of recent investigations (Kirkup, Varadharajan, Braun, Buffler, & Lubben, 2015).

Implications for practice

The survey analysis detected a discrepancy in the learning models implicitly adopted by demonstrators and students and implicated it as a possible impediment to a more effective implementation of an inquiry-oriented model of learning in the laboratory. To assist in overcoming this discrepancy there needs to be improved management of student expectations (Bruck & Towns, 2009), as the students' previous and concurrent experience in the laboratory can subvert the inquiry model. It falls primarily to the demonstrators, as the instructors in the laboratory, to inculcate in the students' minds the expectations of the respective roles of students and demonstrators and their interactions demanded by the inquiry-oriented model. Effective management of student expectations should form a part of demonstrators’ professional development. The subject coordinator or convenor must also reinforce the message that the students will be given more scope and responsibility to design and carry out experiments than they are used to. Moreover, other teaching staff can assist in outlining the inquiry-oriented laboratory model in their interactions with students. The assumption that students can smoothly transition into the inquiry-oriented model is evidently not justified and better designed scaffolding should be considered. There are indications in the survey data of aspects of the laboratory where the inquiry model has not been fully embraced by the demonstrators. This points to the need for further assistance to the demonstrators in the form of tailored professional development courses, just-in-time support for each experiment as well as ongoing monitoring and feedback. Interaction between academic staff responsible for the laboratory program and the demonstrators, just prior to the laboratory session, would allow for advice to be given on how the activity links with other elements of the subject and, more broadly, with the students’ majors. Pre-laboratory consultations would also provide an opportunity to emphasise the importance of interacting with students consistent with the inquiry-oriented model, and encourage student to student, and student to demonstrator communication.

Most of the experiments in the PAN laboratory were carried out in a single session, i.e. they did not carry over more than one week. It is possible that this restricted the extent to which students took charge of their learning. For example, as students were given a modest amount of time to think about how they should proceed with their experiments this possibly led to a greater reliance in the demonstrator to guide them through the experiment, hence favouring a direct instruction approach. A comparison of student and demonstrator experiences with inquiry-oriented experiments carried out over two or more weeks, allowing time for students to take more control of their actions could form the basis of a valuable study.

This study focussed on student and demonstrator experiences and perceptions of an inquiry-oriented laboratory program in a large-enrolment physics service subject. There would be value in carrying out a comparable study in a similar service subject which has a laboratory program dominated by recipe-type experiments to explore whether the type of experiment impacts on students perceptions of the experiment and the interactions with the demonstrators.

Conclusions

Many academics hold the conviction that inquiry-oriented activities so naturally mimic those of scientists that the experiences of students undertaking inquiry-oriented experiments will: a) be more engaging than those offered by recipe-type experiments and b) develop capacities of continuous and sustained value, irrespective of their career trajectory. This study points to a number of issues that can act to frustrate the promise of inquiry-oriented laboratory programs, including: students not being well prepared to undertake inquiry-oriented experiments, leading to a reliance on the laboratory manual and on demonstrators to direct them in their actions; the students’ view that the skills they develop in the laboratory will not assist them in their future career, and the students’ lack of belief that knowledge of physics itself is an important part of their education. This latter concern is unlikely to be addressed effectively by a laboratory program in isolation from the rest of the curriculum.

We have found significant differences between students' and demonstrators' perceptions of interactions in the PAN laboratory. Overall, the demonstrators appear to follow the precepts of the inquiry-oriented model of learning although there are indications that they may be uncomfortable with some of the consequences flowing from the adoption of the model. The prevailing model adopted by the students is that of direct instruction although there are indications of the recognition of deeper level engagement in their interactions with the demonstrators. The dichotomy of the adopted models has the potential to frustrate students and hamper their achievements in the class. There appear to be multiple reasons for the dichotomy including inadequately managed expectations, lack of conviction in the validity of the inquiry model and prevalence of direct instruction model in students' prior and concurrent laboratory experience.

The surveys carried out as part of this study were not able to delve deeply into issues that impact student and demonstrator views of inquiry-oriented laboratories. An example is the effect of alignment between the background, ambitions, and views on teaching and learning of students and their demonstrators on student engagement and satisfaction. To address such issues, we need to explore in more detail demonstrators' and students' views about learning and teaching in the physics laboratory, and the ways these views impact on the attitudes of both groups towards inquiry-oriented laboratory experiments. A study is currently underway involving structured interviews with students and demonstrators to explore and elaborate on these issues.

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