ALTC Associate Fellowship Report

New perspectives on service teaching: tapping into the student experience

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Executive summary

Physics service subjects impact on thousands of students annually in Australia, affecting attitudes towards physics, student retention and the economic viability of the majority of physics departments. How a physics subject may be best developed for non-physics majors in order to enhance student learning, engagement and the sense of relevance to students’ contemporary and future needs, is seldom given the attention it deserves.

The goal of this Fellowship was to develop an effective approach to the curriculum development of physics subjects designed for non-physics majors in order to enhance student engagement and learning, and which is sensitive to the future needs of students. This was accomplished by directly tapping into the student experience of the undergraduate curriculum, for example, by attendance at lectures and laboratories in the ‘serviced’ disciplines, as well as through surveys, interviews and reviewing course materials available to students in an online environment.

The focal point of much of the Fellowship was a large enrolment first year physics service subject at the University of Technology, Sydney, allowing approaches to examining the student experience to be evaluated, as well the trialling of innovations designed to enhance that experience.

Several key insights emerged during the Fellowship: attendance (and participation in) at lectures and laboratories allowed me to experience, firsthand, the cultures and conventions of the other disciplines as experienced by new students. This gave me a critical perspective on the challenges facing students as they navigate their way through an undergraduate science degree. One of the tangible outcomes has been to incorporate material within the physics service subject drawn directly from other subjects. This material was derived (with permission) from slides, handouts and other documents provided by academics to students during the semester. Incorporating such material brings emphasis to the utility of physics and its relationships to students’ other studies.

A particular issue that emerged through this Fellowship relates to the laboratory experiences of students within physics service subjects. The laboratory is a key learning environment in science, accounting for up to 50% of the formal contact time of a subject. Through surveys of recently completed students, as well as of those that had enrolled in the subject in earlier years, students expressed the view that the physics laboratory was not a positive learning experience. This finding was also echoed in two other recent ALTC-funded projects. A significant proportion of this Fellowship was devoted to examining the student experience and, in particular, creating (as well as implementing and evaluating) a versatile template of local and national value that could be used to develop a physics laboratory program. The template was designed to assist in the development of a whole laboratory program, giving special attention to the objectives of the program, the educational analysis of experiments, and demonstrator support. Attachments 3 and 4 of this report describe the template in detail, its purpose, and how it may be implemented.

The significant outcomes of this Fellowship include creating a framework for laboratory work that effectively engages non-physics majors. The framework and the template that accompanies it draw on the student experience in laboratories, lectures and online environments. This work has been (and is being) disseminated nationally through: non-refereed and refereed papers, and invitations to present the work to academics at The Australian National University, Curtin University of Technology, La Trobe University, The University of Queensland, The University of Sydney, and the University of the West of Scotland in the UK.
Outcomes

Much of the work of this Fellowship was carried out as a case study whose goal was to enhance student learning experiences and student engagement in the UTS first year physics subject ‘Physical Aspects of Nature’ (PAN). PAN has an annual enrolment of \( \approx 500 \) students drawn from the Medical, Environmental and Biological (MEB) sciences.

This Fellowship was designed to achieve the following outcomes:

1. **Framework for service teaching enhancement with emphasis on student laboratory experiences**

   This study has institutional and national significance and influence through the creation of a template and a framework for improving the quality service teaching in the area of laboratory experiences designed for non-physics majors. This framework, and the case study that informed it, was communicated through workshops organised by the ALTC, national gatherings of the physics community at UniServe conferences and the Australian Institute of Physics (AIP) Congress, and through invitations to present the work at universities around Australia. The involvement of academics in evaluating the framework led to its enhancement and practical dissemination.

2. **A map of associations between first year physics and second and third year science subjects**

   Key findings of this study including recommendations for a viable framework for service subject laboratory development have been communicated to academics within UTS. Seminars detailing the findings of the Fellowship were given within UTS through the vehicle of the UTS Teaching and Learning Forums in 2007 and 2008. An update of progress is anticipated to be delivered to the UTS community at the 2009 Teaching and Learning Forum.

3. **Re-evaluation and revitalisation of an existing physics service subject acting as a good practice example**

   A key outcome of this Fellowship was the re-evaluation of the impact of PAN on students from the MEB sciences. The revitalisation of PAN began with a review of objectives, contexts and content. In particular, the reconsideration of the value of physics laboratories to MEB students led to a substantial redevelopment of the PAN laboratory program. Prototype experiments were developed and trialled as part of this Fellowship using the framework and template described in this report.

4. **Dissemination of Fellowship findings through national conferences and peer-reviewed papers**

   Findings of this project were disseminated at conferences at Curtin University of Technology (2008), peer reviewed papers at Uniserve Conferences (2007 and 2008) and the AIP congress (2008) and a Teaching and Learning Conference at the University of the West of Scotland (2009).
Approach and methodology

A case study based around a large enrolment physics service subject at UTS, Physical Aspects of Nature (PAN) was a key element in achieving the goals of reviewing and enhancing the design, delivery and evaluation of service subjects. Early in the data gathering and analysis phase it became apparent that students’ laboratory experience in PAN was a significant factor affecting their engagement and special attention was paid to this. In effect, the development of a framework and template for laboratory enhancement became a ‘case study within a case study’. The methodology adopted for reviewing and enhancing the laboratory experience of students will also be described here.

Part I: Methodology for review and renewal of a physics service subject

Examination of valued Graduate Attributes
A subject-based initiative to improve student learning and engagement has an improved chance of success if it is in harmony with the strategic directions of the department, unit or faculty in which the subject is embedded. To this end, I contributed to the development and mapping of desired science graduate attributes within the UTS Faculty of Science in 2007–2008. This allowed the local outcomes of this Fellowship to be shaped in ways of strategic value to the Faculty.

Review of relevant literature
The process of review and renewal is enhanced if it is informed by credible and well established research into learning and teaching. A literature search was undertaken that considered the creation of student-centred activities in order to enhance learning and engagement. This allowed any proposed curriculum development (for example within the context of the laboratory) to be appraised in light of established good practice1.

Examination of relationships with serviced disciplines
Synergies between PAN and the disciplines it services were probed through attending first, second and third year subjects which have a natural dependence on physical principles. To an extent this approach leant on an emerging educational methodology, ‘Design-based research,’ through which a better understanding of student learning may be derived from hands-on enquiry in authentic settings, such as the classroom or laboratory in which learning is designed to take place. In order to be better informed of the student experience (for example of the culture or conventions) of other subjects studied in parallel with PAN, I participated in first year subjects taken by students enrolled in PAN.

Subject review and stakeholder perspectives
I employed a range of methods to review other subjects taken by PAN students in order to establish

1 Though a detailed literature review is not included here, it is worth mentioning a publication co-written by ALTC Senior Fellow, Professor David Boud (from the University of Technology, Sydney), to emerge from an Australian Universities Teaching Committee funded project ‘Information and Communication Technologies and their Role in Flexible Learning’ co-led by ALTC Fellow Professor Ron Oliver (from Edith Cowan University). This publication assisted me greatly as I reviewed the value of learning activities developed as part of this Fellowship. That publication is Appraising New Technologies for Learning: A Framework for Development (2002) by Boud D and Prosser M in Educational Media International, volume 39, number 3, pages 237-245.
lecturers’ ambitions for those subjects, and where those ambitions might intersect with the support that could be offered within PAN. Methods included formal interviews, direct observation, participation in classroom activities and discussions, and analysing subject documents. In order to assess the impact of a physics service subject, a survey was created to examine the expectations of students in PAN at the start of semester (for example of the perceived value of PAN to their whole degree). A complementary survey was devised and administered at the end of semester to assess the students’ experiences of PAN. One purpose of the survey was to identify issues that may affect student learning or engagement in the service subject. A survey was also devised and administered to senior students (i.e. students in the second and third year of study) asking them to reflect back on their experiences of PAN. This was done to establish whether themes emerging from the comments of students who had just completed PAN were also apparent in the responses of senior students. The surveys can be found in attachment 1 of this report.

Subject renewal actions and dissemination of findings
The evaluation of surveys, interviews, teaching materials and experiences of participating in lectures and laboratories led to advice and action to renew a service subject (using PAN as a case study) and to the dissemination of findings at local workshops, learning and teaching forums, and seminars as well as at national conferences.

Part II: Methodology for developing a template for laboratory program enhancement in a service subject

Background
The expectations/experiences survey administered to first year students, as well as surveys administered to senior students indicated that the laboratory in PAN was not viewed as a positive learning experience. If this finding had been limited to PAN then perhaps no special attention would have been paid to it. Due to the fact that the value of the expectations/experiences surveys mentioned above was recognised beyond the Fellowship, the surveys were administered nationally to 22 Australian physics departments that teach physics as a service subject. Alarmingly, similar findings regarding the negative impact of laboratory programs in physics service subjects were revealed. A more general study on laboratory work in undergraduate science degrees carried out by the Australian Council of Deans of Science (ACDS), supported by an ALTC grant, found a disturbing lack of consideration was being given to the role and value of laboratory work. For these reasons, extra emphasis was given in this Fellowship to laboratory work in physics service subjects. In particular, consideration was given to the support that could be provided to those committed to improving the laboratory experience for students taking physics service subjects.

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The initial stage involved drawing together literature on good practice in the development of science laboratory programs. Through firsthand experience of the disciplines obtained through participation on lectures, labs etc, areas were identified that would offer rich opportunities to link physics laboratories to the majors from which the students were drawn.

To assist the development of the template, stakeholders engaged directly with the development of experiments. A student-centred approach dominated the development process. A broad range of stakeholders were invited to be part of the process of enhancing the laboratory program. These stakeholders included former PAN students, demonstrators, and academics from the Department of Physics and Advanced Materials, academics from the MEB science disciplines, and teaching and learning specialists at UTS. Evaluation of the experiment at several stages was a feature of the development. Figure 1 indicates the framework used to trial and evaluate individual experiments.

As the process of developing a particular experiment continued, the challenges faced and findings obtained from stakeholders through stages 1 to 4 in Figure 1 were used to amend, and in some cases transform, the experiment. More importantly, the feedback obtained from stakeholders along with reflections on the larger value of the template, informed essential amendments to the template, so that it:

- is inclusive enough to allow for the development of whole laboratory programs as well as of the creation individual experiments;

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4 A focus was brought to the educational analysis of the experiments and was influenced by Buntine et al. (see for example, Buntine M A, Read J R, Barrie A C, Bucat R B, Crisp G T, George A V, Jamie IM, Kable S H (2007) Advancing Chemistry by Enhancing Learning in the Laboratory (ACELL) Chemistry Education Research and Practice 8 (2) 232-254).
• is flexible enough to apply to the development of laboratory programs for physics service subjects and physics ‘main stream’ subjects;
• is applicable to any level of subject from first to final year undergraduate;
• illustrates, through a specific example, how the template could be actually be employed in practice.

An essential part of the process of developing the template involved inviting academics from several Australian universities to critically assess it. The benefits of such an involvement are two-fold: feedback allows the template to be revised to enhance its value to the sector; and engaging with the project in such a manner allowed for effective dissemination of the goals, methods and outcomes of the Fellowship.

**Using and advancing existing knowledge**

This project builds on prior work carried out in physics service teaching. A detailed description of the issues surrounding physics service teaching and drivers for change in such service teaching in Australia can be found in Kirkup et al. 2007. This Fellowship builds on the earlier work by articulating, implementing and embedding an approach to the review and revitalisation of a service subject which takes a student-centred approach. It does this by placing the academic in the position of the student attending lectures, accessing material online and carrying out experiments in the laboratory. While subject outlines assist in providing an overview of a subject, they cannot communicate the nuances, priorities, prejudices and values of the academics who lecture the subject, or demonstrators who support students in laboratories. This Fellowship puts an academic in the ‘thick of things’ allowing a special perspective that can be used to support the revitalisation of a service subject.

Laboratory developments often begin with good ideas for an experiment. Those ideas may have an appeal from a physics viewpoint, but it is unusual for experiments to be created by asking first where that experiment might fit in to the education of a student who will not major in physics. Too often experiments are transferred from one context (say for students majoring in physics) to another (for students not intending to major in physics) without examining the relevance of the experiment to the new audience and what impact the experiment might have on student learning or attitudes.

This Fellowship has allowed a quite new approach to emerge to the creation of laboratory programs designed for students not majoring in physics. A template acted to guide the process of development of a laboratory program, and was used to develop a new experiment. Experience gained in applying the template was instrumental in its revision. This approach lessened the chance of transferring ‘literature-
based,’ but sometimes impractical, solutions to laboratory program development, which may underestimate the challenges of developing and embedding laboratory programs. The use of senior students and demonstrators working together to trial prototype experiments was particularly valuable, not only for identifying issues to be dealt with before an experiment goes ‘live’ with its intended audience, but also in providing a rich source professional development opportunities for demonstrators.

**Relationship to program priorities**

The Fellowship program priorities/goals can be expressed as:

- **enhancing learning and teaching in their home institution and beyond**
  
  Through this Fellowship I have brought a focus to service teaching within my own institution and beyond. The materials created (for example a template for the design of a physics laboratory program) have impacted positively on enhancing the student experience. The adaptability of the template and the whole framework for laboratory development promises to support other ALTC initiatives (such as those designed to broaden the scope of the ACELL process). The fact that academics from other institutions are keen to apply the findings of this Fellowship within their own institutions further supports the value of this Fellowship program.

- **identifying and addressing learning and teaching issues within or across disciplines**
  
  Early work on this Fellowship to assess the expectations and experiences of students led to the development of surveys which were effective at isolating issues of local importance (with respect to physics service teaching). The transference of the survey to a national platform through the recent ALTC funded project ‘Forging New Directions in Physics Education’ revealed similar issues requiring urgent action.

- **showing leadership to promote and enhance learning and teaching within their home institution and beyond**
  
  This Fellowship accorded me a profile within my institution that has promoted (and hopefully enhanced) learning and teaching at UTS. During the Fellowship period I have shown leadership by heading an interdisciplinary team which attracted Learning and Teaching Performance Fund money to create an innovative science communications activity for students enrolled in a physics service subject. Beyond my institution my learning and teaching leadership has been recognised through invitations to give keynote presentations on my Fellowship at ANU and the University of the West of Scotland.

- **establish and build on national partnerships within the context of the above**
  
  There exists a robust network of physics academics committed to learning and teaching. This network has been built up over several years and is not something I created. However, through my Fellowship activities I believe I have strengthened and extended the network of active tertiary physics academics dedicated to learning and teaching. I have been effective in involving younger academics nationally who can lead the physics community in future learning and teaching initiatives.
• foster networks with recipients of ALTC Teaching Awards, ALTC Fellows and other educators in higher education

I have developed close working relationships with other ALTC Fellows to the benefit of my own Fellowship and the other learning and teaching work I do. There has been a two-way benefit with ideas and advice that I have offered benefitting their work.

The Fellowship Experience

As a consequence of the ALTC Fellowship, my career as an academic at UTS has undergone a significant alteration in trajectory. The networking that has been a natural part of the Fellowship has allowed me to work with academics within and beyond my discipline such that I have contributed to their work in a meaningful way and they, in turn, have had a significant and sustained effect on my own work. An excellent example of this is the close cooperation that has occurred with another ALTC Fellow, Dr Roger Moni of Griffith University. This cooperation led me to re-evaluate aspects of the curriculum delivered to non-physics majors (especially in the area of science communication) and resulted in the adoption and adaptation of innovations spear-headed by Roger which are designed to enhance students’ science communication skills.

The networking that occurred through working with the ALTC has resulted in initiatives from my Fellowship having influence elsewhere, particularly in the area of laboratory program development for non-physics majors. I am participating in a project currently funded by the ALTC, A threshold concepts focus to curriculum design (led by Associate Professor Gerlese Åkerlind from ANU), and in a number of projects involving a range of institutions seeking future ALTC funding.

The exposure received by the work carried out with ALTC funding has resulted in invitations to present my work nationally, and more recently, internationally. Recognition of this work within the community of physics educators in Australia has increased dramatically in the last 18 months to two years – I would say largely due to this Fellowship, but also as a result of other ALTC funded projects to which I have contributed. An example of this is a recent invitation from Dr Kate Wilson (recently of the Physics department at ANU) to write an article on facets of laboratory work for a publication read by those who coach students for the International Physics Olympiad.

Recognition of my work within my own institution has also increased dramatically over the past two years. I am confident that this Fellowship will lead to further productive collaborations (both within my own institution, and nationally) over the next few years.

Increased recognition is not without its challenges, as invitations to lead initiatives or chair committees within my own institution have increased during the period of the Fellowship. Balancing Fellowship and non-Fellowship activities is an issue that future applicants for ALTC Fellowships should take seriously.
Factors critical to the success of the Fellowship

It might be extreme to characterise the following factors as ‘critical’ to the success of my Fellowship, though they all had important roles to play.

- Involvement of Learning and Teaching specialists: This took several forms; direct input through criticism of materials being developed (for example the ‘expectations/experiences surveys’), running of focus groups and support in analysing findings. Less direct input occurred through informal discussions about the progress of the Fellowship and through suggestions for future directions (for example focussing on the importance of professional development of casual demonstrators).

- Cooperation of fellow academics in science at UTS: In fact, I experienced more than cooperation: many academics were enthusiastic about the Fellowship and welcomed me into their classes, to the extent that they involved me directly with what they were doing. This was not always advantageous to the Fellowship aims, as I was unable to remain anonymous when I was singled out by a lecturer to participate in explanations or discussions. I did, however, find the experience enormously enjoyable. Some lecturers asked me to review their teaching and give them feedback. I emphasised that the purpose of my attendance was not to review their teaching, but I found it difficult to refuse as they had responded so enthusiastically to my requests to be part of their classes.

- Involvement of students in surveys, focus groups and in trialling experiments: The student input was vital to moderate some of my more unworkable ideas and helped to assess the success of the Fellowship.

- Teaching relief: Without this I would not have had the time to participate in classroom activities, laboratories etc., and would have had little time to reflect on what I had seen or heard.

- Starting the Fellowship before the due date: This allowed me to do some preliminary work so that I ‘hit the ground running’ as the project began in earnest.

- Feedback from other ALTC Fellows: The ALTC forums and workshops (both Fellowship-related and those related to other ALTC projects) allowed me to benchmark my progress and run ideas past Fellows in a mutually supportive environment.

Impediments

- It is not easy to stand-down from some commitments and I felt I never got the hang of saying ‘no’. This robs you of time.

- The fact that I am a Fellow significantly raised my profile in the Faculty and University to the extent that I was invited onto quite important committees. Balancing the value of such contribution to the University against its impact on the Fellowship goals is a challenge.
Outcomes amenable to implementation elsewhere

A main feature of this Fellowship is a case study based around a large enrolment physics service subject at UTS. While many of the ideas have been trialled on UTS students, the materials created and the approaches adopted were designed to be of value beyond physics and beyond UTS.

The framework and template created for the development of a laboratory program have been designed to be adaptable to contexts beyond UTS and have been reviewed by academics at several universities. As examples of independent commentary of the value of the Fellowship outcomes, with particular reference to the template for laboratory development:

*Overall – [the template has] good features: mainly the stuff at the start which encourages people to think about the purpose and philosophy of their labs. Giving a couple of examples with it could really help people, especially if they were quite different - if someone was putting together a lab program it would be very handy, but I think some "inculcation" into physics education would be necessary so they didn't misuse it.*

*Bad features - very time consuming to actually do - I don’t see how the individual experiment section deals with the concerns raised [elsewhere] – that it works well for simple labs but not open ended or project stuff.*

Physics academic recently employed by a GO8 university

*Thanks for the opportunity to look at the work you have been doing on physics labs. I think this is excellent. What I particularly like is your emphasis on the program of activity rather than just individual experiments. I think this is an important extension to the ACELL philosophy and is something that needs to be incorporated into ACELL and ASELL (Science). This also brings up an issue I thought was lacking a bit in the ACELL documentation about why particular experiments are chosen for a lab program in the first place; what is the relationship between the different experiments in a program and how does it all fit together? What is now needed is some documentation about evaluating the program of activities and how students and staff perceive the whole lab program, in addition to the individual experiments. So an educational template, like your [section] 2.4, for the lab program would be an important addition. I like your section on the philosophy of the program and the relationship to graduate capabilities.*

ALTC Fellow

*Excellent. [This is a] template for the rest of us in future developments in our laboratories. Demonstrators’ discomfiture with stepping back and being less directive has been reported occasionally elsewhere. Important that we realise the teachers and their skills are critical to the success of innovative approaches.*

Anonymous referee response to peer-reviewed paper describing the template
This is a powerful, pedagogically sound, and user-friendly template. However I would like to see more consideration given to how the template could be used by academics in departments which already have established physics laboratory programs, but now wish to update and invigorate it. As it stands, the template is most useful to someone devising a laboratory program from scratch, but in Australia this would be rare. A modification of the template, for people wishing to update their departmental teaching labs, would offer a coherent framework for laboratory development (in most places, lab development has been too piecemeal). I look forward to a published version of your template and I believe it could be used widely in Australia and internationally! I also recommend you consider reframing it for any lab program in sciences in general, not just physics, as I believe the same principles will still apply.

Senior physics academic at ATN university

[This template] makes [academics] think explicitly about what they want the program to achieve, & hence what they should do to achieve it. (Rather than cobbling together an assortment of experiments that are judged "good" for various reasons. This is an exaggeration, but I think you’ll get the picture.) i.e.: There is a framework for doing the developing. At [my university] we are talking about doing a review of all the experiments we offer at first-year; I think this template, or revision of it, could be very useful to us.

Physics academic at large metropolitan university in Queensland
Links between this Fellowship and other Fellowships/ALTC projects

1) Physics Project (2004-2005) Learning Outcomes and Curriculum Development in Physics, supported by the Australian Universities Teaching Committee (AUTC) and the Carrick Institute for Learning and Teaching in Higher Education.

The Learning Outcomes and Curriculum Development in Physics project considered a wide range of issues and articulated the changes and challenges faced by Australian physics departments, and how departments were responding in their learning and teaching practices. The project identified service teaching to be of vital importance to physics departments and a particular recommendation of the project report which resonates with this Fellowship is that:


This Fellowship responds to that recommendation by developing and disseminating materials designed to enhance physics service teaching.

2) ALTC project (2007-2009) Forging New Directions in Physics Education in Australian Universities

A major strand of this project considered service teaching, taking a national perspective (report available at [http://www.physics.usyd.edu.au/super/ALTC/documents/Service-Report.pdf](http://www.physics.usyd.edu.au/super/ALTC/documents/Service-Report.pdf) and www.altc.edu.au/resources). There were significant synergies between the Fellowship and this ALTC project, in particular with regard to the focus on the impact of the laboratory on the student experience in physics service subjects. As the projects ran concurrently, they informed one another in ‘real time’. Another important factor, facilitating the cross-fertilisation of ideas, was that I co-led the Forging New Directions in Physics Education in Australian Universities (with Manjula Sharma of The University of Sydney). Many of the initiatives which were created for the Fellowship, for example the creation of expectations/experiences surveys, saw immediate impact through the rolling out of the surveys nationally through the Forging New Directions project. The strong relationships between the Fellowship and the project allowed ideas emerging from the Fellowship to be raised, challenged and disseminated amongst the broader tertiary physics education community. A recommendation from the ALTC project that emphasises issues that emerged from this Fellowship is that the Australian tertiary physics community should:

recognise that the laboratory experience of students in first year physics subjects (including service subjects) across the majority of the tertiary physics institutions in Australia is a matter of concern, demanding urgent action.

This ALTC funded project was carried out by the Australian Council of Deans of Science (ACDS). This project also focused on the experience of students in first year laboratories (in physics, chemistry, and biology) and there was an interchange of experiences and findings through discussions with the project co-leader, Professor John Rice. One of the recommendations of the project echoes the urgent emphasis that needs to be given to laboratory work (though of course my Fellowship limited its consideration to physics). A key recommendation of the project *Reconceptualising Tertiary Science Education for the 21st Century* that is in sympathy with this Fellowship is that:

*The* ACDS *[should] develop a policy statement on the inclusion of laboratory experience in entry level science courses, addressing the broad rationale and learning objectives for it in a way that acknowledges the diversity of student backgrounds and potential futures.*

4) ALTC funded project: *A threshold concepts focus to curriculum design* (co-led by Associate Professor Gerlese Åkerlind of the ANU and Dr Jo McKenzie of UTS). This project considers common misunderstandings of students using Threshold concepts as the underpinning methodology. Understanding of students enrolled in physics service subjects of the concept of measurement uncertainty is a main theme of the project and aligns closely with the focus brought in the Fellowship to laboratory work in service subjects.

5) ALTC Fellow Dr Roger Moni has developed a ‘Personal Response’ activity designed to enhance the communication skills of (first year) students in the biosciences. Roger accepted an invitation to talk at UTS about his innovation, as it has particular relevance to curriculum renewal priorities which forms part of my Fellowship. Roger’s work has been adapted, and through partial support of an internal grant at UTS, been incorporated in PAN.
Sharing outcomes of the Fellowship

The outcomes of this Fellowship have been shared in several ways. Some sharing was informal, involving members of the physics community nationally (for example at physics education forums such as that offered by UniServe science through its physics discipline day). Sharing was also formal and below is a list of papers, conferences and workshops attended in which the Fellowship activities and outcomes were disseminated. Several initiatives/projects emerged as a direct consequence of the Fellowship. I have included those below.

Peer reviewed papers


Presentations at conferences, workshops and Teaching and Learning Forums

T&L forum UTS 15th November 2007 Practice oriented teaching and learning in the first year physics laboratory.

T&L forum Curtin University of Technology 30th January 2008 Why are we doing this subject?: Examining the expectations/ experiences of bio/medical science students taking introductory physics at UTS.

T&L forum UTS 27th November 2008 Transforming practice-oriented activities for first year science students.

T&L conference University of the West of Scotland 24th June 2009 Cross-disciplinary initiative drives graduate-attribute-focussed curriculum transformation.

Workshop on Interactive Learning in Undergraduate Physics, The Australian National University, 27th March 2009: Enquiry-Oriented Laboratories for Non-Physics Majors.

Invited talks

The University of Queensland 2008 Designing and embedding an enquiry-oriented laboratory program in a service subject 7th May 2008.

The University of Sydney, School of Health Sciences, 3rd February  2009 Why service teaching is the most important teaching you’ll ever do.

ALTC organised workshops, including Fellowship workshops

The Culture of Assessment in Higher Education and roundtable discussion which was part of Distributive leadership for learning and teaching: Developing the faculty scholars model Project. 18th September 2008 (Brighton-le-Sands, Sydney).
New perspectives on Service Teaching: Tapping into the student experience.

ALTC Fellowships Workshop Brisbane, 1st and 2nd September 2008.

Local Presentations


UTS Physics seminar 31st March 2009 Forging New Directions in Physics Education in Australian Universities.

UTS Faculty seminar planned for November 2009.

UTS Institute for Media and Learning seminar 22nd May 2008 Making educational development ideas a reality.

UTS Casual Academics Conference 8th December 2008 Demonstrating in Science Laboratories.

Initiatives/projects to emerge from Fellowship

UTS project (led by Professor Tony Baker of Department of Forensic Science and Chemistry at UTS) supported by LTPF grant, 2009: Better experiences in laboratory teaching and learning in Science LTPF (amount granted $10,000).

UTS project with Catriona Bonfiglioli, 2008 supported by LTPF grant: A practice-oriented approach to enhancing science students’ communication skills LTPF grant (amount granted $37,000).

Papers/presentations authored or co-authored during Fellowship period, with strong affinities to Fellowship


Mapping associations between PAN and other subjects

The PAN curriculum was renewed so that physical principles underpinning areas of importance within the serviced disciplines were emphasised. Associations and links were mapped between physics and subjects study concurrently with PAN as well as those encountered in later semesters. This was accomplished for several subjects at UTS which are core to the programs of students enrolled in degrees in the medical, biological and environmental science. Those subjects are shown in table 1.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Level and (partial) information from subject outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Biosphere</td>
<td>First Year: The subject explores the environment in which life exists and how it has developed, interactions among the various components within the biosphere, and with external factors such as climate, the fundamental construct of the Earth’s crust, and conditions and resources associated with land and water.</td>
</tr>
<tr>
<td>Cell Biology and Genetics</td>
<td>First Year: The subject introduces the student to the basic concepts of cell biology, cell structure and function and the underlying genetic code.</td>
</tr>
<tr>
<td>Chemistry 1</td>
<td>First Year: [introduces] matter, chemical reactions, atomic structure, stoichiometry, the periodic table, intermolecular forces and crystal structures, molecular geometry, introductory carbon chemistry.</td>
</tr>
<tr>
<td>Geological Processes</td>
<td>Second Year: Understanding of physical principles underpinning the formation and evolution of surface environments.</td>
</tr>
<tr>
<td>Physiological Systems</td>
<td>Second year: provides an understanding of cell membrane transport processes and how these principles apply to the human body.</td>
</tr>
<tr>
<td>Medical Devices and Diagnostics</td>
<td>Final Year: subject provides an introduction to the principles of operation and use of typical devices encountered in medical practice.</td>
</tr>
<tr>
<td>GIS and Remote Sensing</td>
<td>Final Year: students should develop an elementary understanding of the physical principles of remote sensing underpinning techniques currently used by orbiters to study Earth Systems.</td>
</tr>
</tbody>
</table>

Table 1: Subjects mapped during Fellowship

With permission of coordinating academics, I enrolled in the subjects in table 1. This allowed me (via the internet-based education support system, Blackboard) to receive general messages sent to students, access the discussion board and download all materials. Subject outlines were reviewed for synergies with physics. After obtaining permission from the subject coordinator, I attended lectures and laboratories. These were usually chosen through reviewing the timetable for each subject then identifying those lectures/labs that were likely to have strongest affinities with physics. I completed a proforma during each lecture and laboratory to assist me to focus on actual or possible links between the subject and PAN (see attachment 2). I also made notes designed to draw out any discipline conventions (for example with nomenclature or vocabulary) that might aid or impair students’ grasp of links between their major area of study and physics.

I interviewed academics delivering the lectures (some time after the completion of the lecture) to understand better what they were intent on achieving with their own subject and what links they
believed it would be valuable to make between their subject and physics. The interviews were recorded and transcribed. The questions I asked were:

1) Ideally, what qualities/capabilities should a degree in science develop/enhance in students?

2) Which qualities/capabilities is it your intention to develop/enhance through your subject?

3) In what way(s) can a physics subject support your students in order to help (directly or indirectly) develop/enhance those qualities/capabilities?

4) Do you have any specific expectations of students who enter your subject with respect to their physics preparation?

Through the feedback I received, I reviewed the teaching method, content and particularly the contexts presented to students within PAN. As well as undertaking a major renewal of laboratory experiences (prompted by student feedback as well as interviews with academics) there were other modifications made to the subject. Some of these modifications were quite minor in the sense that they were trouble-free to implement. For example, I suggested to all academics teaching PAN that they introduce their section of the syllabus through direct reference to a topic that either had been taught or would be taught in the students’ major area of study. A topic would be chosen which had a compelling relationship, perhaps through techniques or principles, to physics. To this end, I extracted from the lectures materials I had collated (such as PowerPoint slides), specific examples related to the physics topic to be introduced that could be incorporated into the lecture (with permission of the lecturer who had developed the notes).

**Conclusion**

This Fellowship has allowed me to take the part of a student, by attending lectures, laboratories and linking into the online environment as experienced by students. This experience allowed me to re-evaluate a subject designed specifically to introduce physical principles to students drawn from the MEB sciences. Attendance at the lectures allowed me to isolate physics-related concepts given special emphasis by academics, allowing me to revitalise a physics subject designed for students from the MEB sciences. The approaches adopted here to reviewing and revitalising a service subject would be equally applicable to other disciplines, such as chemistry and mathematics.

Tapping into the student experience made it possible to identify key issues that needed urgent attention, in particular the provision of laboratory experiences for students required to take a physics subject, but who are non-physics majors. The issue of laboratory provision for non-physics majors is of national significance. The findings of the survey developed here, which showed that students by and large did not view the labs as a positive learning experience, were echoed across many Australian universities. The development of engaging, relevant and challenging laboratory programs for non-physics majors is an area that deserves to be given more attention, as so many non-physics majors nationally are required to enrol in a physics service subject. This is a direction that I would like to pursue further.
Details of Attachments

Attachment 1 contains the questionnaires used to survey student expectations and experiences of a service subject. Attachment 2 contains the proforma used to assist in mapping the association between the service subject and the lectures and laboratories attended in other subjects in which students were enrolled.

Attachment 3 describes the template for creating a new laboratory program, but does not indicate how you might use it. In attachment 4 there is a description of the development of a novel experiment which utilises many of the elements of the template and considers some of the wider issues relating to laboratory work (for example the critical role of the demonstrator). This part of the work was done collaboratively with other academics at UTS. The paper was presented at the Australian Institute of Physics, 18th National Congress, Adelaide, November 2008.
ATTACHMENT 1

Major..................................

PAN questionnaire A

This questionnaire is part of a study to improve the provision of physics which supports students drawn from the Medical, Biological and Environmental sciences. You are free withdraw from participating in this study at any time without giving a reason. You can choose to not fill in this questionnaire, or to hand in a questionnaire that is blank. All responses remain anonymous.

Below is a number of statements. Please put a number next to each statement to indicate to what extent you agree with the statement. The scale to use is,

<table>
<thead>
<tr>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
<th>Not Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

1. It is apparent to me that PAN is a valuable part of my degree [   ]
2. Only unusually able people are capable of understanding physical principles in science [   ]
3. I am keen to see how PAN links to my major area of study [   ]
4. I am anxious about studying PAN this semester [   ]
5. I am confident that my mathematics background is sufficient for me to be successful in PAN. [   ]
6. If offered, I would take advantage of extra maths support that was directly related to the maths I need for PAN [   ]
7. I am looking forward to doing labs in PAN [   ]
8. If it were possible, I would have avoided taking PAN [   ]
9. I expect the links between PAN and my major area of study to be made obvious throughout the semester [   ]
10. I expect to have to work harder in PAN than for my other subjects this semester [   ]
Please answer the following questions

11. What final grade are you aiming for in PAN (please circle)?

   P   C   D   HD   Don't know yet

12. Did you study HSC physics at school? Circle yes even if you did not complete the HSC in Physics

   Yes   No

Open ended question.

13. Please describe briefly any particular expectations you have as you begin your study in PAN. If you need more space, please write on the other side of this questionnaire.
Major..................................

PAN questionnaire B

This questionnaire is part of a study to improve the provision of physics which supports students drawn from the Medical, Biological and Environmental sciences. You are free withdraw from participating in this study at any time without giving a reason. You can choose to not fill in this questionnaire, or to hand in a questionnaire that is blank. All responses remain anonymous.

Below is a number of statements. Please put a number next to each statement to indicate to what extent you agree with the statement. The scale to use is,

<table>
<thead>
<tr>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
<th>Not Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

1. It is apparent to me that PAN is a valuable part of my degree [   ]
2. Only unusually able people are capable of understanding physical principles in science [   ]
3. I am able to appreciate the links between PAN and my major area of study [   ]
4. I am anxious about my upcoming exam in PAN [   ]
5. I believe my mathematics background was sufficient for me to be successful in PAN. [   ]
6. My achievements in class tests in PAN exceeded my expectations [   ]
7. I enjoyed the PAN labs. [   ]
8. I would advise others to avoid taking PAN if at all possible [   ]
9. The lecturers succeeded in linking PAN to my major area of study [   ]
10. I worked harder in PAN than for my other subjects this semester [   ]

Please answer the following questions

11. What final grade are you aiming for in PAN (please circle)?

   P   C   D   HD   Don’t know yet

12. Did you study HSC physics at school? Circle yes even if you did not complete the HSC in Physics
13. Open ended question.

Please describe briefly your experience of PAN this semester, and in particular what you think might be done to improve the subject. If you need more space, please write on the other side of this questionnaire.
Major..................................

Physical Aspects of Nature (PAN) questionnaire C (for students in years 2 or 3 of their course)

This questionnaire is part of a study to improve the provision of physics which supports students drawn from the Medical, Biological and Environmental sciences.

You are free withdraw from participating in this study at any time without giving a reason. You can choose to not fill in this questionnaire, or to hand in a questionnaire that is blank. All responses remain anonymous.

I ask you to think back to the time you studied PAN, and to reflect on your experience(s).

Below are a number of statements. Please put a number next to each statement to indicate to what extent you agree with the statement. The scale to use is,

<table>
<thead>
<tr>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
<th>Not Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

1 PAN made me aware of where physical principles are applied in my major area of study

2 The labs were a valuable part of PAN

3 I believe I learned a lot in PAN which will be of lasting value to me.

4 I found the learning experiences in PAN thought provoking.

5 PAN should be an elective subject, not a compulsory subject.

6 I would have appreciated the opportunity to enrol in a second subject dealing with physics topics relevant to my degree.

7 I valued the opportunity to see how physicists think

8 PAN has made an important contribution to my undergraduate education

9 My appreciation of the relevance of PAN to my degree has increased since completing PAN

10 I believe taking PAN has benefited my understanding in other areas of my degree
Please answer the following questions

11. When did you study PAN (please circle). If you repeated PAN, please circle the semester you last took it.

Before 2004  Aut 04  Spr 04  Aut 05  Spr 05  Aut 06  Spr 06  Aut 07

Open ended questions. Please write a few comments.

13. What is your most vivid recollection of PAN?

14. In what ways do you think PAN could be improved to increase its usefulness to future students enrolled in your degree?

15. Which areas/topics covered in PAN have you found to be most relevant/useful to you since you completed the subject?

16. Which topics/material should be included in PAN that were missing when you studied it?

17. Has anything you learned in PAN had a significant impact on your subsequent learning? – Please give an example if possible.

18. If you had one piece of advice to give the academic staff involved with developing PAN, what would it be?
**ATTACHMENT 2**

Fellowship Proforma to assist with mapping associations with service subject, (PAN)

<table>
<thead>
<tr>
<th>Subject</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester</td>
<td></td>
</tr>
<tr>
<td>Teaching Week/date</td>
<td></td>
</tr>
<tr>
<td>Lecturer/instructor</td>
<td></td>
</tr>
<tr>
<td>Lecture or Prac?</td>
<td></td>
</tr>
<tr>
<td>Lecture/Prac topic</td>
<td></td>
</tr>
<tr>
<td>Explicit relationships to Physics/PAN</td>
<td></td>
</tr>
<tr>
<td>Implicit relationships to Physics/PAN</td>
<td></td>
</tr>
<tr>
<td>Implications for PAN</td>
<td></td>
</tr>
<tr>
<td>Wider Implications</td>
<td></td>
</tr>
<tr>
<td>Comments/notes</td>
<td></td>
</tr>
<tr>
<td>What would I ask students after the lecture/lab?</td>
<td></td>
</tr>
<tr>
<td>What would I ask the academic/instructor after the lecture/lab?</td>
<td></td>
</tr>
</tbody>
</table>
ATTACHMENT 3

A design template for the development of a physics laboratory program
A design template for the development of a physics laboratory program

Introduction and overview of template

Many elements blend to make a successful undergraduate laboratory program. These include: accounting for students’ background and preparedness for experimental work; the extent of engagement promoted through the laboratory experience; the relevance of the experiment as perceived by students to their current or future needs or their everyday experiences; the clarity of the goals of the laboratory program and the quality of the support offered to students while they are in the laboratory setting.

To develop a successful program, a clear vision needs to be articulated of how the program relates to other components of the subject, course or unit in which it is embedded and what the program is intended to achieve with respect to student learning.

As examples, is the program designed to

- link to other elements of a subject, such as the lectures?
- be ‘stand alone’ with no direct link to lectures?
- focus on the conceptual development of students?
- aid students to learn something about the goals (and values) of trained scientists, the methods and procedures they use, and the ways in which they communicate their results?\(^7\)
- Replace lectures completely in the manner of problem-, or enquiry-based learning?

Presented here is a fleshed-out template designed to encourage the clarification of the philosophy of laboratory programs in physics, the aims of individual experiments and to bring a focus to such matters as:

- which graduate capabilities/attributes are supported by the laboratory program
- the role of the demonstrators and specific guidance to support the demonstrators
- the assessment of the laboratory program.

The template derives from two significant influences. The first is the need to rethink laboratory experiences for students locally and nationally enrolled in physics subjects but who are non-physics majors\(^8\). The other is the work of a group of Australian academics from chemistry who are developing a means of assuring high quality student learning outcomes in

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\(^8\) This is a finding of national study indicating that students enrolled in physics service subjects do not regard the laboratory as a positive learning experience. (Kirkup L, Mendez A, Sharma M, and O’Byrne J AIP (2008) One semester of physics: What difference does it make to non-physics majors? Australian Institute of Physics, 18th National Congress, Adelaide).
chemistry laboratories. Towards this end they have created, trialled and evaluated a template to foster and encourage such outcomes. The template was developed by the group ‘Advancing Chemistry by Enhancing Learning in the Laboratory’ (ACELL)\(^9\) (Buntine et al. 2007).

Whereas the ACELL template concentrates on individual experiments, the template described here considers the laboratory program in its entirety and how that program fits within the subject as a whole.

Embedded in the template are surveys which are intended to examine the views of:

- students for whom the experiments have been designed
- senior students who have completed the subject and who can offer a perspective on the value of the experiment to students who are non-physics majors
- demonstrators
- academics drawn from the bio/medical/environmental sciences
- Physics academics

While the template presented here suits the development of a whole laboratory program, there are elements of the template that would naturally assist the design of an individual experiment. We expect that those elements of the template that are most appropriate to the job in hand will be used or adapted and other discarded, i.e. the template should not be viewed as a ‘straight-jacket’, but rather as a versatile combination of elements which can be employed together, or individually in the pursuit of enhanced laboratory experiences for students.

The sections of the template given below begin with a description of the purpose of each section in a green font (except where the purpose is self evident and so needs no further commentary). This is followed by a ‘worked example’ (on a shaded background) which is intended to illuminate what typically might be contained within that section. The worked example is based on a fluid flow experiment devised at UTS using the template and which is currently (2009) featured in a laboratory program for students from the medical, biological and environmental sciences enrolled in a first year physics subject.

Figure 1 shows in schematic form the elements of the template leading from the context of the course in which the subject and its lab program are embedded through to the materials created for students, demonstrators and technical staff.

![Diagram of template for development of a laboratory program](image-url)

Figure 1: Template for development of a laboratory program
Figure 2 indicates the sections of the template of most value depending on the purpose of the laboratory development (for example, is the development of a whole laboratory program being planned or just the development of a single experiment?).

<table>
<thead>
<tr>
<th>Primary Goal</th>
<th>Sections of template</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop whole laboratory program</td>
<td>Section 1</td>
</tr>
<tr>
<td>Develop a new experiment</td>
<td>Section 2</td>
</tr>
<tr>
<td>Develop demonstrator and technical support material</td>
<td>Section 3</td>
</tr>
<tr>
<td></td>
<td>Section 4</td>
</tr>
</tbody>
</table>

Figure 2: Template usage diagram

Once completed, a natural home for material in Sections 1, 4 and Section 2 up to 2.4 would be in the Demonstrator’s manual. Material in Section 3 would form part of the students’ laboratory manual. Section 2.5 onward considers mainly the evaluation of an experiment and would be of most value to the subject coordinator or convenor and those involved with developing the laboratory program.
Section 1: Overview of laboratory program

Academics involved with a laboratory program, especially casual academics, may have limited awareness of the purpose of the subject, course or unit in which the laboratory program is embedded. This section is intended to offer an overview of the subject, where it fits within the student’s program of study, and the capacities that a student should develop as a consequence of successfully completing the subject or unit.

1.1 Course Context and Subject details

The experiments described in section 2 have been created for a first year subject called Physical Aspects of Nature (PAN) which is a core subject for bio/medical/environmental science students at UTS. Students who take PAN major in a range of disciplines, including medical science, forensic biology, biotechnology and environmental science. PAN is a 6 hours/week subject completed over one semester (13 teaching weeks). The students complete a 2.5 hour laboratory each week of the semester. Brief details of PAN follow.

Subject Details: Physical Aspects of Nature (PAN)

This subject introduces physical principles of relevance to students drawn predominantly from the bio, medical and environmental sciences. Contexts and applications drawn from those areas are used to introduce physical principles.

On completing PAN, a student should:

- be familiar with the principles and laws of physics most relevant to current and future studies in a range of disciplines, including the bio, medical and environmental sciences.
- be able to apply physics concepts to a range of bio/medical/environmental science type problems.
- have developed quantitative and qualitative approaches to problem analysis requiring equation manipulation, the use of appropriate units, an appreciation of the influence of experimental error and consideration of correct orders of magnitude.
- have acquired skills in accessing information from a variety of sources including the Internet and the library.
- be able to demonstrate the capacity to work independently against deadlines.
- have honed effective scientific communication skills including report writing, poster presentation, and the maintenance of an efficient record of work carried out in the laboratory.
- be able to design experiments requiring the application of basic physical principles to a variety of context rich situations.
- be able to apply methods of analysis of experimental data.

No prior knowledge of physics is assumed of students who take PAN. Feedback from students over several semesters indicates that approximately 50% have studied year 12 physics (or equivalent) though some of those do not go on to complete HSC physics.
1.2 Philosophy of laboratory program

General agreement about the goals of laboratory work is difficult to achieve. In fact, it may undesirable to formulate goals that purport to be applicable in all circumstances, as they are likely to depend on several factors, including whether the laboratory program is for junior or senior undergraduates; whether the subject is designed for physics majors, or non-physics majors.

Nevertheless, for any particular laboratory program, it is essential to articulate the philosophy of the program, as only then can experiments comprising the program be judged as consistent or conflicting with that philosophy.

Experimentation is at the heart of science. Science is dynamic by nature; its laws and theories are continually being challenged by experiment as our understanding of nature increases. Through experimentation we can formulate new relationships, question assumptions, and develop and refine new and old concepts.

Scientists convert ideas into practice and express these ideas in a numerical and measurable way. Many of the skills required to convert theory into reality and to explain measurements are learned through experience and practice in a laboratory. The advancement of science and the development of new technologies depends on the acquisition of new knowledge, the ability to analyse this knowledge, and relate it to ‘old’ knowledge. Scientists work on things they do not fully understand; their success comes from their curiosity, perseverance, the compulsive desire to understand and, importantly, a methodical and systematic approach to solving experimental problems and analysing experimental data.

Laboratory work is a crucial element of physics. It serves to deepen understanding of physical phenomena. It acquaints students with the process of experimentation and allows them to develop the confidence necessary to make beneficial use of science. It takes them beyond ‘textbook’ physics to a world in which new knowledge is created and old explanations are challenged. Importantly, it provides the basic analytical and investigative skills required by scientists to solve problems, design equipment, evaluate new products, analyse data or simply provide an objective description of phenomena (Cheary et al. 1995).

At UTS we recognise that in addition to learning the concepts, skills and processes underpinning experimental science students should be able to integrate their knowledge within practical contexts. They should actively participate in creative scientific activities from the outset, experiencing science as a relevant part of their lives as opposed to isolated incidents in a laboratory. They should be able to communicate ideas and results concisely and coherently in both oral and written form. Equally, they should learn to think independently and pursue independent investigations, develop self confidence in their ability to tackle scientific problems, and realise that science is a creative endeavour.

Central to the laboratory programs in physics at UTS is a enquiry oriented approach to learning.

An enquiry-oriented approach opens opportunities for obtaining first-hand experiences in doing science and in developing the skills to identify and define a problem, to formulate an hypothesis, to design an experiment, and to collect, analyse and interpret data. Teaching and learning by enquiry also exposes students ‘to experiences such as curiosity, perseverance, experiencing failure and dealing with doubts’ (Tamir 1983). It can provide the opportunity for students to participate in the construction of knowledge by relating and combining information in a creative and meaningful way.

To teach and learn by enquiry involves integrating different aspects of knowledge in ways that can be used to understand novel situations and problems. Students bring a range of knowledge and experiences to the laboratory that need to be recognised and can be utilised in the enquiry process.
Knowledge comes in a variety of forms: concepts, processes and procedures gained from formal experiences such as lectures and tutorials, and knowledge from informal sources determined by students’ individual backgrounds and experiences. It is when these different aspects of knowledge are related within situations students can relate to that confidence in the accuracy and credibility of knowledge is developed. It is the inter-relation between different aspects of knowledge within a meaningful episode that is crucial to understanding. (White, 1988). The laboratory provides a unique learning opportunity where this can take place and where students can experience science in action through the process of enquiry (Klofler, 1990).

1.3 The Laboratory Program: General

The laboratory is an excellent venue to enhance student capabilities, such as the ability to communicate the findings of experimental work both orally and through written reports. In this section, the general graduate attributes or capabilities are expressed. Most importantly, this section spells out the objectives for the laboratory program. Individual experiments may then be evaluated in relation to those objectives.

The laboratory program for the subject Physical Aspects of Nature (PAN) is designed to support student learning of physics in contexts that they can relate to, taking into account that the majority of students are drawn from the medical/environmental/biological sciences. The experiments are sequenced such that they follow exposure to ideas, principles and concepts introduced in the lecture strand of the subject.

1.3.1 Graduate capabilities supported by the laboratory program

<table>
<thead>
<tr>
<th>Science graduates should be able to:</th>
<th>This laboratory program:</th>
</tr>
</thead>
<tbody>
<tr>
<td>access, utilise and critically assess knowledge from a range of sources.</td>
<td>encourages the acquisition and synthesis of knowledge in practical settings and comparison of results with others.</td>
</tr>
<tr>
<td>learn independently and analytically. This includes thinking critically about learning.</td>
<td>provides semi-formal settings in which students can critique their work and that of others in a mutually supportive environment.</td>
</tr>
<tr>
<td>maintain social relationships and employ communication practices that are integral to a professional setting</td>
<td>encourages purposeful and effective working relationships through small group work and group presentation of work.</td>
</tr>
<tr>
<td>respond, ethically and effectively to the learning requirements in any situation</td>
<td>focuses on ethical behaviour in experimental science, eg fair and honest reporting of results.</td>
</tr>
<tr>
<td>apply their expertise in a practice context</td>
<td>provides opportunities for applying experimental methods to scientific contexts that have meaning for the student.</td>
</tr>
<tr>
<td>respond imaginatively and creatively to new situations.</td>
<td>provide opportunities for developing original approaches to scientifically based, practical, problems.</td>
</tr>
</tbody>
</table>
1.3.2 Objectives of the laboratory program

The general objectives of the PAN laboratory program are to:

**Provide opportunities to investigate, develop and consolidate some of the important principles and ideas of physics by**

- developing physics within a context which is relevant and meaningful to students
- observing and analysing qualitative and quantitative relationships between variables
- measuring and expressing concepts in a quantitative and qualitative form.

**Provide opportunities to develop the skills of experimental enquiry by developing and practising experimental processes associated with enquiry such as**

- designing experimental procedure
- building, testing and refining a model
- observing and recording measurements
- identifying sources of error and quantifying uncertainties
- transforming, graphing and analysing data
- relating measurements to appropriate physical equations
- interpreting the results in relation to the problem.

**Present a humanised view of physics that is both gender and culturally inclusive by**

- investigating physics within contexts that identify the role of physics in industry, technology and the community at large
- incorporating teaching and learning techniques which reduce gender and cultural bias
- encouraging students to build on their own knowledge.

**Foster a positive attitude towards science, creativity, innovation, independent thinking and enquiry by**

- encouraging active participation of students in designing, executing and refining their own experiments
- investigating ways in which science is of benefit to industry and the community.

**Develop formal and informal written and verbal communication skills through**

- critically analysing, discussing and reporting the results of experimentation
- actively promoting class discussion among students and demonstrators
- including written and oral communication in assessment tasks
- present findings of the experiment within a supportive environment to the whole class in a semi-formal manner

**Develop scientific integrity by encouraging an honest and faithful approach to data collection, analysis and reporting.**
1.3.3 Assessment of laboratory program

The laboratory program contributes 25 % to the total assessment of Physics Aspects of Nature and consists of the following elements,

<table>
<thead>
<tr>
<th>ASSESSMENT TASK</th>
<th>Contribution to total assessment of PAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skills Test</td>
<td>7.5 %</td>
</tr>
<tr>
<td>Lab Report</td>
<td>7.5 %</td>
</tr>
<tr>
<td>Poster &amp; presentation</td>
<td>5.0 %</td>
</tr>
<tr>
<td>Prelab and log book</td>
<td>5.0 %</td>
</tr>
<tr>
<td>TOTAL</td>
<td>25 %</td>
</tr>
</tbody>
</table>

For each laboratory session, students are required to:

a. complete the designated pre-lab exercises
b. keep an faithful record of activities in a log book

1.4 Role of the Demonstrator

The demonstrator is the most important learning resource available to students in the laboratory. What is expected of a demonstrator is sometimes unclear. Is the demonstrator expected to remain ‘in the background’ or be proactive in questioning encouraging and supporting students. In this section, the role of the demonstrator is clarified.

Demonstrators in the PAN laboratory need to develop within the classroom a learning environment that encourages students to take an active role in the processes of experimental enquiry. To provide insight into how an enquiry-oriented program differs from a more traditional prescriptive approach, Friedler & Tamir (1990) identified some distinguishing characteristics as:

- the teachers are less direct
- more planning by students takes place
- the processes of science receive more emphasis
- there is more discussion within the laboratory session
- the demonstrator gives fewer instructions in front of the whole class and moves around more, checking, probing and supporting
- students are usually more active and are encouraged to initiate ideas.

In an enquiry-oriented program the role of the demonstrator is more demanding as s/he does not have the same control over experimental procedures and outcomes as is common in a recipe-based approach. It would not be unusual, in an enquiry-oriented program, for the demonstrator to have to supervise and advise on several approaches to an experiment within the one session. The
demonstrator remains a source of knowledge and encouragement for the students although his/her role is not necessarily to always give precise answers on demand, but to guide students towards discovering an answer for themselves. Learning is an interpretative process with new information being given meaning in terms of the students’ prior knowledge. Each learner constructs an understanding rather than receiving it from an authoritative source such as a teacher or textbook. Students need to be given the opportunities to experience new ideas and concepts in a direct way and have time to reflect on and make sense of new information. (Roth & Roychoudhury, 1992).

In the new role as a facilitator of knowledge, the demonstrator endeavours to encourage and promote discussion with and among students, both individually and in groups; allowing and encouraging students to experiment with different ideas and to make mistakes; and prompting students to justify their ideas and actions.

1.5 References

Cheary R W, Gosper M V. Hazel E and Kirkup L (1995) Revitalising the First Year Physics Laboratories at the University of Technology, Sydney A &NZ Physicist 32 119-125
Section 2  Introduction to the Experiment

This section presents an introduction to the specific experiment(s) to be carried out by students and emphasises the context of the experiment, the assumed background knowledge of students before they proceed to carry out the experiment, and the duration of the experiment. The name of the person who prepared the notes is provided, allowing for further clarification to be sought if necessary.

Title of experiment: Investigating fluid flow

These notes prepared by: Les Kirkup

2.1 General context

‘Investigating Fluid Flow’ is a laboratory based learning exercise in which students are presented with a problem requiring a systematic experimental approach in order to reach a solution. Students investigate the relationship between fluid flow and several of the factors that affect the flow. The exercise involves aspects of experimental enquiry and students are supported through the necessary stages of measurement relating to pressure and fluid flow, becoming familiar with the equipment available, designing and modifying experimental procedure, taking careful measurements, transforming, graphing and analysing data and making conclusions based on the experimental data. All groups contribute data which are combined onto a single graph. This emphasises the mutual responsibility for high quality work, while at the same time engaging students in the analysis of data that everyone has contributed to. Students present their graphs and data to the whole class and compare their results with students doing complementary investigations in order to reach a shared understanding of the factors that affect fluid flow.

This experiment is the last in a sequence of experiments designed to introduce students to foundation experimental skills such a quantifying uncertainty in measurement. In particular, this experiment is designed to consolidate the learning of the previous experiments in this sequence through requiring students to apply those skills in a novel situation, namely investigating fluid flow through narrow tubes (in this case hollow blunt needles).

All students, working in groups of 2 or 3, do this experiment simultaneously (ie there is sufficient equipment to have a whole class do this experiment in the same laboratory time slot).

2.2 Assumed background

It is assumed that the student is familiar with;

a) Making a faithful record of experimental activities in a logbook
b) Plotting x-y graphs
c) Drawing a line of best fit through linearly related data
d) Calculating uncertainties in situations in which repeat measurements are made of a quantity

2.3  Time commitment for experiment

| Prior to Lab: | 45 minutes |
| In Laboratory: | 150 minutes |
| After Laboratory: | none |
2.4—Educational Analysis

This section clarifies what is to be learned through engaging with the experiment, how it is to be learned and the indicators that students, demonstrators and academics can look for to establish if the desired learning has occurred.

The learning outcomes of this experiment are classified as Principal (P) or Auxiliary (A).

<table>
<thead>
<tr>
<th>Learning Outcomes Achieved by</th>
<th>Indicators of learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>The students will learn,</td>
<td>The student will learn it by,</td>
</tr>
<tr>
<td></td>
<td>Staff and students will know the outcomes have been achieved by,</td>
</tr>
</tbody>
</table>

Theoretical and Conceptual Knowledge

(P) the relationship between fluid flow through a narrow tube and several variables including tube length and tube diameter.

- a) predicting the relationship between the fluid flow rate and the controlled variables (e.g., tube diameter)
- b) a measuring fluid flow rate as a function of several variables including tube length and tube diameter.
- a) comparing the prediction with graphs obtained of flow rate versus each variable
- b) students documenting their findings in their log book which is reviewed by demonstrators,
- c) communicating their methods to the class during the laboratory session and obtaining feedback.

Scientific and Practical Skills

(P) to derive useful information from graphs.

- plotting graphs, calculating slopes and uncertainty in slope (where relevant).
- Use the information to determine the functional relationship between flow rate and pressure, tube length and tube diameter.
- a) going through the prework in the lab for the whole group prior to the experiment starting,
- b) Obtaining feedback from the demonstrators,
- c) having graphs viewed and discussed collectively.
- Scoring well on the equivalent items in the Skills test (which takes place in the teaching week following this experiment).
### Generic Capabilities

<table>
<thead>
<tr>
<th>Capability</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P) to develop their oral and written reporting/communication skills.</td>
<td>a) presenting their methods and findings orally in the laboratory to their peers and b) carefully recording important details in their a faithful and timely manner.</td>
</tr>
<tr>
<td>(A) to critically assess scientific evidence.</td>
<td>reviewing their data, comparing their methods with others,</td>
</tr>
<tr>
<td>(A) to be ethical in data handling.</td>
<td>recording all data as the experiment proceeds, not expunging data that appear difficult to explain</td>
</tr>
</tbody>
</table>
2.5 – Evaluation

The evaluation of an experiment may draw on the experiences of a number of stakeholders including full time and casual academics, senior students and students for whom the program is designed. In addition, focus groups can reveal issues that surveys may overlook or give insufficient emphasis to. This subsection contains surveys that have been devised to provide evidence, as examples, of the quality of the student experience, the effectiveness of the materials created for students, and whether the experiment is likely to foster a deep approach to learning. Focus group questions are also included.10

Survey A (administered to senior students/demonstrators who trial the prototype experiment)
Recruiting students who have already completed the subject in an earlier semester allows for an informed, student centred, and ‘hands-on’ review of an experiment and brings the issues of context and relevance to the fore. Recruited Physics demonstrators, who have had no input into the design of the experiment brings another perspective to the experiment.

Survey B (administered to independent academics who review the experiment)
Academics who have no stake in an experiment are often able to offer a more detached and objective assessment of an experiment that those who have been intimately involved with the development of the experiment. This survey is intended to assess, for example, whether the experiment is likely to foster within a student as deep approach to learning or whether experiment has relevance to a student professional development.

Survey C (administered to ‘real’ students once the experiment has gone ‘live’)
This survey is intended to probe a student’s experience of an experiment and contains similar questions to those appearing in survey A, allowing for a comparison between senior students attitudes towards the experiment and those of novice students

10 Details of the evaluation of the Fluid flow experiment can be found in the Appendix to this document
Survey A (administered to senior students/demonstrators who trial the experiment)

<table>
<thead>
<tr>
<th>statement</th>
<th>Extent of agreement (Please Tick)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The experiment worked</td>
<td>Strongly agree agree Neutral disagree Strongly disagree</td>
</tr>
<tr>
<td>2 There is sufficient time to complete the experiment.</td>
<td></td>
</tr>
<tr>
<td>3 The experiment is likely to assist students in developing their conceptual understanding.</td>
<td></td>
</tr>
<tr>
<td>4 The prework is helpful for orienting the student to the experiment.</td>
<td></td>
</tr>
<tr>
<td>5 The experiment is likely to assist students to develop their scientific and practical skills.</td>
<td></td>
</tr>
<tr>
<td>6 The notes for students should include more detailed instructions.</td>
<td></td>
</tr>
<tr>
<td>7 The experiment is likely to assist students in developing their teamwork skills.</td>
<td></td>
</tr>
<tr>
<td>8 Students are likely to find this experiment interesting.</td>
<td></td>
</tr>
<tr>
<td>9 Sufficient background information is given in order for the student to make sense of the experiment.</td>
<td></td>
</tr>
<tr>
<td>10 The method by which the experiment will be assessed is clearly stated.</td>
<td></td>
</tr>
<tr>
<td>11 The experiment is likely to assist students to develop their time management skills.</td>
<td></td>
</tr>
<tr>
<td>12 The experiment is likely to assist in improving the student’s oral communication skills.</td>
<td></td>
</tr>
</tbody>
</table>

As a learning experience how would you rate this experiment? Please circle one of the following options:

Outstanding very valuable worthwhile of little value of no value

Opened ended questions
What are the strengths of this experiment?

In what way(s) could this experiment be improved?
Based on the written details available on this experiment, there is evidence that the experiment, **Extent of agreement**  
(Please Tick)  

<table>
<thead>
<tr>
<th>To foster deep approaches to learning</th>
<th>offers students a wider perspective on the role of physics.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>integrates with the theory presented in lectures.</td>
</tr>
<tr>
<td></td>
<td>is sequenced with the lecture classes.</td>
</tr>
<tr>
<td></td>
<td>has open elements to it.</td>
</tr>
<tr>
<td></td>
<td>adopts an enquiry oriented approach to learning.</td>
</tr>
<tr>
<td></td>
<td>utilises students prior knowledge/experiences</td>
</tr>
<tr>
<td>To have a relevance to students’ professional development</td>
<td>has a medical, biological or environmental science flavour ¹¹.</td>
</tr>
<tr>
<td></td>
<td>relates to a real world problem or issue.</td>
</tr>
<tr>
<td></td>
<td>encourages development of experimental design skills.</td>
</tr>
<tr>
<td></td>
<td>needs careful measurements.</td>
</tr>
<tr>
<td></td>
<td>utilises data analysis techniques.</td>
</tr>
<tr>
<td></td>
<td>involves the comparison of models with experimental data.</td>
</tr>
<tr>
<td></td>
<td>requires students to engage in effective teamwork.</td>
</tr>
<tr>
<td>To develop students’ lifelong learning skills</td>
<td>has opportunity for student autonomy.</td>
</tr>
<tr>
<td></td>
<td>requires information technology/literacy skills.</td>
</tr>
<tr>
<td></td>
<td>fosters time management/scheduling skills.</td>
</tr>
<tr>
<td></td>
<td>has assessment which consists of a variety of components.</td>
</tr>
<tr>
<td></td>
<td>requires student participation in discussion.</td>
</tr>
<tr>
<td>To develop students’ other generic skills</td>
<td>fosters teamwork skills in students.</td>
</tr>
<tr>
<td></td>
<td>encourages the development of written communication skills.</td>
</tr>
<tr>
<td></td>
<td>encourages the development of oral communication skills.</td>
</tr>
<tr>
<td></td>
<td>develops skill in leading discussion (presentation of results).</td>
</tr>
<tr>
<td></td>
<td>encourages lateral thinking &amp;/or problem solving skills.</td>
</tr>
</tbody>
</table>

Can you suggest ways in which the materials prepared for student can be improved?

¹¹ This item would be modified to reflect the discipline(s) in which the students were majoring.
## Survey C (administered to ‘real’ students once the experiment has gone ‘live’)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Extent of agreement (Please Tick)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly agree</td>
</tr>
<tr>
<td>1  The experiment worked</td>
<td></td>
</tr>
<tr>
<td>2  There is sufficient time to complete the experiment.</td>
<td></td>
</tr>
<tr>
<td>3  The experiment was easy</td>
<td></td>
</tr>
<tr>
<td>4  The prework helped prepare me for the experiment.</td>
<td></td>
</tr>
<tr>
<td>5  The prework was easy</td>
<td></td>
</tr>
<tr>
<td>6  The notes for the experiment should include more detailed instructions</td>
<td></td>
</tr>
<tr>
<td>7  The class discussions aided my understanding of the experiment</td>
<td></td>
</tr>
<tr>
<td>8  I found this experiment interesting.</td>
<td></td>
</tr>
<tr>
<td>9  Sufficient background information is given in order for me to make sense of the experiment.</td>
<td></td>
</tr>
<tr>
<td>10 The method by which the experiment will be assessed is clearly stated.</td>
<td></td>
</tr>
<tr>
<td>11 I can see the relevance of this experiment to the course I am majoring in.</td>
<td></td>
</tr>
<tr>
<td>12 Through this experiment my confidence in talking about the results of my experiment has increased.</td>
<td></td>
</tr>
</tbody>
</table>

**As a learning experience how would you rate this experiment? Please circle one of the following options:**

- Outstanding
- Very valuable
- Worthwhile
- Of little value
- Of no value

**Opened ended questions**

What are the strengths of this experiment?

In what way(s) could this experiment be improved?
Focus group questions

Questions for focus group sessions following trial of experiment with senior students and demonstrators

*Short focus group sessions can bring to the surface issues that may not have been anticipated during the development of the experiment and can reveal matters (such as the attitude of demonstrators towards a new experiment) which may be of vital importance when the demonstrators themselves run the experiment.*

Do you think the experiment you performed has relevance to students going on to major in [insert major]? (can you explain/describe the relevance)

What are the best features of the experiment?

Were there any aspects of the experiment/notes provided that were confusing?

Is there anything key that you believe the developer of the experiment should address before running the experiment with ‘real’ students?
Section 3 Materials for Students

3.1 Experimental notes for students

Your next experiment considers fluid flow, and in particular, factors that affect the amount of fluid flowing through narrow tubes. There are many practical examples of fluid flowing through narrow tubes or pipes (for example, think of blood flowing through a syringe needle).

3.1.1 Prelab

In an experiment to study factors that affect the rate of flow of fluid through narrow tubes, a mixture of water and glycerine was placed in a container. The container was connected via a plastic tube to a narrow metal tube, as shown below.

An experimenter collected the water flowing out of a narrow metal tube.

The liquid level was at height, $h$, above the metal tube. The water was collected in a measuring cylinder over a period of time, $t$, where $t = 20$ s. These steps were repeated twice.

The table below shows the raw data obtained of the volume of water collected for a range of heights from $h = 12$ cm to $h = 40$ cm. The flow rate, represented by the symbol $Q$, is found by dividing the volume of water collected by the time, $t$ (so, for example, $Q_1 = V_1/t = V_1/20$).

The top row of the table has been completed for you. It shows the mean flow of water, $\bar{Q}$, found by taking the average of $Q_1$, $Q_2$, and $Q_3$. The uncertainty in $\bar{Q}$, written as $\Delta Q$, is found using the equation.
\[ \Delta Q = \frac{\text{max} Q - \text{min} Q}{n} \] where \( n \) is the number of repeat measurements (here \( n \) is equal to 3).

<table>
<thead>
<tr>
<th>( h ) (cm)</th>
<th>( V_1 ) (cm(^3))</th>
<th>( V_2 ) (cm(^3))</th>
<th>( V_3 ) (cm(^3))</th>
<th>( Q_1 ) (cm(^3)/s)</th>
<th>( Q_2 ) (cm(^3)/s)</th>
<th>( Q_3 ) (cm(^3)/s)</th>
<th>( \bar{Q} ) (cm(^3)/s)</th>
<th>( \Delta Q ) (cm(^3)/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>8.2</td>
<td>6.0</td>
<td>8.5</td>
<td>0.41</td>
<td>0.30</td>
<td>0.43</td>
<td>0.378</td>
<td>0.042</td>
</tr>
<tr>
<td>18</td>
<td>12.0</td>
<td>13.0</td>
<td>13.6</td>
<td>0.60</td>
<td>0.65</td>
<td>0.68</td>
<td>0.643</td>
<td>0.027</td>
</tr>
<tr>
<td>25</td>
<td>16.8</td>
<td>16.6</td>
<td>17.8</td>
<td>0.84</td>
<td>0.83</td>
<td>0.89</td>
<td>0.853</td>
<td>0.020</td>
</tr>
<tr>
<td>33</td>
<td>23.2</td>
<td>22.0</td>
<td>19.2</td>
<td>1.16</td>
<td>1.10</td>
<td>0.96</td>
<td>1.073</td>
<td>0.067</td>
</tr>
<tr>
<td>40</td>
<td>28.0</td>
<td>26.4</td>
<td>29.6</td>
<td>1.40</td>
<td>1.32</td>
<td>1.48</td>
<td>1.400</td>
<td>0.053</td>
</tr>
</tbody>
</table>

For you to do:

a) Complete the table above

b) Plot a graph of \( \bar{Q} \) versus height, \( h \) (use the graph paper on the next page).

c) Add error bars to each point.

d) Draw the line of best fit through the points on your graph and determine the gradient and the intercept of the line (don't forget that your gradient and intercept will have units).

e) With the aid of the error bars, draw the lines of ‘worst fit’ onto your graph.

f) Find the slope and the intercept of the lines of ‘worst fit’.

g) Using the lines of worst fit, estimate the uncertainty in the slope and intercept of the line.
3.1.2 Student notes

Investigating fluid flow

<table>
<thead>
<tr>
<th>Learning Experiences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Investigating the factors that affect the rate of flow of water through narrow tubes</td>
</tr>
<tr>
<td>3. Deriving and interpreting results and uncertainties from graphs</td>
</tr>
<tr>
<td>4. Recording data in a log book</td>
</tr>
<tr>
<td>5. Reporting findings of the experiment to the class</td>
</tr>
</tbody>
</table>

Background to Experiment
Understanding the factors that affect fluid flow is important in the medical and environmental sciences. As examples….

**Medical Science application**

The science of fluid flow applies to many facets in the field of radiology, from arteriography and angioplasty to percutaneous drainage. Precise modeling of physiologic fluid flows under real-life flow conditions is complex. A workable model may be devised from the first principles to create a first-order approximation that suits most purposes.


**Environmental science application**

Bulk flow [of water] can obviously work in phloem and xylem as these are basically pipes. Moreover as short plants evolved into tall trees, the xylem had to increase the number of pipes feeding the canopy. This explains the evolution of secondary growth. It is also not surprising that as dicots evolved into trees with massive canopies, tracheids became eclipsed by vessels with much greater radius. These changes help supply the water needs of a massive canopy such as those in tropical trees.

Care with blunt needles

You must take care when handling the blunt needles. If sufficient force is applied, a needle can puncture the skin.

EXPERIMENTAL DETAILS

General Aim: To devise and carry out an experiment to determine the factors that affect the rate of flow of fluid through a narrow tube.

General note: Be sure you record all your results carefully in your logbook as you proceed.

Stage 1, Objective: To accurately measure the rate of water, $Q$, flowing through a narrow tube.

Set up the equipment as shown in figure 1. Set $h$ to 25 cm. Using the measuring cylinder and the stop watch, measure the rate at which water flows from the narrow tube, once you have fully opened the tap. You should record your flow rate in cm$^3$/s.

Repeat this twice (with $h$ kept at 25 cm).

Question: based on your three measurements of flow rate, what is the mean flow rate, and what is the uncertainty in the mean flow rate?
Stage 2, Objective: To discover the relationship between water flow rate, Q, and the height, h.

Use the method from Stage one to obtain a mean flow rate and uncertainty for one other height, h. The height you use should be decided in consultation with your demonstrator. Combining your data with that of other groups in the lab., plot a graph of flow rate, Q, versus h (remember to include errors bars, as in the prework).

Question: Inspect your graph of Q versus h. From your data does it appear that the relationship between Q and h is linear or non-linear?

Assuming the relationship between Q and h to be linear, draw a line of best fit and determine the slope, and uncertainty in the slope.

Stage 3, Objective: To discover the relationship between water flow rate, Q, and EITHER the diameter of the tube, d, OR the length of the tube, l.

To do this you will need to replace the blunt needle used in stage 2 with others of different length or different diameter and measure the flow rate as before (note needles of various diameter and length are available). You should make only one measurement of flow rate for each needle you use.

Plot a graph of Q versus d, or Q versus l.

Question: Inspect your graph of Q versus d or l. From your data does it appear that the relationship between Q and d or Q and l is linear or non-linear?

Discuss with your demonstrator how you can obtain a quantitative relationship between Q and the variable you have studied.

Assessment of this experiment:

There are 3 components to the assessment of this week’s experiment: Two components are the prework you did for the lab and your record of the experiment as reported in your log book which your demonstrator will assess after the lab. session. Indirect assessment of aspects of the experiment, such as graph plotting and deriving useful information from graphs takes place in the Skills test.

........................................................................end of student notes..................................
The laboratory record is not an essay or a formal report. Basically it is a faithful record of your work. It should, however, be written up in a way that enables a colleague to easily understand your experimental procedures, measurements and analysis.

You are advised to enter all readings into the notebook directly as they are taken. If you make a mistake, do not obliterate it completely or tear the page out of the book. You should keep a record of your failures as well as your successes as often as much is learned by a failure as a success. Also, it is a fairly common experience that many things which are classed as mistakes in the heat of the moment later turn out to have been quite correct. Thus, one of the criteria of a good laboratory notebook is that it should be an accurate record of everything that happened in the experiment.

The normal layout for an experiment would be, in broad outline:

- Aim
- Simple sketch of apparatus
- Measurements
- Analysis of Measurements
- Conclusion

Since the notebook contains your personal record of your work there is no rigid format. The following list gives some of the things that should be recorded:

- A descriptive title of the work and the date.
- Zero readings, calibration factors etc. for all instruments used.
- A record of laboratory conditions which are, or might be, important (e.g. temperature, pressure, light intensity, etc.).
- Details of procedure or apparatus not included in the notes.
- Circuit diagrams showing the actual connections used and relevant equipment diagrams.
- Tables of all original readings (i.e. as read on the instruments), with headings, explanatory notes, units and the associated measurement errors.
- All calculations. Make these intelligible by setting them out neatly with explanatory headings. Do not mix calculations with original data.
- Graphs. Those drawn on special (or separate) graph paper should be taped or glued into the book close to the table of results which they represent.
- Estimates of uncertainties in all results.
Section 4 Demonstrator and Technical Support notes

The section provides the demonstrator with specific advice regarding the experiment, including its purpose, main features, and suggestions for enhancing the student’s learning experience. It is particularly valuable to new demonstrators to include a lesson plan advising the demonstrator on how long to spend on each stage of the experiment, as well as what might be focussed on in each stage. Example data may also be given in this section.

In order to assist the technical staff to support the experiment, a detailed list of equipment is provided. Though hazards are pointed out to students in the student notes, the safety advice is also contained in this section for the added benefit of demonstrators and technical staff.

4.1 Demonstrator notes for Investigating Fluid Flow experiment

Investigating fluid flow is a learning exercise in which students are presented with a problem requiring a systematic experimental approach to the solution. The exercise involves aspects of experimental enquiry and students should be guided through the necessary stages of understanding the purpose of the investigation, becoming familiar with the equipment available, designing and modifying experimental procedure, taking careful measurements, transforming and analysing data and drawing together the results of several experiments.

Of particular importance:

- Students should be encouraged to think about what they are doing, and be able to justify their approach.
- The results of measurements should be recorded directly into log-books, graphs should be clearly labelled with appropriate scales. Sources of experimental uncertainty should be identified and quantified.
- In stage 2 of the experiment, results from different groups should be combined (by the students themselves) on a single graph
- Results from different groups should be presented to the class for discussion and constructive comment.

One of the aims of the laboratory program is to develop effective communication skills and an integral part of this unit is the development of oral reporting skills. Students tend to shy away from presenting their findings. It is important to encourage students at all stages and also to suggest ways that the student might proceed and not to criticise students who are, in all likelihood, new to experimental investigations in physics. In summary, it is expected that the students’ will:

- Develop an experimental approach to investigating a problem
- Understand the relationship between flow rate and several variables
- Measure flow rate
- Derive and interpret results and uncertainties from graphs
- Present their results in a logbook and orally to the class

Suggested Sequence of events

1) Check and discuss Pre-lab (15 minutes)

2) Introduction to fluid flow experiment by demonstrator (10 minutes). A useful animation related to the effect of a construction on the flow of blood is an excellent way to ‘set the scene’
3) Students hypothesis how the factors mentioned in 2) affect fluid flow (15 minutes)

4) STAGE 1: Measuring flow rate, \( Q \) – including repeat measurements (10 minutes)

5) Reporting method of measuring \( Q \) (10 minutes)

6) STAGE 2: Perform experiment to measure \( Q \) with varying height, \( h \) (15 minutes). Have all students use the same type of needle (ie the same length and internal diameter) so that results can be combined. Have each group do one height only and make 3 measurements of the flow rate.

7) Combine data from all groups and have everyone plot data (15 minutes)

8) STAGE 3: Perform experiment to either study \( Q \) versus \( d \), or \( Q \) versus \( l \) (20 minutes)

9) Plot graph of \( Q \) versus \( d \), or \( Q \) versus \( l \) (10 minutes)

10) Discussion (10 minutes)

**Pre-lab**

At this point in the semester students will have been introduced to ideas of visually representing their data through plotting graphs and the use of error bars and lines of best fit. The pre-lab exercise is designed to give further opportunities to calculate means, uncertainties and translate these into graphical forms. In addition, the students are required to use error bars in order to assess the uncertainty in the slopes and intercepts of lines of best fit. It is important to be aware that students will NOT have dealt with fluid flow in lectures by the time they do this experiment.

**Class discussion**

It is suggested you encourage discussions at three key points during the experiment. Specifically these points would be at steps 3), 5) and 10) above.

Step 3) Factors affecting the flow of fluid through a narrow tube. This could be a small group activity. Each group could be asked to predict how the fluid flow would vary with the variable they have been asked to consider – and turn this prediction into a graphical representation.

Step 5) Reporting methods of measuring \( Q \). Bring some students forward to describe the method they used to determine the flow rate and show the calculation of the means flow rate and the uncertainty for a few groups. Is there a group that has a particularly large or particularly small percentage uncertainty?

Step 10) Have students present their results – how does the graph of real data compare with the predicted graphs (‘guessed at’ in step3)? Students are likely to underestimate the effect that diameter has on flow rate. Drawing out the effect of diameter is a point worth emphasising and relating to real world consequences by referring back to the animation shown early in the laboratory session.

In general each group needs to be aware of:

The procedures for measuring flow rate

The problems associated with the measurement of flow rate

What need to be done to improve accuracy of measurements
**Fluid Flow experiment – Sample Data**

Stage 1

Flow rate vs height (repeating each measurement 3 times) for needle length 0.43 cm and internal diameter 1.000 mm

<table>
<thead>
<tr>
<th>h (cm)</th>
<th>t (s)</th>
<th>V (cm³)</th>
<th>Q (cm³/s)</th>
<th>Mean Q (cm³/s)</th>
<th>ΔQ (cm³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.31</td>
<td>4.7</td>
<td>1.09</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.06</td>
<td>5.8</td>
<td>1.15</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.03</td>
<td>5.2</td>
<td>1.03</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>5.2</td>
<td>1</td>
<td>2</td>
<td></td>
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</tr>
<tr>
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<td>5.5</td>
<td>1.04</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>5.2</td>
<td>1.05</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.44</td>
<td>5.4</td>
<td>0.99</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>0.97</td>
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<td>4.8</td>
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<tr>
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</tr>
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<td>6.66</td>
<td>5</td>
<td>0.75</td>
<td>2</td>
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<td></td>
</tr>
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<td>6.59</td>
<td>5</td>
<td>0.76</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.97</td>
<td>4.6</td>
<td>0.77</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph

**Flow rate versus height**
Stage 2

Flow rate ($Q$) when length of tube ($l$) is varied

Table of results:

Diameter of needle used = 0.820 mm

<table>
<thead>
<tr>
<th>$h$ (cm)</th>
<th>$l$ (cm)</th>
<th>$t$ (s)</th>
<th>$V$ (cm$^3$)</th>
<th>$Q$ (cm$^3$/s)</th>
</tr>
</thead>
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<tr>
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<td>12.72</td>
<td>4.8</td>
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<td>8</td>
<td>8.94</td>
<td>4.2</td>
<td>0.47</td>
</tr>
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<td>5.6</td>
<td>11.03</td>
<td>5.8</td>
<td>0.53</td>
</tr>
<tr>
<td>48.5</td>
<td>4.3</td>
<td>11.96</td>
<td>7.2</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Graph

Stage 3

Flow rate ($Q$) versus diameter ($d$)

Length of needle 43 mm

Table of results:

<table>
<thead>
<tr>
<th>$h$ (cm)</th>
<th>$d$ (mm)</th>
<th>$t$ (s)</th>
<th>$V$ (cm$^3$)</th>
<th>$Q$ (cm$^3$/s)</th>
</tr>
</thead>
<tbody>
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<td>4.8</td>
<td>0.08</td>
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<td>56</td>
<td>0.820</td>
<td>7.78</td>
<td>5.2</td>
<td>0.67</td>
</tr>
<tr>
<td>56</td>
<td>1.000</td>
<td>6.5</td>
<td>7.4</td>
<td>1.14</td>
</tr>
</tbody>
</table>

Graph
Flow rate versus needle diameter

Q (cm³/s)

d (mm)
4.2 Notes for technical staff

Equipment list for each experimental set-up (ie per student group which is advised to consist of 2 or 3 students)

1 Water container + rubber tubing
1 18G blunt needle (length 38 mm)
1 syringe
1 stopwatch
1 10 ml plastic measuring cylinder
3 boss-heads
3 clamps
2 retort stands
1 plastic tray
1 pack of blunt needles of varying length (but fixed diameter)
1 pack of blunt needles of varying diameter (but fixed length)

General equipment/facilities to be available in laboratory

Tap water
Sink
Paper to mop up spilled water
Food dye to colour water (optional)

4.3 Hazard / Risk Assessment

You must take care when handling the blunt needles. If sufficient pressure is applied, a needle can puncture the skin.
Framework utilising elements of the template in attachment 1


A Framework For Developing Enquiry-Oriented Experiments For Non-Physics Majors

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Abstract

A recent review of the purpose and merit of physics laboratories, prompted by student concerns of relevance, has led to the development of context rich, enquiry-oriented, experiments for students enrolled in a physics subject at UTS, but who are majoring in the bio/medical sciences. An intended outcome of the development process, supported by funding from the Australian Learning and Teaching Council, is to revitalise laboratory programs for non-physics majors through the establishment of a framework that fosters the creation of engaging and student-centred learning opportunities in a laboratory context. The framework is also intended to promote the examination of diverse and discriminating views brought by a range of stakeholders including senior non-physics majors, academics drawn from the bio/medical sciences, academic developers, and laboratory demonstrators. These perspectives encourage the review and revision of desired learning outcomes for individual experiments as well as for the whole laboratory program. An element of the framework brings together senior students who are non-physics majors and physics demonstrators to work as equals on prototype versions of experiments. This paper describes aspects of a case study in which a particular experiment was developed, trialled and evaluated using the framework. Emphasis is given to the examination of focus group findings which reveal that demonstrators tended to focus on the technical aspects of the experiment, rather than the student learning that might emerge as a consequence of carrying out the experiment. This has implications for the ways in which demonstrators are prepared for their roles of supporting students to make the most of learning opportunities that enquiry-oriented experiments offer.

Introduction

Partly due to the promise they offer to foster the development of the graduate capabilities such as effective oral and written communication, working productively in groups, and devising and testing creative solutions to novel situations, there has been a revival of interest in enquiry-based, or enquiry-oriented, learning in science laboratories (Anders et al, 2003; Hume and Coll, 2008).

Enquiry-oriented physics laboratory programs for large cohorts of first year engineering students were introduced at University of Technology Sydney (UTS) in the late 1990’s (Kirkup et al. 1998). The
enquiry-oriented laboratory approach was extended to a subject in which students from the bio/medical sciences were required to enrol called Physical Aspects of Nature (PAN). Concerns of context and relevance were expressed by students about the PAN laboratory program through surveys, including UTS’s standard end of semester student feedback instrument. The findings of the surveys gave impetus to the reconsideration of approaches that should be adopted, and stakeholders who should be involved, as part of the process of creating laboratory-based experiences for students enrolled in PAN that would enhance student capabilities, for example in the areas of oral and written communication.

Methodology and Framework

The framework for developing and evaluating an experiment is outlined in Figure 1. Prior to the development of experiments for bio/medical science students, first hand experience was obtained of their discipline areas. This was done primarily through attendance by LK at bio/medical sciences lectures. Attendance at lectures was found to be more helpful than solely reviewing subject/course outlines, as it allowed the developers a perspective of the basic and persistent themes that students encountered that had overt relationships to physics. The stakeholders involved in the development and evaluation of the experiments were current and ‘ex’ PAN students, demonstrators, academics from the Department of Physics and Advanced Materials at UTS, academics from the bio/medical sciences and teaching and learning specialists from the Institute of Interactive Media and Learning at UTS. Evaluation of the experiment occurred at several stages. A particular focus was brought to the educational analysis of the experiments and this was influenced by the work of the group operating under the title: ‘Advancing Chemistry by Enhancing Learning in the Laboratory’ (Buntine et al. 2007).

The process of development and evaluation as shown in Figure 1 is iterative with responses used as the basis for reviewing and revising the experiment. The numbers adjacent to the lines indicate the sequence in which each step of trial/evaluation process was initiated. Those steps are briefly described:

Figure 1: Framework for developing and evaluating physics experiments for non-physics majors

Step 1 is characterised by informal feedback on the technical aspects of the experiment such as the likely time required to carry out the experiment. Step 2 involves physics and bio/medical sciences
academics with no involvement in the experiment assessing the materials created for the experiment. Step 3 involves recruiting students who are majoring in the bio/medical sciences and who have already completed the subject in an earlier semester. Inviting such students to be part of the development allows for an informed, student centred, and ‘hands-on’ review of an experiment and brings the issues of context and relevance to the fore. Physics demonstrators, who have had no input into the design of the experiment (up to this point), are recruited to bring another perspective to the experiment. Students and demonstrators work together on the experiment as equals and are required to complete the tasks required of students enrolled in PAN. The experiment is evaluated by students and demonstrators through a survey and in focus group sessions, in which demonstrators and students (in separate sessions) are asked for feedback. In step 4 the experiment is rolled out to students normally enrolled in the subject.

Details of the experiment

In order to give substance to aspects of the framework, we give a brief account of the development and evaluation of one experiment. Attendance at lectures and a review of subject outlines indicated that fluid flow is an area of some importance and relevance to bio/medical science students as it applied to blood flow, for example. Through group discussion in the lab, students are asked to hypothesise what variables might affect the flow of fluid through narrow tubes, such as tube length, and to predict the form of the relationship between the variables and the rate of flow of water. Students are asked (in small groups) to sketch the form of the graph and then defend their predictions to the whole class prior to the start of the experiment. At this point predictions can be modified. Students devise and carry out the experiment to establish the relationship between the variable they have discussed and the flow rate. Towards the end of the laboratory session, a representative of each group is asked to show their data to the whole class and to compare the relationship they found with the one they predicted.

Evaluation of the experiment

Seven students who had completed PAN in a previous semester and four demonstrators volunteered to carry out the experiment. This was a pivotal step in the development and evaluation process and we now focus on this. During the experiment LK acted as principal demonstrator and LS as assistant demonstrator. As far as possible, students and demonstrators were paired together, with only one group consisting solely of students.

Survey administered to students and demonstrators

At the end of the fluid flow experiment all participants completed a written survey which included 12 statements, and two open-ended questions; ‘what were the strengths of this experiment?’ and ‘how could the experiment be improved?’, the results of which have been published elsewhere (Kirkup and Srinivasan, in press).
Focus groups

Following completion of the survey, KW conducted a focus group with student-participants and JP conducted another with demonstrator-participants. The questions common to both groups focused on participants’ perceptions of the best aspects of the experiment, the relevance of the experiment to their study major and the adequacy of the accompanying notes. Demonstrators were asked how comfortable they felt running a similar experiment and whether they wanted any further support to be able to run the experiment themselves. Students were asked how this experiment compared to the experiment it replaces, what they saw as the role of the demonstrator in this experiment and whether the demonstrators’ role had been different in the experiments they completed last year.

Analysis of focus groups

Immediately following the focus group interviews, two authors (JP and KW) discussed and compared their initial perceptions from these interviews. Written transcripts were analysed using a long table approach for a preliminary qualitative identification of themes (Krueger, 2000). These preliminary themes were iteratively discussed and re-analysed together with the transcripts to arrive at the following findings.

Findings from focus groups: Perceptions of relevance

Students identified the clear relevance of the experiment as one of its best aspects. Students and demonstrators cited several illustrative instances such as relevance to theory (results were related to theory), relevance to the topics covered in lectures and the timing of the lectures, relevance to the future work environment, relevance to a medical discipline, relevance to depictions of medicine in the media, instantaneous visual relevance of the equipment to medicine and to a “medical room”. For students this clear relevance also had a motivational aspect “…putting the red food dye in the water just makes it more fun”. Demonstrators predicted potential problems with relevance in a larger laboratory session where students may have different subject majors, differing levels of experience and knowledge in maths and science, different innate abilities in physics and different levels of preparation. In the pre-lab notes, demonstrators appreciated that some students would have found the descriptions and illustrations of flow in plant and animal cells relevant, but they did not find the section particularly useful: “I’m a physicist and when I saw the cells I thought ‘Oh my God’ ”, “I jumped to the maths part.”

Encouraging thinking

Students described how the design of the experiment had encouraged them to freely explore different experimental methods: “I think that’s good in a way that they didn’t tell us which way to do it because then we started with one way and we realised, oh the other way might be more accurate”. The demonstrators described how the experiment encouraged students to think logically by extrapolating from everyday experience and practice the “scientific method” by predicting about what might occur in the experiment if the variables were changed. The demonstrators expressed a preference for limiting students’ choice of procedure by being more directive with their instructions to students in the initial parts of the experiment or by allowing students to proceed to subsequent sections based on how they were coping with the initial section. Demonstrators described this as “nailing (it) down more.”
Managing confusion

Students and demonstrators described this experiment as “clear” and “straightforward”. Students contrasted this to other laboratory classes where they had felt unclear about what was expected of them. In those situations, students described coping strategies such as focusing on trying to get the right answer, and getting the experiment finished. Demonstrators also commented on student confusion in previous laboratory classes. They identified four areas as sources of confusion - confusion with overly complicated or malfunctioning equipment that consumed valuable time, confusion over hand-drawing of graphs, confusion over inaccurate or incorrect results and confusion in the write-up of the discussion. In this experiment, demonstrators highlighted how ‘approachable’ the equipment was in the fluid flow experiment. It was simple enough to quickly get the experiment started, easy to assemble and use and helped to instil confidence “… there’s a level of ‘I actually know what’s going on...this bit goes in here and that bit screws on’ so you bond with the equipment.” Some demonstrators commented that were they to run or redesign the experiment, they would give students a more structured experience by reducing the initial time spent in the group discussion of the pre-lab work and introduction, adding in predictive-style questions in the text and limiting the group presentation of results so students presented only the final part of the experiment or fewer student groups presented or replacing the student presentations with a demonstrator-led presentation of sample results.

Role of the demonstrator

Students described the demonstrator of this laboratory class as mobile (i.e. moving around the lab from group to group), available and approachable. They recalled several instances where the actions of the demonstrator had been especially helpful and encouraging. These included starting the experiment with a helpful explanation of the pre-work, prompting a group discussion of the pre-work and method, stimulating further thinking by talking with and questioning students individually and in groups throughout the experiment, making it clear that variation of results between groups was normal and acceptable and facilitating a final discussion of the connections between the theoretical concepts in this experiment to the human body. This was in contrast to the students’ recollections of their laboratory experiences in previous years and in other subjects where they felt that some demonstrators barely spoke to the class or gave lengthy explanations of areas where they did not need help (e.g. the method, rather than the pre-work) or focused solely on having students write down the correct answer.

Discussion and conclusion

The purpose of the framework described in this paper is to assist in the creation of improved laboratory based learning experiences for students who are not majoring in physics. Examination, through focus groups sessions, of the perspectives of students and demonstrators by teaching and learning professionals led to several benefits including; independent and detached evaluations of student and demonstrators views of the experiment, identification of issues requiring further action, such as demonstrator comfort with running enquiry-oriented experiments, and uncovering matters that cause confusion in the minds of students and demonstrators and the method each group employs to manage the confusion.

The evaluation of the fluid flow experiment indicates that the framework promoted a laboratory experience which addressed students concerns of relevance in a rich multi-dimensional manner. Students also valued the efforts made to provide a motivating and relevant environment. Interrogating the experiences of students and demonstrators through focus group feedback, highlights the
importance of making the laboratory “genuinely interesting, so that students find it a pleasure to learn” (Ramsden, 2006). The early use of classroom observations, review of subject outlines and consultation with staff from multiple disciplines, strengthened the perceived relevance of this experiment by situating it within the wider context of the subject syllabus and the course curriculum. However, the subsequent evaluation of the experiment identified the multiple meanings of relevance from the students’ perspective showing many important nuances which otherwise may have been overlooked. The flexibility in the experimental method, the demonstrators’ hypothetical questioning and encouragement of a trial and error approach also strongly contributed to students’ motivation and is linked to the idea that “students do their best work when given the freedom and space to use their own judgement” (Biggs and Tang, 2007).

Some unanticipated findings with strategic implications emerged from the qualitative evaluation. The demonstrator group, although appreciating the value of an experiment which was relevant to the students’ discipline, expressed some views which were dissonant with an enquiry-oriented approach. From a professional development perspective the experience of participating as a student promoted confidence in running the experiment from a technical perspective. However, analysis of the focus groups transcripts suggested that the demonstrators were not wholly comfortable with activities integral to an enquiry-oriented lab approach. These results imply a greater focus on facilitating enquiry-oriented learning is required as part of the demonstrators’ professional development.

Acknowledgement

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References


