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Fix on Physics

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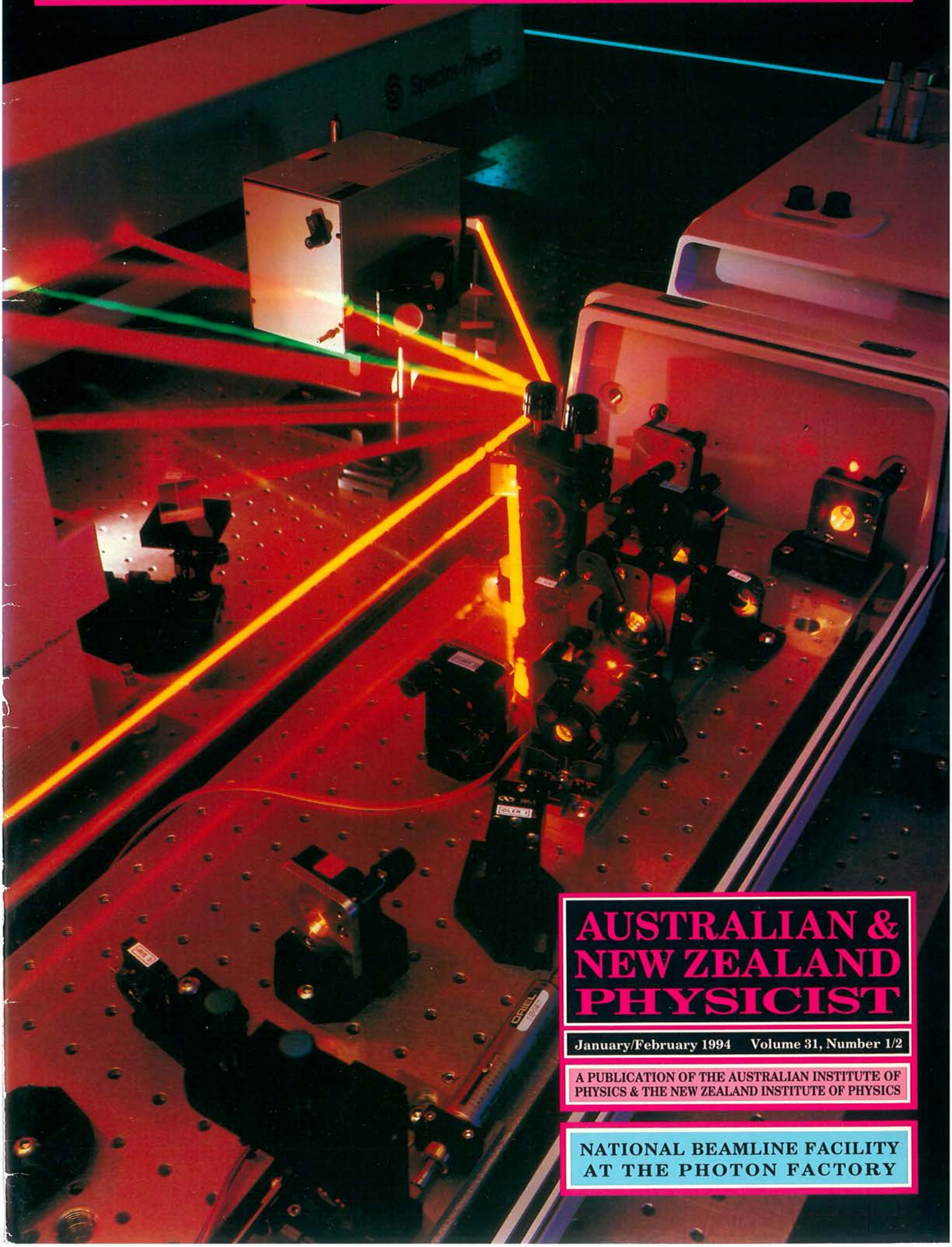

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FIX ON PHYSICS

EDUCATION SUPPLEMENT JAN / FEB 1994

AN INTERESTING PHYSICS EXPERIMENT

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Introduction

In 1992, the Faculty of Science at the University of Sydney initiated a pilot "Talented Students program". The purpose of this program is to provide talented students with the opportunity to undertake activities which depart somewhat from the normal undergraduate course offerings. Students may for example, take advanced courses without necessarily completing normal prerequisites, or they may select from a much wider range of courses in order to develop greater breadth than is possible within the usual program. As part of the Talented Students Program, a group of students and staff in the School of Physics undertook an interesting and challenging project during Second Semester. The aim of the project was to develop an experiment for the First Year Laboratory course, starting from the basic physical concepts, and ending with hardware and laboratory notes which had been trialled in the laboratory itself. The activity was challenging and stimulating for the students and staff alike and represented an extremely enjoyable learning experience. Whilst not achieving all of its aims, the outcomes are sufficiently promising that we wish to share our experience with others.

Organisation

Students were selected from all three undergraduate years - 8, 6 and 2 from First, Second and Third year respectively. They were chosen by the Year co-ordinators of the Experimental Physics program from a much larger number of students who had indicated a wish to participate. Students who were not selected expressed some disappointment - we need to work harder in the future to avoid this. The students met formally (actually it was pretty informal!) with three members of Academic staff for 2 hours each week. Extensive activity took place outside these formal meetings.

To the maximum possible extent, the project was "student driven". The staff tried to let the group develop its own approach and set its own priorities. In hindsight, the staff might have been somewhat more prescriptive in the early stages of the activity before the natural leaders emerged from the student group.

The group experienced all of the challenge, frustration and excitement of any creative activity. They learnt that real experimental physics is not much like their 3 hour undergraduate laboratory experiments. They obtained insights into the nature of research work and group participation, particularly in a group involving participants with a wide range of skills and experience.

The Experiment

The experiment which the group developed aims to measure the thermal conductivity of a range of ▷

materials - from metals to insulators. At the commencement of the activity most of the students had little, or no quantitative knowledge of heat transport. An understanding of the concept of thermal conductivity was developed in a collegial way and this led to two basic measurement principles - steady state and transient. In addition, the need emerged for methods of temperature measure-ment, power generation and heat removal.

At the end of each weekly meeting, groups of students took the responsibility for obtaining information on specific aspects of the experimental design. This ranged from technical information on component performance to the determination of the size of the equipment in order that the experiment could be performed in a reasonable time. The group frequently divided into sub-groups and reformed to discuss progress.

Early in the activity, two basic design principles were decided which determined most of the future design decisions. The experiment was to be steady state, and the apparatus was to be modular, permitting exchange of test specimens. The groups debated extensively the experimental design including:

- Size of the equipment
- Method of assembly of modular parts
- Temperature sensors
- Data logging (a particularly contentious issue!)
- Measurement of input power
- Rejection of heat
- Methods of insulating the equipment
- Estimation of heat losses
- Experimental procedure.

Major design constraints were imposed by practical factors. For example the experiment had to be performed within a 3 hour time period. In addition, the use of cooling water from the tap was not permitted due to the possibility of flooding. Cost of the equipment had to be low.

The experimental concept evolved from its basic form through a series of progressively more complex designs incorporating various refinements and finally back to a very simple final system. It was particularly exciting to observe the way in which unwanted complexity and unnecessary features were, with reluctance, discarded as the benefits of simplicity became obvious.

Figure 1 shows the final experimental design. The apparatus consists of several separate components - heater, test specimens, cooling element, insulation - which can be rapidly assembled. Temperatures throughout the system are measured with a thermocouple which can be inserted through a central hole. To obtain adequate resolution it is necessary to use a microvoltmeter to measure the thermal emf, rather than a hand-held digital thermometer. Issues such as thermocouple calibration and reference junctions therefore need to be addressed.

Factors which limit performance include the time to reach steady state (requiring a relatively short distance between thermal source and sink), and temperature drops across the interfaces between the modular parts (making the use of a heat transfer paste mandatory). The latter problem has led to a questioning of the validity of the original design decision for modularity. The elimination of the interfaces improves system accuracy, but diminishes the value of the experiment as a teaching tool. Detailed designs of the equipment are available on request. Values of thermal conductivity were obtained over nearly three orders of magnitude (copper to glass) which are within ±20% of "*book*" values.

Group Dynamics

As seen by the students

At the first meeting of the group most of us were very uncomfortable. Before this, we had all only ever worked by ourselves or in pairs. It was disconcerting being in a room with "*green*" First years, "*questioning*" Second years and "*omniscient*" Third years. The tension was lifted somewhat when the academics introduced themselves on a "*first name*" basis and things became easier.

Initially, group discussions were subdued. It was hard to interrupt someone you didn't even know. Some of the First years were a bit intimidated, and some of the people involved did not actually say anything at all for the first few weeks. Once it became apparent that certain individuals would simply never stop talking unless you interrupted them, the whole discussion process became a lot smoother.

Another problem in the first few weeks was the barriers that needed to be broken down between students from three years. There were obvious differences in knowledge between years, best illustrated when the Third year students were asked to explain the heat transfer equation to the rest of the group, resulting in a lot of blank faces. Soon it became apparent that no one understood the basic concepts of heat and temperature very well. We know them now, though!

The management of the group fell to the academic staff. Originally they had their own ideas about how the experiment should look, but withheld these thoughts, wanting to see what we came up with ourselves. When the group digressed (as seemed to happen more often than not) or got confused about aspects of the theory or design, it was one of these three who got us back on track with some advice, guidance or explanation. In the first few weeks, we all looked to them for instructions. Many of us were unsure of what we were supposed to be doing, but as the project proceeded everyone gained more enterprise and independence.

The primary advantage of these guiding hands was the enormous amount of experience they provided. Between them the academics had many years of experience at teaching physics and at working in and managing groups, and this proved invaluable. They continued to amaze us by successfully predicting exactly what we would be thinking at different stages of the project. When our initial design yielded results that were out by ridiculous amounts, they told us that the problem was caused by the air gaps between the parts - something that had simply not occurred to us.

On the down side, sometimes the group felt stifled by this guidance. On one occasion, the group had been talking for an hour or two about different designs and their problems, when Professor Cram interrupted the discussion and proposed his own design. His idea was a lot better than any of ours but the fact that it completely displaced all our previous ideas made us all feel a bit like excess baggage. Professor Cram also occasionally observed that ▷

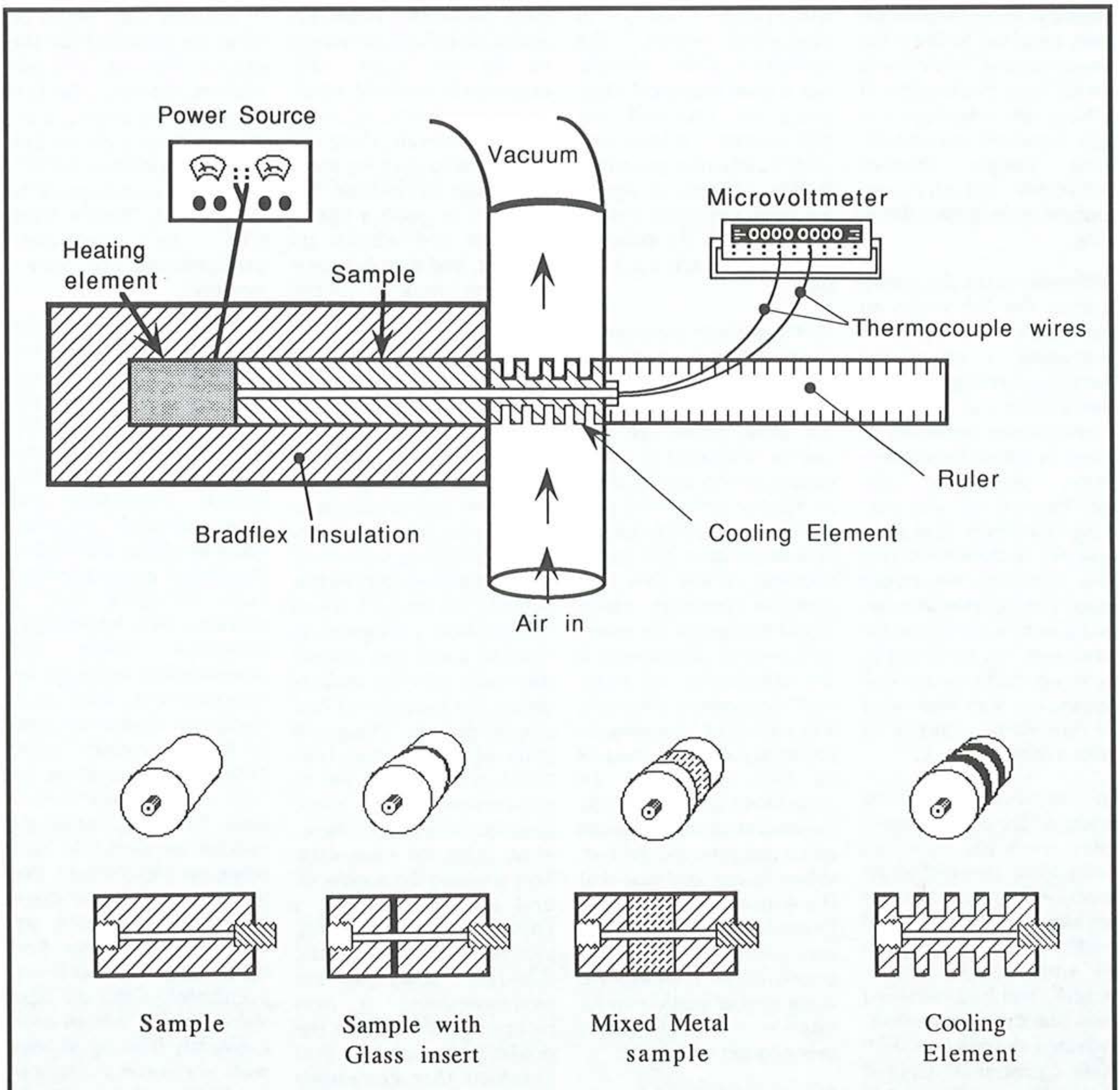

Fig 1 **Schematic diagram of the thermal conductivity experiment**

the project had now moved into a particular, well-known phase or that he was excited to see what we would do next. All this made us feel like guinea pigs or rats in a maze under observation, but in a sense, I suppose we were. The whole experience was new to the members of staff as well as to the students, and we didn't always follow the most expedient route to our destination.

Although we all felt uncomfortable at first, very soon individuals began taking clear roles within the group. Some people were consistently optimistic, some were pessimistic.

Some were continually concerned with technical details and difficulties, others liked to discuss the soundness of our theoretical arguments. Obviously the biggest difference in participation was between those who said too much and those who said too little. It was satisfying to note that as the project wore on, everything evened itself out. In the end it was fair to say that everyone made at least one intelligent contribution to our discussions. The requirement of having to co-operate over an extended period of time forced people to change their patterns of communication. Extroverted people learnt restraint, and the quiet ones realised that others wanted to hear what they had to say. The more senior students learnt to have patience in explaining their ideas, and the rest of us made more of an effort to understand.

As a learning experience, working in a group was invaluable, and we all gained something as a result.

While each week we all met and discussed the project for two hours, during the week we were breaking into ▷

subgroups to accomplish the tasks required to keep the project running. While things would have been better if division into subgroups was more organised and specific, some people showed incredible industry and application in getting things done.

Different tasks included writing the lab notes to accompany the experiment (including a crossword puzzle), investigating the workability of making themocouples ourselves in order to measure temperature, examining the specifications of, and ordering equipment, and error analyses to determine just how accurate we could expect our experiment to be. Doing extra work during the week was not specifically worth any marks, so any task undertaken was motivated by interest or a desire to make a contribution.

The most disheartening aspect of the project was a three week period when everything seemed to go wrong. At this stage, we had submitted what we thought would be our final design to the workshop for manufacture, and had received some prototype components. Repeated experiments with these components yielded results that were not only wildly inaccurate but also hopelessly inconsistent. Extra effort and precautions seemed to make no difference, and we were at a loss over what to do next. Many of us began to lose interest, or think that we were just not cut out for research work. The project seemed to grind to a halt. The problems turned out to be very simple and was related to errors. We had not realised that the errors in our readings were large compared with their values. We had large temperature drops across interfaces, and were using input powers which were too low to reduce other temperatures variations to negligible levels. The realisation of this difficulty was a giant conceptual leap. Once we changed our procedures, minimising errors became routine. Within a couple of weeks, we were obtaining results within 20% of the expected value and were back on track.

As the project progressed, computers were both our friend and foe. In our first rough ideas for the design of the experiment, we had visions of dozens of temperature sensors placed along an iron bar along which heat was flowing, all connected to a data logger. This would transmit all the data to a personal computer, which would then graph the results and perform calculations. If the experiment was to be time dependent, then this was seen to be tremendously advantageous, and most of us had visions of an experiment where basically the student sat at a keyboard and a computer did the rest. When it was decided that the experiment had to be primarily time independent it was necessary that measurements of temperature along the bar would now be taken with a single sensor over a longer time span.

The need for computer was now lessened but we were still still enthusiastic about the idea. The problem with our great vision came when we recalled a particular experiment in the standard physics course which consisted solely of computer work, and which was by far the most boring experiment any of us had ever done. We had already gone to so much effort to try and make our experiment interesting; were computers going to make it deadly dull? Other problems also became apparent. The basic purpose of a computer in experimental physics, it was agreed, was to store and analyse large amounts of data, especially when this would be difficult or tedious to do by hand. Our experiment involved measuring the temperature at regular intervals along the apparatus to give no more than about 30 readings. We then had to graph a line of best fit and obtain its gradient, and then put some numbers into a simple formula. Surely this was standard undergraduate, if not even high school fare?

In what almost amounted to a coup d'état, the case against computers was excitedly put forward in group discussion with those fighting for the computers only countering with weak arguments. It was agreed that it might not be such a bad thing to have a computer on hand to graph and analyse the results after the students doing the experiment had already done so. This would provide a comparison between their result and its uncertainty, and a more accurate computer calculation using the same data. This provided the novelty of, and experience with, a computer while still forcing students to exercise the standard skills of experimentation. It was interesting that when the project began it was assumed that computers would play a major role, and we were all rather surprised when we realised that we didn't actually need them after all.

During our first meeting, when the logistics of the program were being explained to us, we discussed the topic of assessment. The program was replacing our normal laboratory course, and so had to be worth a similar number of marks. Deciding to try something new, Professor Cram told us that we would be giving ourselves the marks for the project. In the final week, we were to submit a mark out of 100 with our justification for it, and this mark would be what we received for the project. This was first met with incredulity. The first inevitable comment was, "Great! This means we can all give ourselves 100%", and the second, quick to follow was, "One's mark will be inversely proportioned to one's morality".

But as we soon realised, the method of self-assessment is a lot more than choosing what mark you want. Each week, we filled in a self-assessment sheet containing five categories: experimental, theoretical and computational physics, communication and understanding of group activities. Each category had 3 sections: new knowledge, improved insight and understanding, and scope for improvement. After each discussion session we tried to give ourselves some comments or a rating on how we performed in each area. The most important column we were told, was scope for improvement. We were to judge our mark based on how much we needed to improve one week, and how well we accomplished this the next week. The fact that we were constantly thinking of how well we were doing (or could have been doing) made it very hard to inflate our marks. If anything we all had a tendency to under rate our performance and ability and had to be constantly encouraged to give ourselves better marks. Included in the assessment procedure was a short essay on group management worth 25%, which was returned to us with comments, and then assigned a mark by us. As the project progressed, self assessment worked better and better. It was a key element in ensuring everyone did their fair share of work, as those who tended ▷

Continued on page 6

disciplinary projects is a good test of students' communication skills. As the final presentation of the project was very critical, students also had experience in digital video recording, quicktime etc.

One staff member and one student from the teams winning second and third places will fly to Cupertino for the final presentation.

Suhashini Shankar worked on this project as a graduate student in Physics at UTS and is now an Associate Lecturer in that department.

Editor's Note: Further details of this project will appear in a future issue of the Physicist. ◆

AN INTERESTING PHYSICS EXPERIMENT *Continued from page 4*

to let others do all the work during a particular week promptly give themselves a shove from behind the next week, having calculated their performance and realising they could have made a better contribution. Everyone was constantly striving to do better, so that they could give themselves a good mark, and feel that it was justified.

It was generally agreed that the experiment was a success. Some comments from members of the group included "an excellent exercise in self-assertion", "self-assessment is too difficult", "the method of learning is appropriate", "a fantastic learning experience", "the only thing I have been to regularly this semester" and "not enough elephants".

There was room for improvement however. If the program is run again next year some things will have to be changed. A specific agenda would give the whole project a more organised feel. The staff involved probably should have provided more supervision, and less input, and certainly division into subgroups should have been a more organised process. But apart from structural problems, the program was a lot of fun, and can be regarded as a resounding success.

Self Assessment

By the end of the program students had mastered the spirit of self assessment and had become reflective about and more engaged in their learning. Student insights expressed through the self-assessment reports included "in the past I groaned every time I thought of doing an experiment.......now I get genuine enjoyment out of doing one.....making more of an attempt to understand the physics", "perhaps the most interesting aspect.....is the power dynamics of the group," "I'd assessed my practical skills before I was required to demonstrate to the First Years......gave myself a higher mark."

The range of marks allocated by students was understandably narrow, given that they were selected from the top. No student failed to think very carefully about their performance in absolute terms and relative to their peers. Some students were too hard on themselves, but could be persuaded to give themselves appropriate "marks".

The experiment in self assessment was a success, and appeared to contribute to the goal of increasing the breadth of learning in experimental physics.

Conclusion

The comments above clearly indicate a consensus amongst the students that this was a successful initiative. The feelings of the academic staff are very similar - some regard it as their most exciting teaching (and learning) experience. The project did not get as far as we had hoped. The test drive in the undergraduate laboratory effectively had to be abandoned because the equipment was insufficiently characterised and the laboratory notes not adequately prepared.

In our next activity, it will be necessary for the staff to provide a little more guidance, particularly in the early stages, and in the establishment of an appropriate time-scale for critical activities. Nevertheless, we commend the idea to others involved in undergraduate teaching - you will find it most rewarding! ◆