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Learning Physics in the Laboratory

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INTRODUCTION

Among students and many people in the wider community, physics is perceived as a discipline which emphasises the acquisition of rules, theorems, procedures and skills in highly abstracted forms at the expense of meaningful integration of knowledge with technology and everyday occurrences (Romer, 1993). Assessment methods reinforce this approach with success in examinations being heavily dependent on factual recall and rote learning. The situation is similar in the traditional undergraduate laboratory. Many student physics laboratories reveal a history of the teacher as the sole source of a body of knowledge which is transmitted to students through controlled verification exercises (Hegarty-Hazel, 1986;1990). There is little or no encouragement for independent investigation or scientific enquiry. Students are rarely asked to explore a phenomenon, develop a procedure, design or construct apparatus or formulate tests on scientific models. The learning experiences do not seem to be characterised by recognition of the student as a learner, by student autonomy or, by students' reflecting on their learning. Overall, it seems that students have a very narrow range of learning experiences in physics laboratories and a poor appreciation of the role of physics in industry and everyday life.

The need to reform traditional physics laboratory programs and introduce new approaches to laboratory teaching and learning cannot be overemphasised. Too many students are put off physics by its lack of humanity and never experience the thrill of designing an experiment and putting the laws of physics to work. All too frequently students complete first year physics with only a 'textbook' understanding of the subject and are unable to relate even the simplest concept to a physical reality. Undergraduate students in chemistry, materials science, geology and engineering who do not continue with physics beyond their first year are often left with a false impression of physics and its fundamental value to the education of all science and engineering undergraduates. At the University of Technology, Sydney (UTS) a significant number of Physics majors either lose interest in the subject or are not convinced there is a future in studying Physics, and transfer to other degree programs particularly Electrical Engineering.

An enquiry approach to physics laboratory teaching has been introduced for first year undergraduate students enrolled in the School of Physical Sciences at UTS. Student learning is problem oriented emphasising the links between physics and human activities in a context that is easily identified by the students and related to their own knowledge. The importance of scientific enquiry and experimentation is promoted as a method of problem solving and as a means of being involved in science and scientific discovery. Teaching laboratory physics by stressing the nature, structure and processes of science, and encouraging the use of higher cognitive skills, offers a broader range of learning experiences than traditional content-driven and instruction-based laboratory programs (Stinner, 1989; Wheatley, 1991). Students gain experience of transforming qualitative ideas into measurable quantities and, conversely, transforming experimental data back into something that can be understood by a non-scientist (Klopfer, 1990). Class discussion is fostered to encourage interaction amongst students, and greater autonomy and accountability by each student to the student group rather than the laboratory demonstrator. In this way we seek to make laboratory physics exciting, informative, rewarding, and personally and vocationally relevant to the students' chosen careers.

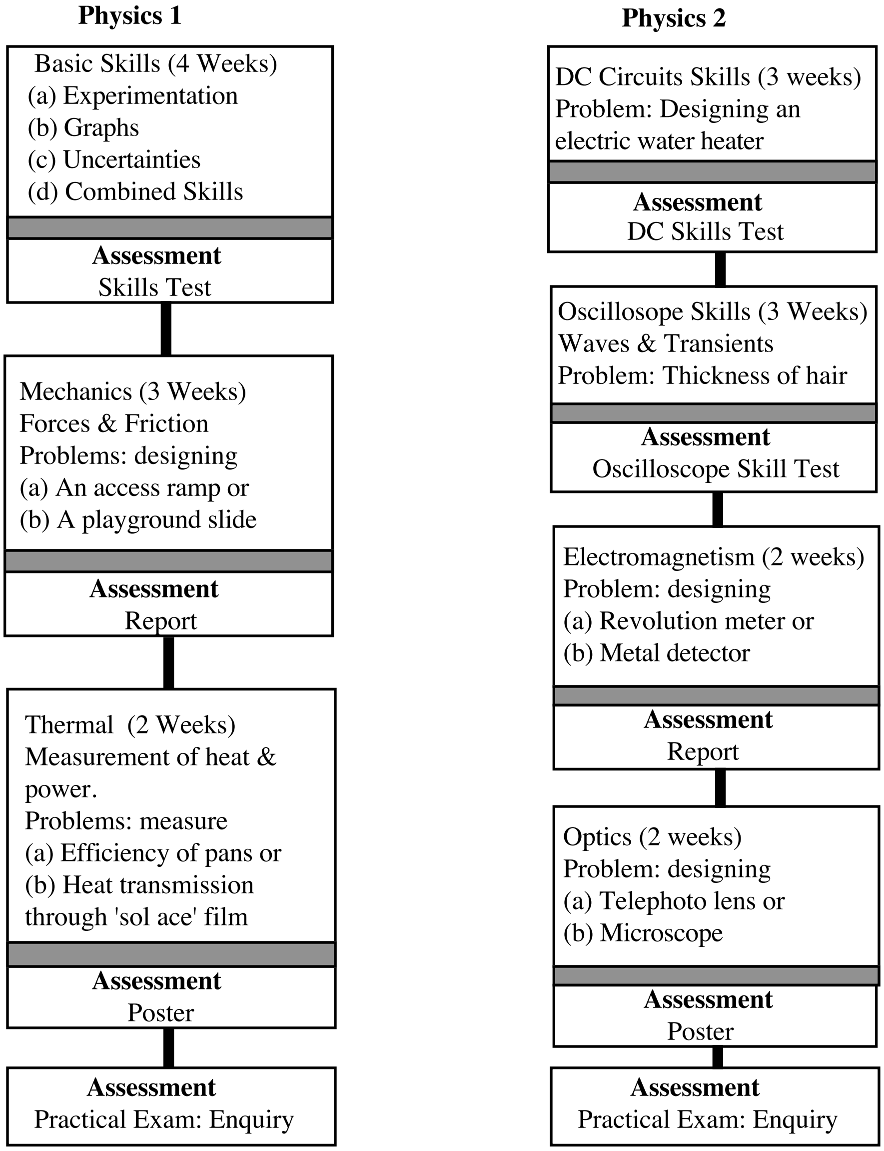
In this and an accompanying paper at this conference (Gosper, Cheary, Hazel & Kirkup, 1993), we will describe some of the developments that have taken place at UTS to introduce a new first year physics laboratory program. This paper describes the practical aspects of its implementation; the type of experiments we have introduced and the method of presentation adopted to create relevant, less traditional and more gender inclusive experiments.

FIRST YEAR PHYSICS FOR PHYSICAL SCIENCES STUDENTS AT UTS Physical Sciences programs at UTS are committed to supplying graduates to commerce and industry rather than the traditional university research pool, as such, there is an emphasis on applied science. Each year up to 200 full time and part time students enrol in Physical Sciences majors of which 160 to 170 are non-physics majors (ie. chemistry, geology and materials science). All of these students undertake a common first year physics program which consists of Physics 1 and Physics 2 over consecutive semesters. Each course consists of six hours per week of formal contact time with laboratory work taking up 2.5 hours per week and lectures/tutorials the remaining 3.5 hours. Both courses are traditional introductory physics courses; Physics 1 deals with mechanics and thermal physics whilst Physics 2 covers electricity, waves and optics.

Before 1993 the laboratory components of Physics 1 and Physics 2 consisted of experiments based on abstract themes, verification of formulae and data analysis. At best, students gained some low level analytical skills from this approach and little else (Hegarty-Hazel & Cheary, 1993). It was the view of the staff of the Department of Applied Physics that the laboratory program was unlikely to enhance students' interest or sense of excitement about physics, unlikely to motivate students to continue physics studies at a higher level, unlikely to help develop positive attitudes to science or build scientific literacy. Moreover, the laboratory program offered an uninspiring impression of physics and did little to justify the importance of physics in the education of a non-physics majors.

GENERAL THEMES OF THE NEW FIRST YEAR LABORATORY PROGRAM During 1992, the Department of Applied Physics at UTS, with the aid of funds from the Australian Government, undertook a review of its laboratory programs and at the start of 1993 introduced a new enquiry based program for Physics 1 to a group of 64 students spread over four different laboratory groups. A corresponding program for Physics 2 commences in the Australian Spring semester 1993. The steps leading up to these changes and the formulation of new aims and objectives are described in more detail in an accompanying paper by Gosper, Cheary, Hazel & Kirkup (1993). Following the trend set by the Workshop Physics program (Laws, 1991), we have adopted a policy of “less is more”, but from a different perspective. The number of experiments students are expected to do has been halved and as a consequence only a limited number of topic areas are covered in the laboratories. An overview of the programs for 1993 is illustrated in Figure 1 below.

Figure 1 Laboratory programs for first year physics at UTS



Each program is divided into several units of work which focus on a particular theme, for example, experimental skills, mechanics, thermal physics, DC circuits, oscilloscopes, electromagnetism and optics. The areas chosen for each unit involve phenomena that are amenable to observation, are covered in the lecture program, and have a context that students can readily identify. Each unit of work is designed as an integrated learning experience, as opposed to a series of unrelated experiments, with some experiments extending over two or three weeks. By using this approach we hope to provide students with the opportunity to become familiar with new equipment, procedures, concepts and applications. This should afford students the opportunity to reflect on and consolidate their knowledge, and to engage more effectively in the process of enquiry. Over the semester the program progresses from a prescriptive approach with directions provided, to one which allows students more autonomy and the opportunity to take a more active role in the design and refinement of their own experimental models. Feedback to staff was obtained through weekly meetings with the laboratory demonstrators involved in the program, and by interviewing participating students. This provided the means for program developers to identify problems and make appropriate changes for the future.

CHARACTERISTIC FEATURES OF THE LABORATORY PROGRAM The new program features many of the characteristics of an enquiry oriented program. These have been identified by Friedler & Tamir (1990) as: the teachers being less direct, more planning taking place, the processes of science receiving more emphasis, more discussion, the teacher giving fewer instructions in front of the whole class and moving around more, checking, probing and supporting, and students being more active and initiating ideas more readily. During the planning and implementation of the program shown in Figure 1, a number of important conditions and approaches were deliberately incorporated into the experiments to support our aims, to motivate students and make the learning process more enjoyable and rewarding. These are discussed below. We have included the guidelines handed out to students for two of the experiments in the Physics 1 program, “Modelling a Film Stunt” and the “Thermal Efficiency of Pans”, as Appendices 1 & 2 at the end of this paper. These contain important elements of the features discussed below and are refereed to for illustration.

(a) “User Friendly” Physics

Physics is often described as "impossibly difficult and incomprehensible without an advanced course in mathematics. Physics is a vast collection of formulas. Science is cut and dried, and scientific truths are final" (Romer 1993). In many instances this is the view of physics held by a large number of students entering university. Altering this conception of the discipline and demonstrating to students that the world of physics is open to all, and that the solution of sophisticated scientific problems is feasible without a vast knowledge of physics, was a central issue in the planning of the new program. One of the early experiments is based on a film stunt involving airborne cars (see Appendix 1). The experiment proved to be popular with students and it introduced physics in an exciting and engaging way through the modelling of a real life situation. It also demonstrated that when students are relaxed and confident with their experimental set-up they contribute more to class activities. More importantly students realise that they already possess valuable knowledge about physics, sufficient to satisfactorily undertake the experiment and make decisions on the type of conditions that will produce both a spectacular and a safe stunt. These conclusions would be very difficult to predict theoretically, thus emphasising the value of experimental science. The stunt experiment also fostered the notion that physics does not depend wholly on formulae and novices can actively participate in physics without highly specialised knowledge. In other experiments we have introduced items used in the home, such as cooking pots, or items that can be purchased in supermarkets. Throughout we have tried to keep equipment simple except where we believed it was essential to the students' education (eg. the oscilloscope). In such cases we put the students through a skills program so that they are not troubled by the equipment in later experiments.

(b) Putting physics in context

One of the principal aims of the program is to humanise physics and release it from the realms of being abstract, inaccessible and likely to produce anxiety. As a means of achieving this, experiments are no longer developed as isolated laboratory exercises, they are developed within a meaningful context. From the controlled exercises at the start of the semester to the extended experiments later in the semester, the relationship between theory and everyday practice is repeatedly emphasised and experiments without an obvious or explicitly described context are not included in the program. This process is essential if physics is to be viewed in a positive way and as a constructive and integral part of the education of non-physics majors. Some applications of physics and physicists surprise students who often have a limited view of the subject and from this viewpoint alone it is of value to include a variety of contexts. In the controlled exercises which form the laboratory skills component we have introduced context through modelling stunts, by measuring the salinity of Sydney Harbour, by calculating the "stickiness" of adhesive tape and by investigating the light levels across spot lights. Higher levels of scientific enquiry are pursued in the later experiments by using examples that everyone in the class can appreciate. The concepts of forces and friction are investigated by requiring students to design either a ramp into a building or a playground slide.

A meaningful context provides the basis for students to be able to recognise the underlying theoretical principles and strengthen the links between theory and practice. It is important for students to recognise that the experimental procedures and skills they are introduced to are more than isolated experiences encountered in a laboratory. When placed in context the usefulness of taking accurate measurements and calculating uncertainties becomes evident and provides students with a working framework they can confidently apply to other situations. The context is reinforced by requiring students to write a report to various members of the community, other than scientists, based on their results. For example, as part of an experiment on uncertainties, comparing the "stickiness" of two adhesive tapes brand X and brand Y, students are required to prepare a short report for an Executive Officer of a company which manufactures brand X. With this as a context, students readily recognise the relevance of uncertainties and the need to take multiple measurements if they are to be sure of their "facts" before reporting to the Executive Officer.

(c) Fewer instructions and pre-lab work

Before 1993, students were provided with a 200 page laboratory manual of prescriptive experiments and extensive theoretical background information that very few of them ever read! In the new program the experiments have fewer instructions requiring students to participate in the planning of their experimental procedure. The experiment guidelines handed out to students, such as those in the Appendices, are typically one or two pages in length including diagrams, with well defined sections outlining the learning experiences, the contextual background, the guidelines for doing the experiment and the problem arising out of the context. To facilitate the planning process, students are given compulsory pre-laboratory work, a week in advance, which is directly related and highly relevant to the laboratory investigation or theme of the following week. In addition to calculation based pre-lab work, students are also given pre-lab work on experimental planning, critical analysis of report writing and poster presentation. The knowledge and background gained from pre-lab work is critical in helping students understand the experiments and make sense of new experiences. Further support is given to students through group planning discussions which are held at the beginning of each session, concluding with representatives from different groups being invited to present their plans to the class. This has been successful in alerting students to the range of options available, and giving them the opportunity to refine their own procedures and learn from other students rather the demonstrator. The role of the demonstrator therefore becomes that of a facilitator leading discussion and encouraging students to think for themselves or amongst themselves.

Although initial evaluation has shown that fewer instructions are generally favoured by students, there are those who felt more guidance was necessary in some experiments. Students have a range of backgrounds and confidence in physics so it is up to individual demonstrators to determine when and how much extra assistance is necessary for students to understand the experiment.

(d) Problem solving

Many undergraduate students (and staff!) believe that undergraduate physics experiments exist to verify physical equations. Even after a semester of the new program this myth has not been dispelled. It is important for students to recognise that applied science exists to solve problems of relevance to industry and the general community. In the new program we introduce this notion of applied science in the very first experiment and continue the emphasis throughout Physics 1 and Physics 2. On entering University students possess some skills in solving textbook puzzles but are very rarely able to solve practical problems using a scientific approach. Most students have had no experience of converting ideas and concepts into tangible measurements in the “real world”, or working out measurement strategies to solve problems. Solving practical problems by scientific processes requires high level skills involving the ability to describe observable events in terms of physical measurements and recognising how those measurements can be used to solve problems. Two important aspects involved in solving practical problems are addressed in the new program; the physics or conceptual framework underpinning the problem, and the process by which the physical concepts are expressed as measurements and then converted into a qualitative “humanised” solution. In recognition of the importance of an appropriate framework and qualitative reasoning, particular care is taken to place experiments in a context students can easily recognise. This allows the problem solver to recognise the underlying concepts and principles involved which can then be used as a guide in devising, executing and monitoring a plan of action (Mayer, 1992).

In the experiment based on “Modelling a Stunt” (see Appendix 1) the students are asked to model the conditions for a stunt to be both safe and spectacular given certain constraints. They identify the qualitative problem and have an intuitive understanding of the theory involved, but find it very difficult to devise a plan of action which will provide them with a solution. They are unfamiliar with experiments that mirror the types of problems encountered by applied scientists in a work environment. Developing a strategy for solving a problem experimentally is a new phenomenon for the overwhelming majority of first year students. They feel uncertain and a little insecure at first. It is at this point that group discussion becomes important because students are made aware that the anxiety and uncertainty they are each experiencing is something common to all the class. With careful guidance the group formulates a systematic measurement strategy. After collecting the data students find that surprisingly clear patterns emerge, which enable them to make informed and reliable recommendations to the insurance company. In particular, they identify that a take off angle of approximately 25° is the optimum; below 20° the car does not gain enough height to pass the hole and above 30° the motion of the car is not reproducible and does not always pass through the hole.

A further example of an experiment with a problem orientation is the investigation of frictional forces expressed in the context of designing either a ramp for the disabled or a playground slide for children. Students readily appreciate the desirable qualities of slides and ramps, and can see the necessity for investigating friction and whether factors such as surface area and weight are significant. They also have to interpret their results and write a consultants report which is to be read by non-scientific personnel.

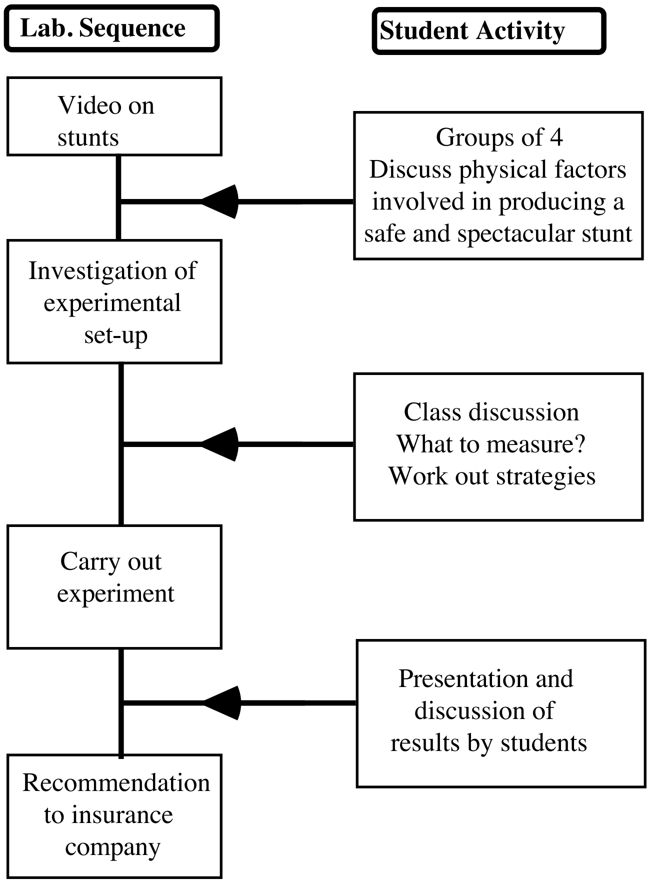
(e) Self-Direction, Class Discussion and Communication

An important aim of the present program is to assist students to become responsible for their own learning and develop a sense of self direction and autonomy. This is implemented in part by letting students determine their own experimental procedures provided they are addressing the problem posed and suitable equipment is at hand. This approach has been possible because some experiments extend over more than one session. During the three week experiment on forces and friction it was gratifying to see that in one laboratory class the eight different student groups had each adopted a slightly different method of measuring the coefficient of friction even though they each had the same set of apparatus. Staff were surprised at the creativity and talent of some students when given the opportunity of setting their own agendas. Moreover, many students develop a strong sense of ownership of their work and have a sense of individuality which is not present in a laboratory setting where many groups of students are following identical procedures.

Class and group discussions are encouraged in the initial planning stages of the experiment. In addition, further formal (and informal) discussions are encouraged during the experiment where appropriate. At the end of each session a post-lab discussion has proved valuable for summarising the events of the day, consolidating ideas and enabling students to present their results to the class for positive comment and criticism. Demonstrators have found that students focus their attention on tasks and make an extra effort to understand once they realise they may be required to present their work for peer review. Although there are differences from week to week, three formal periods of “student discussion” per laboratory period, each lasting anywhere between 10 and 30 minutes, would be typical of most of the experiments although one or two of the earlier experiments may have more short sessions. Figure 2 below illustrates the structure of class discussion in the "Modelling Film Stunts" experiment (Appendix 1). During the two and half hour laboratory class there are three sessions during which students are either discussing the problems of setting up a stunt and the physical parameters that need to be considered, deciding what are the critical measurements and determining possible experimental strategies, or discussing the outcomes of the experiment.

The majority of students find class discussion valuable particularly those with a weak physics background from school. Being able to talk to others as part of the learning scheme makes it easier for them to carry out the experiment and gives the demonstrator the opportunity to identify their problems. We have come to the same conclusion as Heller, Keith & Anderson (1992) who found that better problem solutions emerged through co-operative group learning compared with individuals working independently.

Figure 2 Breakdown of Laboratory Sequence and Student Contributions in the "Modelling a Stunt" experiment in Appendix A



Formal communication is integrated throughout the program through class discussion, through pre-lab work and as part of the assessment process. Teaching time is allocated for introducing students to formal report writing. Addressing this issue explicitly over a number of sessions has resulted in students' first attempts at writing reports being at a higher standard than in previous years. Students are required to make the problem to be solved the focus of the report. A number of our experiments are based on consumer products and assessing the quality of these products, and in each case the student report is in the form of a recommendation directed at people without high levels of scientific knowledge. In the “Stunt Modelling” experiment the report is addressed to the insurance company covering the stunt concerned. With this approach the report becomes an integral part of the experiment unlike in many traditional undergraduate experiments where the report is seen by students as an unnecessary appendix. Another form of report used is the poster presentation; a method of communication encountered in both the academic world and the business world. The poster requires students to distil their investigations down to the basic concepts, requiring a thorough understanding of the principles involved. An example where this is used is the "Thermal efficiency of cooking pans" experiment summarised in Appendix 2. The task for the students is, "To present a poster for display at a shopping centre which will attract attention, advertise your chosen pan, and support the claims of thermal efficiency". Once again the students are given guidelines on designing and presenting posters during class time and through pre-lab work. An added benefit for both staff and students is the opportunity for students to reveal a creative side to their intellectual development that is often overlooked in physics classes.

CONCLUDING COMMENTS

By incorporating the features described above into the new laboratory program the level of openness for enquiry has been increased quite markedly over the old program. Using the scheme of Herron (1971) adapted by Hegarty-Hazel (1990) which is illustrated in Table 1 below, the majority of experiments in the new program are classified as level 2A. At this level students have the opportunity to experience enquiry without placing unreasonable demands on the Department's resources. Controlled exercises at level 1 are still required to develop fundamental skills and techniques that need to be well specified and practiced to a high degree of competence. These are particularly useful at the early stages of Physics 1 for students who have had little or no experience in a laboratory environment.

Table 1: Levels of Openness for Scientific Enquiry

Level	Aim	Materials	Method	Answer
0	Given	Given	Given	Given
1	Given	Given	Given	Open
2A	Given	Given whole or part	Open or part given	Open
2B	Given	Open	Open	Open
3	Open	Open	Open	Open

Now that an enquiry based laboratory program has operated for one semester with a large number of students, the next priority is consolidation. This can be done by expanding the number and scope of options available to give the program greater depth and prevent it from reverting back to a traditional program. Most importantly, it will be necessary to set up structural mechanisms within the Department, such as regular staff development and review programs to help maintain freshness and vitality for staff and students over the coming years. While "science as enquiry" has been successful for the physical sciences the wholesale application of this approach to all laboratory teaching may not be appropriate. A parallel program for enhancing laboratory teaching and learning for engineers is planned to start in the near future but before any planning decisions can be made, the role of physics education in engineering will have to be reviewed to formulate a new set of aims and objectives.

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APPENDIX A EXPERIMENT A : MODELLING A FILM STUNT

Planning a Film Stunt

There is no higher or lower knowledge, but one only, flowing out of experimentation

Leornardo da Vinci 1452-1519

Learning Experiences

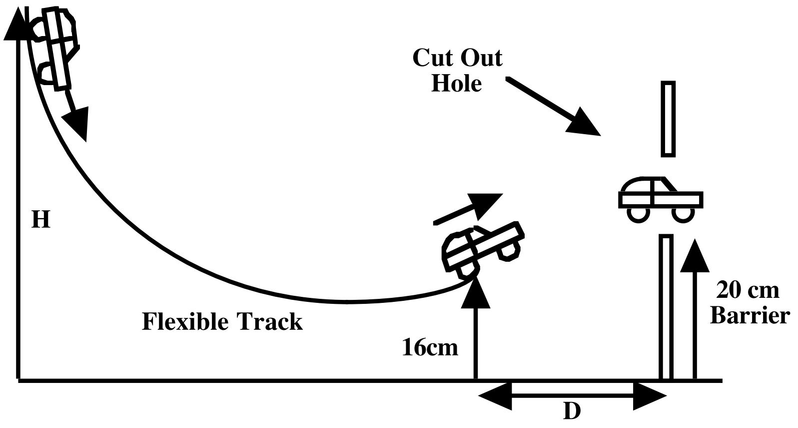
1. To set up an experiment and take measurements in a systematic way
2. To record and tabulate measurements
3. Use measurements to draw conclusions

Background to Experiment

This experiment has its basis in a film stunt in which a car takes off from a ramp and crashes through a brightly coloured neon advertising sign. Before allowing the stunt to go ahead the insurance company covering the stunt insists on a rigorous preliminary investigation to establish what the car would do under different conditions. The physicist advising the film crew did this by simulating the event with a small scale model similar to the present experiment.

Equipment Available

You are supplied with a fixed length of flexible plastic track and a model car which can roll down the track. In this experiment the car is released from the top of the track and takes off at the end of the track which is to be fixed at exactly 16cm above the bench as shown in the diagram below. The car is required to pass through the cut out hole in the box supplied. This is equivalent to going through the neon sign.



THE PROBLEM

What the insurance company wants is information on the 'track conditions' that will result in the car passing through the hole without hitting the box either above or below the hole. For this experiment the 'track conditions' can be represented by two things; the starting height H which can be increased up to ~75cm and, the take-off angle which should be limited to a maximum of 40° to avoid damaging the track. By varying these parameters in a systematic way and examining whether or not the car passes through the hole, you should be able to draw up a table of measurements giving a range of D values for each set of 'track conditions'.

How you go about this experiment is your decision. Before starting you should agree with your partner on (a) how you will make the measurements and what instruments you will use (b) the order in which you will carry out the measurements.

APPENDIX 2 EXPERIMENT B: THERMAL EFFICIENCY OF PANS

Thermal Efficiency of Cooking Pans

One must learn by doing the thing; though you think you know it, you have no certainty until you try

Sophocles 495 - 406BC

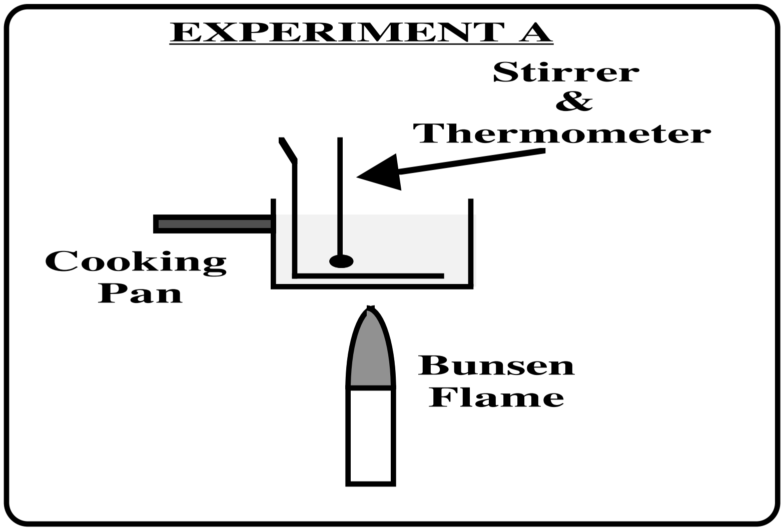
Learning Experiences

1. Understanding the relationship between heat and power
2. Measuring heat and power
3. Deriving and interpreting results and uncertainties from graphs
4. Presenting results and discussion as a poster

Background to Experiment

There are many retail items used in the home which should be designed to either use heat energy efficiently or prevent heat being transmitted. A cooking pot on a gas stove should be designed so that all the thermal power in the flame reaches the contents of the pan. In practice, cooking pots lose heat. This experiment is concerned with measuring thermal efficiency.

EXPERIMENTAL DETAILS



GENERAL GUIDELINES

The thermal efficiency ε of heat uptake by two different types of cooking pans is defined as

$$\varepsilon = \frac{\text{Power absorbed by pan contents}}{\text{Power supplied by flame}}$$

This experiment can be divided into two parts.

Part 1:- First we need to know how much power is supplied by the flame. To do this we use a special copper calorimeter containing water which is designed so that all the heat from the flame is transmitted to the calorimeter and its contents. To prevent heat losses this calorimeter needs to be well insulated. Assuming the mass of water and the mass of the copper are known, then the power supplied by the flame can be determined from measurements of the rise in temperature with time.

Part 2:- The power absorbed by the pan contents is the rate at which heat is supplied to the water. This can be done by measuring the rise in temperature of known mass of water with time

Requirement

(a) To devise and carry out an experiment to determine and compare the thermal efficiency of a thick copper based pan and an aluminium pan.

(b) To present a poster for display at a shopping centre which will attract attention, advertise your chosen pan, and support the claims of thermal efficiency. Include the method of investigation, the measurements obtained(with graphs) and discussion of your results in a manner easily understood by a person with a high school education.