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:

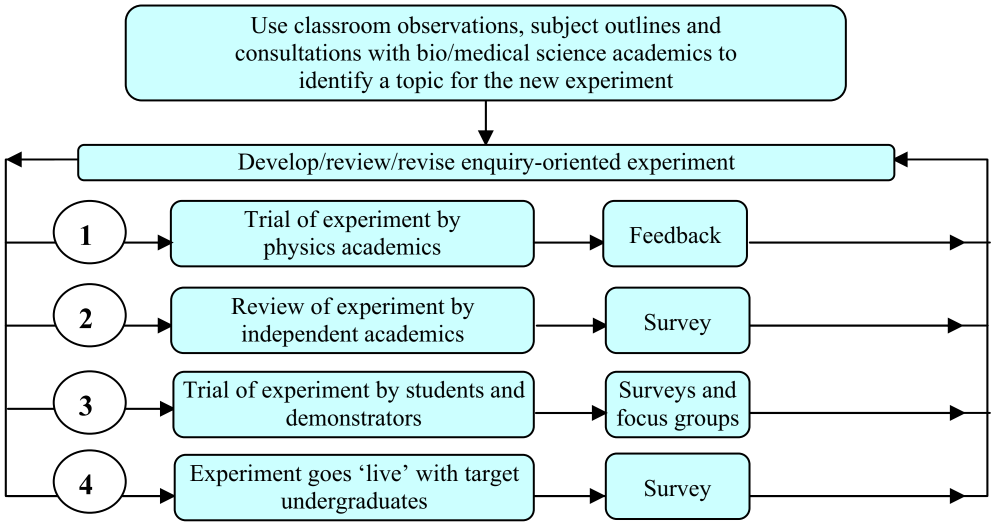

Figure 1: Framework for developing and evaluating physics experiments for non-physics majors

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 applies 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 with the experiment it replaces, what they saw as the role of the demonstrator in this experiment and whether the demonstrator's 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 <u>topics</u> covered in lectures and the <u>timing</u> 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 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-lab 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 and 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-lab 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.

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