A practical project resource book

Roy Skinner

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A PRACTICAL PROJECT RESOURCE BOOK

Dr. ROY SKINNER
A PRACTICAL PROJECT RESOURCE BOOK

Dr. Roy Skinner

Edith Cowan University
Churchlands
Perth, W.A.
DEDICATION

To my wife Sylvia and our seven children who supported me in this enterprise and cheerfully accepted the ever closed door.

Grateful thanks to Gordon Smith and the CREST-N.Z. team at Massey University, Denis Burchill, Glynn McGregor and especially Professor Derek Hodson for their helpful criticisms and enthusiasm for REAL science.

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February 1992

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INTRODUCTION

(NB The WA equivalent of Science Fair mentioned throughout is Science Talent Search.)

1.1 PRACTICAL PROJECTS

This book has been written to help school students like yourself to produce better science projects. Project work of a practical kind would not have been very common when your mum and dad were at school, but over the last few years or so most schools have begun to encourage their students more and more to take up creative project work during the science courses.

You will find this work interesting and enjoyable - practical projects are fun!

You may have decided to do your project out of sheer interest and curiosity or your school may be involved with the two main project organisations in New Zealand - Science Fair and CREST. Both of these are similar in the investigative science that they are trying to encourage and this Practical Project Resource Book has been written specifically to help you with this activity.

Investigating, Experimenting, Designing, Measuring, Planning, Inventing, Thinking, Making, Observing, Communicating - are all key activities linked with good, creative science projects and are what you should aim at including in your work. Both the Science Fair and CREST schemes encourage these
activities as an essential part but each has a slightly different emphasis.

**SCIENCE FAIR**

Science Fair is an annual display held for students from different schools around the country to find the most outstanding science projects. The best ones in each school go on to the Regional Science Fair and one or two are selected to compete in the New Zealand Science Fair. Prizes and awards are made in different topic areas and age groups to reward hard work and good science skills and effective presentation.

**SCIENCE FAIR ENTRIES**

**EXAMPLES:**
Three Levels
Forms 1 and 2
3 and 4
5, 6 and 7

Three Categories
Experimental
Applied Science
Display

Two Divisions
Natural Science
Physical Science
CREST, on the other hand, is an individual award system where students know at the start the standards they must reach to qualify at a Bronze, Silver or Gold level.

Investigative science projects involve creativity, perseverance, sound scientific method, good collection and assessment of data, and often a range of technical skills. In addition, Science Fair looks to the presentation of the project as a public display. Often a CREST project can be entered in a Science Fair competition at a later date, with the addition of some more eye-catching display items such as colourful diagrams, models or posters.

Details about what is required for entry to Science Fair - display sizes, special topics, etc. can all be found out from the special Science Fair Magazine which comes to schools.

If your school is registered with CREST - N.Z. then your science teacher will also have the information sheets which tell you how to go about doing a CREST Bronze, Silver or Gold project - with helpful hints on how to register, plan your time and reach the standards (criteria) necessary to gain an award.

This Project Resource Book will not include too much of the details found in the Science Fair or CREST booklets, but the idea is to supply you with helpful hints and much more detailed information on how to be successful at each stage of your project when you reach it.

1.2 WHY DO CREATIVE PROJECT WORK?

There are several reasons why we are attracted into practical project work:
(A) ACHIEVING FEELS GOOD

If you put a lot of your own time and effort into something worthwhile and it succeeds, then it really makes you feel good doesn't it? That same feeling you get when you train hard, turn up every week for your team sport and win, then it all seems worthwhile. Whereas, if don’t put in the effort, and don’t get the best out of yourself (even if you win), then somehow it doesn’t quite give you so much satisfaction.

We all need goals to aim at and targets to reach so that we can improve, use our talents and feel good about ourselves.

Achieving goals is what motivates us or makes us want to do even better. We learn better when what we are doing has a purpose and is enjoyable.

CREST gives everyone the opportunity to achieve goals and succeed without having to beat anyone else. It does this by telling you what your personal goals will be right at the start. The goals are reached by meeting what are called CRITERIA (a tick-list of skills). All of these must be achieved to obtain a CREST award.

(B) IT IS PART OF THE COURSE

Many schools are now using practical projects as part of their science courses to give all students an opportunity of experiencing project work for CREST or Science Fair. This kind of work in the 3rd or 4th form could help you gain an award. Students find that it makes a nice change from the learning of
straight factual topic work (like Earth Science, Chemical reactions or Forces) and the kind of practical work where they follow the teacher's instructions everytime. The CREST approach is Open-Ended, which means that you take charge of your own planning of experiments. It is now possible to gain good marks in the teacher assessed project section of a school course and to enter for Science Fair or CREST at the same time.

**PRACTICAL PROJECTS CAN BE WORTH MARKS!**

(C) **WHEN YOU LEAVE SCHOOL**

A good project says something to people about you as a person that examination certificates cannot do. It shows, for instance, that you can think for yourself and take charge of your own decisions. It shows that you can solve problems and design things. Success in Science Fair or CREST means that you can persevere, overcome difficulties and stick with it.

These are many of the important personal qualities which employers and people who select students for Further Education value. What good are students who know all their school science facts, but who cannot make decisions for themselves or work without supervision? Which kind of employees will an employer value most - those who can only follow routine instructions, or those who are able to come up with creative ideas of their own?

Creative project work helps develop that independence and creativity which makes you a valuable employee in today's world, a world in which countries can only
survive economically by coming up with new scientific and technological ideas and inventions.

TECHNOLOGY in schools will be very important in the future and projects can involve you with this NOW by encouraging applied science and inventiveness. In the next few years the whole world is going to be very short of creative scientists: working for Science Fair or CREST gives you the opportunity of developing your creativity and experiencing what it is like to work as a creative scientist.

When you go to an interview for a job or maybe apply for a University or Polytechnic course it is a good idea to take along your science project to show people. The interviewers will find it interesting and the project will form a good starting point for questions and conversation. The CREST award or Science Fair certificate will also be a good addition to your CV folder.

There are lots of cases where a Project Report taken to interviews has made all the difference to the person getting the job.

**HAVING A SCIENCE PROJECT AWARD SAYS SOMETHING ABOUT YOU AS A PERSON!**

**(D) SCIENCE IS FUN**

When you work on your own project you learn a lot of good science which may sometimes involve things which your teacher doesn't even know. If you do research work on a real problem which it is important to solve it is quite exciting to gradually become an
Jane's sights set on being a vet

JANE says people usually laugh when she tells them what she is doing for the Crest Award: "I guess I can understand why. Being interested in studying veterinary science when I leave school, I wanted to do something in the field of biology so when I came across a project titled 'Establishment of drinking (teat) order in newborn piglets', I knew it was the project for me." Once she had contacted Dr Bill Smith, who became her consultant, and found some pigs to study at the Massey pig unit after arranging with the manager to give her a call when the next pig started farrowing, Jane was well on her way.

The first call to contact the pig unit came during a particularly dull biology period. "It seemed a much more exciting way to spend the morning," Jane says.

"It was pouring with rain and when I arrived my uniform was drenched. I observed the end of the birth and then made my way back to school. My wet uniform and the smell of pigs told my friends where I had been.

"That afternoon I biked out again to observe feeding (it was still raining). With overallis and gumboots on, sitting in a warm room full of sows and contained, feeding newborn piglets, the project seemed to take on a whole new light. I found it really enjoyable, being alone with them, quietly observing and talking to nobody... 40 minutes alone with a litter of baby piglets is actually very soothing."

Jane noted the birthweight of the piglets in two litters. She observed them during the first few days after birth and again four to five times during the following two weeks. Her observations were carefully recorded, the sow's teats numbered and each piglet marked on its back so Jane could carefully track their movements. She wanted to see if newborn piglets stayed in the same position on the udder.

After a settling down period of two to three days, she found they continued to hold on to one particular teat.

Birthweight, on-going growth rate and pecking order were obviously related factors.

"Milk production is better nearer the head of the pig, so a tiny piglet at birth isn't going to have the strength to get in there and fight for a better teat. A big piglet is going to push the rest out of the way."

At weaning, Jane recorded weights again. Her results were not completely written up when we spoke to her, but she was pretty sure her figures were telling her weight gain had a lot to do with which teat piglets were able to hold on to within their first few days of life.

Jane is now finishing off her Sixth Form Certificate year. It has been harder than the rest she says, but she has managed to keep going. She has taken six subjects — chemistry, physics, biology, English, maths and art.

"I'm one of those people who thankfully has good routines and I've managed to keep up."

She still has her sights on being a vet. "That's why I'm doing triple science."

She is also determined to keep working with big animals. "I don't want to work with town cats and dogs. I want to be out on the farm getting muddy."

Jane has grown up on a farm in the Pohangina Valley, 50 kilometres north of Palmerston, so she is realistic about what's in front of her. She knows loving animals is not a good enough reason to want to be a vet.

"There are plenty of girls my age who love animals and want to be a vet, but I want to do the training."

"I want to do something that's got a career."
expert in that area and perhaps come up with important answers. Wouldn't it feel great to find a cure for AIDS or make the first fusion reactor! You may not get that far, but you will be following the same kind of scientific methods in your projects as the great scientists do and get that same kick from finding out something which is useful to people.

So you learn important science facts, methods and attitudes from working on REAL problems which matter. You then have to communicate your ideas and findings to others in an efficient way - perhaps for them to make use of. That's creative science project work - that's fun!

1.4 HOW TO USE THE CREST PROJECT RESOURCE BOOK

This handbook has been written because of requests for more guidance to students on how to go about choosing topics and doing science projects - particularly for Science Fair entries and CREST awards at Bronze, Silver or Gold level. The methods and examples that are given will also help to plan mini-projects done in the classroom in the normal science lessons or at home.

The handbook can be used in two ways, depending on your expertise: if you are totally new to practical project work and methods of working, then you will probably need to read right through it as you work - attempting problems as they come up. These will improve your scientific thinking skills. If you already have experience with this kind of work, or have entered before for CREST or Science Fair, then you will probably use this as a reference book when you get stuck or need to improve your skill level in a
particular area by working on the Problem Solving Exercises (P.S.E.s) and discussing ideas with your teacher.

At the end of each section in a chapter where a new method or skill has been explained, there are references to P.S.E.s for you to try which will help you to practise and develop that particular skill. P.S.E.s are all found in the Teacher’s Guide. Your teacher will give you a copy of each P.S.E. when you are ready.

Answers or helpful hints for each P.S.E. are also found at the back of the Teachers’ Guide which your teacher will have.

Chapter 2 gets you started on choosing a possible project to work on and takes you through the process of planning how to proceed. It also contains a section on CREST and the criteria needed for success in gaining an award. If you are clear about these before you start you can bear them in mind all the way through your project. This will improve your chances of being successful.

Chapter 3 focuses on the Experimental type of project methods. Chapter 4 deals with Design-and-Make type of Projects. Examples are given to help you understand how to produce more successful projects. Chapter 5 explains what is needed for the Project Report and the presentation of your work.

NOTE:
The CREST organisation methods and administration are reviewed and updated from time to time and so some of the details referred to in this book regarding things like Registration, Consultants or other procedures will need to be checked to see that they are still current and correct. The latest procedures in organisation and administration will be found in the information sheets which CREST - N.Z. sends to the schools who have registered.
2

MAKING A START

2.1 CHOOSING A PROJECT

Choosing a project topic in the first place seems to be the most difficult part of all for some pupils - especially those who have never done a practical project before.

How do I start? - they ask.

ARTIFICIAL IVORY

Leland McInnes
Christchurch Boys High School

All throughout Africa elephants are dying. Every 7 minutes an elephant dies. That's 80,000 elephants a year, only 20% of which are killed legally. Man's greed for the elephant's tusks, their ivory, could easily cause the destruction of this magnificent creature.

One man, Dr Sakai, sought to save the elephant by creating artificial ivory. And on the Australian science show "BEYOND 2000" he claimed to have done just that, using:

- Eggshell
- Eggs
- Milk
- Titanium dioxide
- and an enzyme (I decided he most probably used Lipase).

This was then incubated for 12 hours at 90° (the temperature scale, Celsius or Fahrenheit, was left out).

I Aimed To

1. Reproduce the results of Dr Sakai, proving that the process does exist.
2. Compare the product to ivory and its substitutes.
Well, you don't have to be a research physicist to come up with creative ideas. Some Science Fair and CREST entries from younger students are quite revolutionary and outstanding. You may find that ideas for projects come to you as you go about your daily life - talking to friends, watching T.V., sitting on the bus or doing your homework. If your mind is in "search mode' and receptive to ideas at some time you will probably get the inspiration for a project which makes you think "That's it! That would make a brilliant project!"

On the other hand, that may not happen soon enough for you so you may need to go to several common sources to inspire your imagination further. There are some hints on how you might get this inspiration listed below.

(A) INTEREST

If you pick a project topic in an area which interests you then you will find that you are much more likely to work harder on it and follow it through to completion. Your Supervising Teacher should be able to set a task for you to undertake in almost any area of your interest if you cannot find one yourself: skateboarding, netball, aero modelling, animals, music, cars, clothes, gardening, stamp collecting, are all possibilities.

This could be a scientific investigation, such as "The difference in behaviour of male and female kittens" or it could involve making some useful device such as "A clothes hanger which will hold a complete netball outfit".

If the problem to be solved interests you then you will have a greater sense of "ownership" of the project than if it is assigned to you by your teacher, and you will most probably make a much better job of it.
(B) USEFULNESS

It is also helpful if the problem to be solved is a useful one to solve in the first place - useful to you, your friends or relatives, another group of people, or your pet. Finding out which kind of flower grows fastest just for the sake of making a project out of it is not a very useful thing to do. But finding out which kind of nightdress material catches fire easiest could be a really important thing to find out and to tell people about.

You should really have some important REASON in mind for doing your project, like: Helping people or Making things safer, Increasing efficiency, Saving money, etc.
Sometimes school students can find out things which adults, or even scientists, don’t know: Patrick who was doing a project involving toilet cisterns, investigated the minimum amount of water actually needed to flush effectively and he compared this to the amount of water which different cisterns delivered in each flush. The final aim of this project turned out to be an extremely useful one: - To adjust or modify household cisterns in some way and reduce the flush to the minimum level. This could save millions of litres of water a year!

(C) FIND A NEED

One group of people with real needs are Disabled people and it can be quite easy to think up devices which will be of use to them: a boiling water alarm for a blind person, a front door alarm for a deaf person or a remote arm for a person in a wheelchair. There is a definite need with disabled people which is quite clear to see, but other groups of people also have important needs if you look around and ask. One group of CREST students on a course have helped to redesign Palmerston North Airport to fit the needs of disabled travellers.

(D) BRAINSTORMING

Many people get the inspiration for a project from just looking around them and thinking. This is how lots of good inventions are produced.
Schoolboy invents a long arm for disabled

Endorse schoolboy Hamish Koford has won himself recognition in the field of science.

The 18-year-old won a bronze medal and a certificate for his prototype of an invention that allows someone in a wheelchair to reach items on a high shelf.

Hamish made the extension arm for a school project.

"I decided on the idea because I wanted to do something for someone who was disadvantaged." he says.

It took Hamish a month of trial and error to get the mechanics of the arm perfected.

"The trickiest part was working out how to make it grip on to most objects. In the end I made it out of flexi-rubber because it flexes to most shapes.

"The frame of the arm is made from plastic water pipes as it is light in weight and I used bits of an old bike for the moving parts."

Hamish's physics teacher at Auckland Grammar School, Dr Roy Skinner, says the award is part of a British scheme offered by the British Association of Young Scientists known as CREST, for "Creativity in Science and Technology".

The scheme was introduced in New Zealand by Dr Skinner.

The awards are in three categories, bronze, silver and gold. The silver awards are to pupils at Waikato Girls College and it is hoped that the gold awards will be given to New Zealand students next year when Massey University appoints a liaison officer to oversee the scheme on a national basis.

Dr Skinner says although the bronze medal is awarded for school science projects, he considers it to be much more than that.

"The criteria set down for the bronze medal meant that a project must show creativity, perseverance and application in science. The silver awards only awarded to a student who works on a project with someone in industry and the gold, yet to be awarded, will only be given to a student who comes up with something completely original."

Dr Skinner says he is particularly pleased that Auckland Grammar has taken the first bronze award because the school is usually associated with traditional things rather than breaking new ground.

"I think Hamish's award is outstanding because his contribution services a need - it is more than just a science project in the sense that it encourages young people to think for themselves."
My mum has trouble with this .................
I wish I could stop that from happening .................
Wouldn't it be nice if we could .................
I wonder how I could make this better .................
are all good starting points for a project which is relevant to you

T.V. programmes like Fast Forward or Beyond 2000 may also provide some questions to start you thinking.

(E) BOOKS

Science Project Books are also a useful source of ideas, provided that the project you choose allows you to try something of your own creative design and does not just involve following a set of instructions.

If you try some of the experiments in books on Science this can often generate ideas for projects later. For instance, after seeing how eau de cologne evaporating created coldness, a student went on to design a Butter Cooler for camping, using the same principle.

Electronics magazines, such as: Everyday Electronics, Practical Wireless, Practical Electronics, Australian Electronics Monthly, etc. are all full of good electronics and science projects, and can be bought in most magazine shops.

New Scientist and Scientific American may spark your imagination. Computer magazines such as Computer Monthly may also be a good source for project ideas.

Producing some of these devices or programs can be quite difficult and time consuming for you, but the project may still fall short on the CREST Creativity criterion for all of that. A useful hint where this is the case is to ADD creativity to the project by using the device you have built for some useful purpose e.g. make a light meter from a kit, but use it to survey the
light levels within the school or home to see if they are adequate.

Creativity could also be added to a project in the TESTING of the device, but you should consult your teacher if in doubt.

In the case of the Camping Butter Cooler the student was able to measure the butter temperature on hot and cool days as well as asking various campers to try out the device whilst they were out camping. This process of Testing and commenting on the good and bad points of a device is called EVALUATION.

(F)  SCHOOLWORK

Often, projects can be directly developed from experiments which you are doing at school in your science lessons. Your teacher may be able to help you to find a project based on a topic in your science syllabus which takes your fancy.

What food do crickets eat?
Which is the best fertilizer?
How does oiling affect frictional force?
How good is a solar water heater?
How do chemical reaction rates depend on temperature?
How do gestation periods in mammals depend on their size?
Which toothpaste is best?
How can cut flowers be made to last longer?
What colours attract butterflies?
What stones hold the heat best in a Hangi?
Which wet-suit material keeps you warmest?
(G) RESOURCE BOOK

As you read through the Project Resource Book and try some of the P.S.E.s, perhaps some ideas may occur to you which you would like to try out in your full project.

A data - interpretation question on PREVENTING APPLES FROM TURNING BROWN might be the starting point for you on a larger project involving the preservation of food. A P.S.E. from the Teacher's Guide on POWER FROM SOLAR FURNACES might spark your imagination into designing a solar furnace of your own and making one to see if it can be used to cook food. There are over 100 ideas for projects contained in this book and the Teacher's Guide.

(H) DATABASE

One further starting point could be to have a look at the CREST Database. Your teacher will have one. This is a list of project suggestions with some ideas on what to do for each one. It also tells you what is expected of you.

e.g. Database title Number 25 for Bronze is “An examination of fading in blue jeans”.

The Project Outline suggests that you find out whether Light or Washing has the greatest effect on fading of blue jeans material.

The Database section also advises you on the chemicals and apparatus you might need and on how the project will be assessed. In all cases a project must show Creativity, Perseverance and Application (these are discussed, in detail, later).

For this particular project you must be able to explain to the Assessor what dyes are used in blue jeans and how you interpreted your experimental results.
There are many project suggestions like this one in the Database. The aim is that the Database will get added to all the time to include new projects which people have done throughout the country. It will contain some of the ideas they had and some of the experiments they did which may help you to adapt the project to suit your own aims.

2.11 NOT TOO DIFFICULT

A useful thing to remember at this stage is not to choose anything to work on which might be beyond your own personal skills or abilities and hence will not get finished. It is good to aim high, but you must still be realistic in your goals. This is where your Supervising Teacher, relatives, friends or Consultant may be able to advise you.

It is far better to begin working on something simple which can be expanded in difficulty later than to choose to make or do something which is going to be too hard for you to complete. If you are in doubt, then show your ideas to someone who knows you well - like the people mentioned - to see whether they think that you are capable of doing what you have thought of.
SUMMARY FOR CHOOSING A PROJECT

O.K., so now you have fixed on an idea for your project and this will involve many problems which you will have to solve and difficulties which you will have to overcome. You now need to start planning what you intend to do and gathering some ideas.

2.2 PROJECT BRIEF

First prepare a Project Brief, which is a sheet outlining what it is that you intend to do and listing the things which you will need to find out. It outlines some plans and preliminary ideas that you already have and some of the difficulties which you expect to overcome.

Problems which are holding you back from achieving your goals are called Constraints. (You must consider these before starting.)
Some of the constraints in your project might be: lack of knowledge about something, a piece of apparatus which you might not have, problems in fitting in your project work with your out-of-school interests. For CREST particularly these should be considered and mentioned here.

You should put all of these ideas into the Project Brief sheet and give it to your teacher to look at and make comments on. The Project Brief is really a forward organiser or plan of attack. It helps you to foresee any likely problems. It also contains the AIMS of the project.

2.21 TIME PLANNING

Remember that for a successfully completed project you also need to plan your TIME. You should allow for other-activities, such as sports, jobs and clubs. These are all constraints on your project time and must be considered if you are to meet the deadlines for entry to Science Fair.

The CREST information sheets supply you with suggested timetables for when things should be completed by for each of the award levels. You should plan your own activities by referring to these sheets and trying to stick to your target times.

2.22 PROJECT BRIEF USES

Project Briefs also form a basis for a first discussion about projects between students and the teachers, so that they can:

(a) feed you some additional ideas,
(b) make you think clearly about what you want a device to do or an experiment to find out,
(c) check that there is enough scope for creativity in what you are attempting,
(d) prevent you from overstretching yourself and designing a set of tasks of which you are not capable (i.e. making sure you will finish it),
(e) remind you of your targets (aims) which you hope to achieve,
(f) draw attention to any poor scientific methods which you may have planned,
(g) remind you of your target dates.
(h) check safety and animal ethics.

For CREST it is vital that you get the Brief signed as a check by the Supervising Teacher before proceeding on to Registration and practical project work.

**EXAMPLE PROJECT BRIEF**

**TITLE:** Running Shoes

**AIM:** To see which type of running shoes are best.

**INTEREST:** I do a lot of competitive running and it would be useful to know the best shoes for me.

**ALTERNATIVE IDEAS (BRAINSTORMING)**

1. I could do a survey of lots of people to see what they think.
2. I could borrow different ones and try them out.
3. I could use one kind until they wore out, then try the next.
4. I could test each type in the laboratory for wear.
5. I could see how each type gripped on my driveway.
PROBLEMS

- How can I tell which ones grip best?
- How can I tell which ones are most comfortable?
- How can I see which last longest?
- How can I get lots of different shoes?
- How can I find out about manufacturing methods?

SOME SOLUTIONS

Grip: I could see which shoe grips on the steepest slope.

Or

I could pull a metal plate along the sole and measure the friction using a newton meter.

INFORMATION SOURCES

Manufacturing pamphlets
Statistics book
Sports foundation
Physics book on friction
EXAMPLE PROJECT BRIEF PROPOSAL (MORE ADVANCED)

TITLE: Blind person's boiling water alarm.
AIM: To design and make a device which will give an audible sound when water in a saucepan reaches boiling point.
INTEREST: Blind people find it difficult to know when water is boiling. The device would be of great use to them.

ALTERNATIVE IDEAS

The temperature sensor can be a bimetal strip, a thermistor or a thermocouple as all change with temperature.

PROBLEMS

Can I make it sensitive enough? Will steam affect the electronics? Will the device be safe to use? How will it attach to the cooker? What materials shall I make it from? Where can I get a circuit diagram?

DESIGN SPECIFICATIONS

It will switch on within $5^\circ$C of boiling point.
It will use a sealed thermistor probe.
It will run on batteries.
It will attach to the cooker with magnets.
It will be moisture-proof.

PSE#2


2.3 GROUP PROJECTS

You may have decided that you will work together with one or more extra people on your project. So now would be a good time to decide on who will do what. Sharing experimental work with others in the group or letting one person make one part of your device, while you make another part, is O.K. But you must be able to say exactly who did what to satisfy the Science Fair judges or CREST Assessors. (Usually Science Fairs limit the number of people in a group to two).

Everyone must be able to show Creativity, Perseverance and Application. So you cannot have one person doing all the brainwork, while the others just follow his or her instructions.

2.4 CREST REGISTRATION

If you are doing CREST, once your Supervising Teacher is happy with your project proposals outlined on your Project Brief, then you will be allowed to register the project with CREST - N.Z. This involves filling in the Registration form and paying the Registration Fee, both of which are sent to CREST - N.Z. at Massey University (who run the CREST scheme) for their comments and advice.

If you are going for the Bronze award then most of your consultation and help will come from your Supervising Teacher. For the Silver and Gold awards, CREST - N.Z. will have to approve your project proposal first before you can start properly. CREST - N.Z. will then let you know the name of the Assessor(s) who will be assessing your particular project. On the Silver or Gold Registration form, you must also state the name of the person who will act as your Consultant. A Consultant is the person who normally comes from outside your school and is used to help, guide and
advise people during the project. More will be said about this later. Sometimes Silver or Gold projects can be done totally at the Consultant's place of work, forming important links between CREST and Industry.

2.5 JUDGING CRITERIA

It is important at this stage, before you get into serious project work, that you understand the main criteria on which projects are judged.

You do not have to compete against anyone else in CREST, but you must be able to reach the standards on what are called the CREST CRITERIA. These Criteria are particular skills that you must be able to show when doing any CREST project and would be excellent if they were also displayed in any Science Fair project too.

There is the same kind of skills check in the Driving Test, where the criteria for passing would be:

Controlling the car, reversing around a corner, knowing traffic signs etc. If you get a tick for each of these on the examiner's list, then you pass - without having to compete against anyone else.

A student doing a CREST project must reach the standards in all three main criteria. These are:

CREATIVITY,
PERSEVERENCE and
APPLICATION

Each of these is important for good science and in the development of you as a person.

Here is an explanation of what is expected:-
CREATIVITY

Creativity can be seen where people use their own designs and ideas in a way which is not a complete copy of what has already been done before.

Being creative is a difficult skill to develop - especially if you don't normally have to do creative thinking in your science. You can train your mind to think "laterally", or not down normal paths, by using some little Exercises.

For example:-

Make yourself come up with lots of possible solutions to the problem, not just one.
And then think of the advantages and disadvantages of each solution.

In a Washing Powder project, students were finding it difficult to tell which fabric was cleanest. There was not a big enough difference to tell by eye.

One creative solution to this problem was to shine light through each cloth onto a photocell and take a reading. Lateral thinking made one student look, not at the cloths, as everyone else did, but at the WATER. It was the dirtiest water which came from the cloth which was washed cleanest - and the water colour was easier to judge than the amount of stain left.

Learn to question the DOMINANT IDEA in the problem - the one which everyone else takes for granted. So, not looking at the cloth but at the WATER to judge cleanliness was the creative part for the student.

Some of these guidelines below help in coming up with creative ideas:
1. Write down exactly what the problem is which you are trying to solve, and also the difficulties you are finding. e.g. I want to find the exact amount of dirt left on a cloth. Difficulty - A stain is not heavy enough to weigh.

2. Saturate your mind with information about the problem. This could include a lot of reading, getting information from manufacturers, talking with people or finding out how scientists have solved similar problems in other areas.

3. Brainstorming. Say to yourself, for instance, How many different ways can I come up with for finding the cleanliness of cloths or for stopping my trailer from being stolen? or whatever the problem is. List all possibilities. Some will be useful and some will not. It is a bit like the way fashion photographers get the best photos - by taking a lot of pictures in a row and then choosing the best one. Once you have listed the obvious solutions and you are struggling, it is then that you start thinking laterally and are more likely to come up with more creative ideas.

4. Discuss your ideas and solutions with someone else, not necessarily an "expert". Experts often have their minds fixed on a particular Dominant Idea which they find it difficult to break away from; they often don’t think laterally.

5. Study all your solutions to the problem and write a list of the advantages and disadvantages for each one.

6. Pick the best solution and be able to say why you picked it.
Recap of finding solutions:

1. IDENTIFY PROBLEM
2. SATURATE MIND
3. BRAINSTORM
4. DISCUSS
5. ADVANTAGE/DISADVANTAGE
6. CHOOSE LOGICALLY

PUTTING CREATIVITY INTO YOUR PROJECT

You don't have to invent something completely new for your project, although it would be very nice if you did. Scientists often make use of other peoples' ideas, but perhaps in some different, new way. Following exactly what is shown in a text book is hardly creative, but maybe you could change things slightly or combine different ideas in a way which hasn't been done before.
It is possible to make something from a plan in a book and to still pass on the creativity criterion because of the way the device you made was used. For example, you could set up a standard chemistry apparatus to make oxygen, but vary some of the things about it so that you could find out how the speed of producing oxygen depended on catalyst, temperature, surface areas of compounds used, for instance. OR if you made an Electronic Humidity Meter from a kit, then you could use it to investigate how the humidity changes with season, time of day, temperature etc.

**PERSEVERANCE**

Persevering means carrying on after set-backs and showing determination to find a solution to a problem even though first ideas may not have worked. Many great scientists have, at some time, come up against a brick wall with a problem which seemed impossible to solve. By carrying on trying different ideas, and rethinking things, they finally crack the problem.

A teacher or consultant is there to ask for help when you really get stuck.
APPLICATION

By “application,” we mean using (or applying) the knowledge and the skills which you have learnt at school (or outside of school) to your project. Often you will need to find some extra knowledge, which is more advanced or comes from different areas of science to those you have studied at school, and use it in your work. Examples might be: making your own photographic paper, getting details of how toilet cisterns work or finding out how much fluoride there is in toothpaste.

The application of good SCIENTIFIC METHODS is also very important for success in a project. Where the aim of the project is to find something out by an experiment, then you must know how to set up FAIR TESTS to show good scientific methods e.g. which kind of wood rots least? (See section 3.4)

Where your project involves making a device to do a useful job, then the way in which it works must show ideas of applied science. Also, to make the finished device you should have gone through stages of TRIALLING (trying it out), CRITICISM (saying what did not work very well) and MODIFICATION (changing something in the design to make it work better).

For example:
A student’s project was to make an electric door lock. The Application of Science criterion was passed because the student found out about electromagnets and transformers and used them in the design. When he found later that the lock didn’t work very well, as the latch didn’t return properly, he modified the design and included some springs to overcome the problem. All this was recorded in the student’s log so the Assessor or Science Fair judge could judge the Application criterion. (See section 2.6 on the Project Log)
2.6 THE PROJECT LOG

You should now have decided on a project topic. You know roughly what problems you want to solve. You have organised some kind of timetable for working on them.

Part of the CREST and Science Fair requirements are that you keep a log, or diary of events and ideas, so that when you write up a proper Project Report at the end you will know exactly what you did, and when and why. It is a good idea to buy a 4B1 notebook (or similar) before you do any detailed experiments or trials, so that you can show the Supervising Teacher, Consultant or Assessor exactly when you tried something out, had an idea or found out that something did not work.

A Project Log is a running record of everything you did and thought of throughout the development of the project. It is looked at when assessment is made. Your Log should include the following:

<table>
<thead>
<tr>
<th>PROJECT BRIEF</th>
<th>stuck inside the front cover for you to refer to at any time.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATES</td>
<td>whenever you worked on the project</td>
</tr>
<tr>
<td>ACTIONS</td>
<td>what you did on that date</td>
</tr>
<tr>
<td>RESULTS</td>
<td>readings or measurements taken</td>
</tr>
<tr>
<td>PROBLEMS</td>
<td>what difficulties you found in doing something</td>
</tr>
<tr>
<td>POSSIBLE SOLUTIONS</td>
<td>different ideas on how the problem could be solved</td>
</tr>
<tr>
<td>TIME TAKEN</td>
<td>a rough total of the time spent on the project for each activity</td>
</tr>
</tbody>
</table>
Your Project Log is not meant to include any full write-ups, but will contain jottings, sketches, notes and references for use later on. It will **not** be assessed on neatness, but on fullness - i.e. whether it includes all of the things in the above list. It should be written as you progress through the project.

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>30th July</td>
<td>Carried out T-liner ep</td>
<td>-40 mins</td>
</tr>
<tr>
<td></td>
<td>Had to go and buy cotton Bells</td>
<td>20 mins</td>
</tr>
<tr>
<td>11th Aug</td>
<td>Listed and recorded all probs with different objects</td>
<td>-20 mins</td>
</tr>
<tr>
<td></td>
<td>55 mins</td>
<td></td>
</tr>
<tr>
<td>16th Sept</td>
<td>Physics Seminar</td>
<td>-10 mins</td>
</tr>
<tr>
<td>21st Sept</td>
<td>Thought of new object play-do - hopeful outcome as best simulant</td>
<td>-20 mins</td>
</tr>
<tr>
<td></td>
<td>discussed possibilities</td>
<td>205 mins</td>
</tr>
<tr>
<td>14th June</td>
<td>Thought and recorded some possible exp</td>
<td>-625 mins</td>
</tr>
<tr>
<td>27th</td>
<td>Discussed with teacher</td>
<td>-10 mins</td>
</tr>
<tr>
<td>13th July</td>
<td>Found formula for the volume of cistern</td>
<td>-5 min</td>
</tr>
<tr>
<td>15th July</td>
<td>Recorded 10 volumes + depth + timed filling rate</td>
<td>-2 hrs</td>
</tr>
<tr>
<td></td>
<td>Tabled and Graphed Results</td>
<td></td>
</tr>
<tr>
<td>29th July</td>
<td>Exp @ Tried different objects to flush as simulants</td>
<td>2 hrs 10 mins</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6:20</td>
</tr>
</tbody>
</table>
All practical projects will fall into two broad categories:

1. **Experimental** - where we make observations to try to find out how a physical or biological system works
2. **Design and Make** - where we produce a device which does something useful

This 2nd category could include computer programs. Although these are not really devices, they should still do something useful for you and more will be said about these in Chapter 4.

We will focus on the Experimental type of projects and their ground rules in this chapter. In the next chapter we will look at Design - and - Make projects.

### 3.1 FOCUS ON THE EXACT PROBLEM

Sometimes you need to produce, from the title of your project, an experimental aim which defines **exactly** what the problem is which are going to tackle. For instance:
Cleaning the Skin

To compare the effectiveness of different methods of cleaning the skin.

It is now clear that the project will focus on comparing how well soaps, detergents, disinfectants etc. kill bacteria or take off dirt.

The strengths of tissues

To measure the force needed to tear different tissues when they are wet.

It is now clear exactly what is meant by "strength" (i.e. force needed to tear a tissue and not to crush it) and we have also specified the conditions for testing them i.e. when they are wet and not dry.

It is up to you how you specify the aim. It is your experiment. But remember that the answer to the problem you are investigating should be of some use to someone. Choosing to test wet tissues, rather than dry ones in the second example above, is a more useful thing to do, bearing in mind what people do with tissues.

3.2 HYPOTHESISING

A hypothesis is a scientific word meaning "a reasonable guess" or a statement of what you think will happen or what you think the answer is. Before performing any experiments we should really try to write an hypothesis which can be tested by those experiments
to see if it is correct. Most times, past experience or knowledge of a similar situation will give us some idea of the possible results.

**Problem:** Which kind of battery lasts longest?
**Hypothesis:** Energizer, because it is shown as best on T.V.

**Problem:** Which sports shoe lasts longest?
**Hypothesis:** Reebok, because they are the most expensive.

**Problem:** Is filtered drinking water safer?
**Hypothesis:** Yes, because the impurities have been taken out.

Each hypothesis should be supported with some kind of evidence, which will range from near certainty (streamlined cars go faster) to almost no idea at all (life existing outside our galaxy).

---

**3.3 EXPERIMENTAL DESIGN**

Your experiments will have the aim of testing your hypothesis. They will be judged on whether they use **good scientific** methods to obtain results. Experiments which use good scientific methods of judgement are called FAIR TESTS and are probably the most important part of any project.

Fair tests are quite easy to design for physical systems involving things like machines, electricity, chemistry etc. They are far more difficult to design with biological systems, such as plants, animals, humans etc. This is because of the large number of VARIABLES involved in living systems and often "Control Groups" are used to compare the effects of
changing one. A “system” is any collection of working parts which, linked together, perform a useful function. “Variables” are factors which can affect a system and which can be altered.

For instance, a loaded spring is a physical system and the variables which affect its length as it is stretched are: the LOAD on it, its WIDTH, its original LENGTH, the METAL from which it is made and the THICKNESS of the metal. The “length of a spring” variable is quite predictable and reproducible, which makes it useful for making spring balances, car suspensions etc. There would be very little disagreement amongst scientists about how a particular kind of spring would behave in a given situation.

However, if we look at a biological system - such as a human being - we could probably think of hundreds of factors which might affect a human’s height. For example: age, diet, sex, race, diseases, nationality and many more possibilities. Probably the most important one, and the most difficult to predict, is GENETIC INHERITANCE.

In other words, if a baby’s body cells contain a “tall” gene then the child might become tall. But not necessarily so, because the “diet” factor may overcome the genetic one if the food eaten by a baby is not nutritious enough. Genetics involves chance events occurring (mixing of genes from the parents) and these affect the outcome. So although we understand a general trend (height is linked to good diet) it is difficult to predict precisely how the different variables or factors might interact or combine together in living things. A large amount of variability is also shown with systems involving the weather, sociology, economics and human behaviour.
It is this element of unpredictability with biological systems, and the others mentioned, which makes the Fair Tests of a different kind to those used with physical systems. To test hypotheses in a complex system involving human, animal or plant behaviour we usually use Statistics to find out the general trends i.e. how one factor affects another. Statistics tables or programs can show the probability of a result occurring by pure chance.

Dying through lung cancer is a CHANCE event which may or may not happen to you if you smoke. It was very difficult to prove that smoking caused lung cancer, because lots of people who smoked didn't die from lung cancer. Because it was a biological system being studied, Fair Tests on the “smoking” variable had to look at two very large samples of people and then use statistics to analyse the trends: one sample (called the Experimental Group) consisted of Smokers, whilst the other sample (the Control Group) were all Non-Smokers.

To plan your experimental design you need to decide on how much VARIABILITY there is likely to be in your observations and plan the analysis of your results around that.

<table>
<thead>
<tr>
<th>PREDICTABLE SYSTEM</th>
<th>NOT SO PREDICTABLE SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Few variables</td>
<td>Many different variables</td>
</tr>
<tr>
<td>Low variability</td>
<td>Variability</td>
</tr>
<tr>
<td>Laws</td>
<td>Trends</td>
</tr>
<tr>
<td>Single readings</td>
<td>Many readings, averaged</td>
</tr>
<tr>
<td>Use line graphs</td>
<td>Use scattergrams</td>
</tr>
</tbody>
</table>
3.31 PRELIMINARY EXPERIMENTS

Your first piece of research towards the final experimental design should involve some preliminary (test) experiments, which help in the following ways:

1. You can get some idea of the likely amount of variability in readings.
2. You can make trials of your apparatus set-up.
3. You can get some idea of the difficulties involved that you hadn't thought of.
4. You can obtain working values for the variables which you will set in the real experiments.

A few preliminary experiments before you go rushing in and spending time getting lots of readings are really worthwhile. They save time through wasted effort later. These will allow you to modify (change and improve) your experimental design and see if everything works well.
For Instance:

Some students were experimenting with oil to see how its viscosity (runniness) changed with temperature. To do this they planned to time how long it took for cold oil to run out of a pipette and compare that to the time it took for hot oil to run out. It seemed a good method, but a preliminary experiment showed that it took so long to run out that the oil had cooled down by the time the pipette was empty. The students then modified their experimental design so that:

(a) the pipette was insulated to keep the heat in,
(b) they timed the level of the oil to fall between two marks a few centimetres apart, and not the whole way down.

Below is a flow diagram of the Problem-Solving method which can be used in all the different kinds of CREST and Science Fair projects.

(Remember to record the times that you did any preliminary experiments in your Project Log - how and what you did and what the results were).
3.4 FAIR TESTS

Problem-solving experimental work mostly involves comparing what happens with one set of conditions to what happens with another set, e.g. hot oil with cold oil; soap powder 1 with soap powder 2; insects in the dark with insects in the light; one sail shape with another sail shape, etc.

The process of fixing the conditions of an experiment to have particular values is called control of variables and is the most important part of setting up a Fair Test.

3.4.1 CONTROLLING VARIABLES

This is where you can usually show the most creativity by designing good experimental methods for controlling the variables of a system.

The list on P28 showed the method for coming up with creative solutions to problems:

IDENTIFY
SATURATE
BRAINSTORM
DISCUSS
ADVANTAGE
CHOOSE
Firstly, you will need to IDENTIFY THE VARIABLES in the system which you are studying and write them down. You can do this by studying, discussing and thinking about the system, or often merely by just using your common sense e.g.

Amy's father owned a warehouse where he stored bags of flour on wooden pallets on the floor. These pallets could be pushed along by the workers and she wanted to find out what factors affected the force needed to slide the pallets and how it could be minimised.

Amy decided to do some experiments in class to help her solve her father's problem. She needed to decide on the factors affecting the force needed to pull the wooden block along a surface. She decided that the following variables were important for her system:

- WEIGHT OF BLOCK
- SPEED OF BLOCK
- TYPE OF SURFACE
- ANGLE OF SLOPE OF SURFACE
- AREA OF BLOCK
- SUBSTANCE BETWEEN THE TWO SURFACES
There are probably more variables than this, Amy decided to neglect others such as Temperature of the day, Gravity, Position of hook etc. because they were found to be of little importance in preliminary experiments. She had no way of altering the force of gravity.

The list above includes what are called the **Independent Variables**. These can be altered at will, and do not depend on anything else. For example, we can fix the weight, angle or area at any value we wish.

The variable which we do not fix or control, but is used for observations is called the **Dependent Variable** and is always included in the AIM of our experiments e.g.

Finding how **Frictional force** depends on speed.
Finding how the the **Brand of shoe** affects grip.
Finding how **Plant growth** depends on amount of fertilizer.

Frictional force, Amount of Grip and Plant growth are all the **DEPENDENT VARIABLES**

In this case the dependent variable is the Frictional Force, "F" which Amy decided could be measured by the reading on the spring balance.
One way in which creativity can be assessed is by looking at how you use your measurements to judge the answer to the problem.

Amy had decided on the independent variables which were important and now she had to decide on

(a) how to control each of them, and
(b) how to measure the dependent variable effectively.

Let us look at two possible methods which she considered for studying the "Weight of block" variable.

**METHOD A**

Pull a light block along the floor and measure F. Then pull a heavy block along the floor and measure F again, as a comparison.

**METHOD B**

Pull a block of known weight along the floor and measure F. Put some weights on the same block and pull it along the same part of the floor to measure F.

Which is the better experimental design, A or B?

The rule is: **only alter one variable at time.** In method A, the AREAS of the two blocks could have been different, as well as their weights. And so the difference in frictional force could have been due to either or both of these variables - we are not sure which. Not enough thought was given in the experimental design to the proper control of area in method A.

Method B is a better experiment.

Can you see why Amy decided to use the **same part of the floor** for both readings in method B?
Method B would be an example of a good Fair Test method, but method A would not be acceptable as a proper scientific control of variables, and would not reach the standards of the Application criterion.

3.42 WHICH IS BEST?

With the "Which is Best" type of problem, the method of judgment from the dependent variable measurement becomes much more difficult and you will have to start off by saying how you are going to define "Best". And what method you will use to judge it.

There is never really a single right answer to the "Best" problem

PROBLEM: Which is the best washing powder?

RESULTS:

<table>
<thead>
<tr>
<th>NAME</th>
<th>PRICE per Kg</th>
<th>Amount Needed</th>
<th>Cleans Oil</th>
<th>Cleans Stains</th>
<th>Works In Hot Water</th>
<th>Works In Cold Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$5.40</td>
<td>20g</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>B</td>
<td>$10.20</td>
<td>10g</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>C</td>
<td>$11.00</td>
<td>15g</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>D</td>
<td>$ 7.80</td>
<td>25g</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

POSSIBLE ANSWERS:
A    is best because it is cheapest
B    is best because you don’t need so much
C    is best because it cleans all kinds of dirt
D    is best because it can be used cold and it's cheaper because there are no heating costs.
The real answer is that what might be best in one case might not be best in another. Like the running shoe problem, it all depends on how you are going to use it.

You should look carefully at results and then make judgments based on the conditions which you think are going to be important.

For cold wash of oil stains, B is better than D (because it is cheaper per wash). But for a hot wash of STAINS, A would be better than either of these. Because it is so difficult to define "Best", we often see several different manufacturers claiming in advertisements that their products are best. Of course, they don't tell you how the test was done!

"Colgate is best because it removes plaque"

"Nothing beats Janola for cleaning concrete"

Swansdown toilet tissue "For a longer roll and greater economy"

Comfort "Reduces static cling and makes ironing easier"

Johnson's baby shampoo - "A richer, thicker lather"

Coldwater Surf - "Top performance in cold water"

How could we judge "greater economy", or "richer lather"?

Example 2:

**Problem:** Which is the "best" dish-washing liquid?

**INDEPENDENT VARIABLES:**

1. Food type used,
2. utensil type used,
3. temperature of wash,
4. length of wash,
5. concentration of liquid,
6. amount of agitation,
7. type of dish washing liquid.
DEPENDENT VARIABLE: Cleanliness (which liquid cleans more thoroughly)

How to judge cleanliness?:

1. LIST ALL POSSIBILITIES:
   (a) Judge by eye,
   (b) find weight of food left,
   (c) look at cleanliness of water etc.

2. DISCUSS

3. Find ADVANTAGE/DISADVANTAGE of each method.

4. CHOOSE logically the best method.

Because one type of dish-washing liquid would work better under one set of conditions than another set you must fix all the other independent variables whilst only one of them is chosen for investigation. In other words, **only change one variable at a time**. For example, how well does each type of dish-washing liquid wash off each **different kind** of food type remnant?

The experimental set up for this would be to allow only variable number (1) and (7) to change and to control (fix) the others by, perhaps, the following methods:

(2) Utensil type - use a the same plate.
(3) Temperature - fix at 60°C (as this is the usual temperature used for washing)
(4) Length of wash - fix at 20 seconds (as a survey showed this was the average wash time).
Having controlled all the other variables, we could then put a measured amount of butter, egg, tomato sauce etc. on the plate and see how well dishwashing liquid A performed. Then repeat the experiments with liquid B, and so on.

Having completed your tests with variable 1 (food type), you would then see how Cleanliness was linked to each of the variables (e.g. temperature) by fixing all but that one and repeating the experiments.

You will note that there should always be a good reason for fixing any variable at a particular value: 3 cm³ of liquid per bucketful is a reasonable concentration because it comes from the instructions on the bottle, which have been modified to suit the experimental set-up. For example, if the manufacturer recommends 3 squirts per sinkful and this equals 6 cm³ of liquid per 10 litres of water, then our bucket, which is only 5 litres, will need 3 cm³ to give the same concentration.

3.43 ALLOWING FOR SIZE

Often we try to compare two things which are not equal in size or mass. It is still possible to make a fair comparison if we allow for size mathematically.

Suppose we wanted to find out which kind of wood, from several samples, absorbs most water. To make it a Fair Test we should allow for the difference in
size of each block of wood in some way - perhaps by using blocks with the same measurements. This method would not always be possible and not really necessary if we link the amounts of water absorbed to the size of the blocks by calculating fractions or percentages. e.g.

<table>
<thead>
<tr>
<th>WOOD</th>
<th>SIZE (cm)</th>
<th>VOLUME (cm³)</th>
<th>WATER ABSORBED (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A CEDAR</td>
<td>2 x 2 x 2</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>B KAURI</td>
<td>5 x 4 x 3</td>
<td>60</td>
<td>5</td>
</tr>
<tr>
<td>C RIMU</td>
<td>2 x 1 x 20</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>D PINE</td>
<td>6 x 2 x 1.5</td>
<td>18</td>
<td>3</td>
</tr>
</tbody>
</table>

The table shows that block B (Kauri) absorbs the most water, but is this the most absorbent kind of wood?

If we divide the amount of water by the wood volume we can find the amount absorbed by each CUBIC CENTIMETRE of wood. This value then gives a fair comparison of the woods' absorption.

The results were: A - 0.125, B - 0.083, C - 0.1, D - 0.17 or 12.5%, 8.3%, 10% and 17% respectively - showing that, in fact, PINE was the most absorbent kind of wood.

You would have to apply this division method where there is some change occurring in objects of different sizes or masses to compare increases in a fair way e.g. comparing plant growth, comparing substances stretching, comparing weight losses on diets, etc.

If we wanted to compare something like the cot-death rates in N.Z. with other countries we would have to allow for size by quoting the figure as "Deaths per 100 live births" or something similar.
Similarly things like Unemployment Figures are always quoted as percentages i.e. number out of work per 100 of the population.

3.44 VARIABILITY

At this stage, you must decide on how variable your results are so that you will know how to process them. A good way of checking variability is to repeat some of your experiments under the same conditions. Always remember to keep a record of all your results collected somewhere. If you get the same answer as before then it should be good enough just to record the single observations or readings, but if there is quite a bit of difference in your observations then you will need to use a different method of processing results as discussed on P37 i.e. you will need to repeat the same experiment several times and use some method of averaging. The unpredictability in the system will mean that you will only be able to comment on a trend rather than a law in your final report.

Summary of Experimental Design

FOCUS ON EXACT PROBLEM
MAKE AN HYPOTHESIS, WITH LOGICAL REASONS
DO SOME PRELIMINARY EXPERIMENTS
MODIFY YOUR DESIGN

FAIR TESTS
IDENTIFY DEPENDENT AND INDEPENDENT VARIABLES
DECIDE ON METHODS OF CONTROLLING VARIABLES
DEPENDENT VARIABLE MUST BE ABLE TO JUDGE RESULT
CHANGE ONE VARIABLE AT A TIME
LOOK AT VARIABILITY TO PROCESS RESULTS
3.5 OBSERVATIONS

Observations in an experiment are things which you see, feel, hear, smell or taste i.e. any inputs to the senses. Normally, however, observations or results are things which we have seen and recorded. We can get much more precise answers to our problem if our results involve measurement rather than just judgment by eye i.e. when we use a measuring instrument of some kind we will get greater accuracy. Unfortunately, this is not always possible.

In the Dish Washing problem, weighing the amount of food left is a far more precise measure of cleanliness than just judgment by eye, and a 3 cm³ measurement of liquid made for a better Fair Test than using number of squirts.

3.51 RULE OF MANY

A useful rule which helps to increase the accuracy of experimental results is to make measurements of a GROUP of articles and then to find the average value. This Rule of Many can be useful in two types of situations:
(a) where the observed measurement of a single object is too small for the measuring instrument and
(b) where there is large variability in individual measurements.

Examples of increasing accuracy with small quantities:-
(i) The time of one swing of a pendulum is less than 1 second : time 10 swings and divide by 10.
(ii) The diameter of a wire is less than 1 mm: wind 20 turns on a pencil, measure the total width with a ruler, then divide by 20.

(iii) One drip of water from a tap is less than 1 cm$^3$: measure the total volume of 100 drips and then divide by 100.

(iv) The mass of one grain of salt is less than 1/100 of a gram: measure the mass of 1000 grains and divide by 1000.

Examples of increasing accuracy with very variable systems:

(i) Is New Zealand's climate getting warmer? : record the day time temperature for every day of the year and compare the average temperature of this year with other years.

(ii) Are N.Z. babies getting heavier? : record the weights of all the babies born this year and compare the average weight to that of previous years.
The Rule of Many can be used in all cases of experimental measurements. But with easy, large values, or with systems having low variability, it will not be necessary. Use your own judgement!

When setting the Independent Variable values to make measurements on the Dependent Variable set them at REASONABLE or USEFUL VALUES - values which are close to those in normal, everyday use. We wouldn’t test washing up liquid at 0°C or 100°C because the water temperature in the sink is never at these values. We wouldn’t test a plate with 10 grams of tomato sauce on, because that much would normally be scraped off before washing.

Within the reasonable range, use the widest range of values that you can for your experiment, so that later on you can see any trend that is shown in the results. For the same reason, you should also make a good number of observations over the whole range which you have set.

For instance, suppose you wanted to see how effective the washing up liquids were at different temperatures and you found that the lowest water temperature normally used in households is 30°C and the highest is 80°C. A badly designed experiment would make cleanliness measurements only at 50, 55, 60°C. A good “fair tester” would make observations at 10°C intervals over the whole range from 30 to 80°C, repeating each observation several times if there was a large variability present. Information gained from experiments is called DATA and this is later analysed to try to find out the answer to the problem being investigated. Data may be numerical (numbers) or not. It could be colour changes, for example, which is non-numerical.

With biological experiments, repeated observations can be just as valid as precise measurements - if repeated often enough (e.g. Pukekos feeding)
SUMMARY FOR GOOD DATA GATHERING:

AIM FOR THE MOST ACCURACY

TRY TO USE AN INSTRUMENT FOR MEASUREMENTS

SET REASONABLE VALUES FOR INDEPENDENT VARIABLES

MAKE MANY OBSERVATIONS OVER THE WHOLE RANGE

3.52 RECORDING DATA

You will, of course, write down all your observations results or data in your Project Log as you make them. But at some stage it is important to tabulate the data, or put your data into a table of some sort. This table of data allows you to see results in a logical order e.g. from lowest to highest, or classified in some way so that you can detect any trends or patterns which the data are following.

A TREND is a kind of loose link between two variables with a lot of variability e.g. "boys tend to be taller than girls" is a trend statement as it is generally true for a fixed age.

A LAW is an exact relationship or link between two variables for which there is no variability and is, therefore, always true. "1 litre of water has a mass of 1 kg, and 2 litres of water have a mass of 2 kg".

A PATTERN is a link between variables of some kind which is found from close inspection of the data and can range from a TREND to a LAW.
Example 1 from log:

**COLOUR OF A MOTH ON DIFFERENT COLOURED BACKGROUNDS**

Moth observed: June 85
Well camouflaged on tree trunk in forest: Several found in cane area.

Colour: Light brownish with dark spotted wing along body
Size: Body: 25-30 mm
Trend found from table of data: "I have noticed that these moths can change their colourings to greens or greys very well, but have a lot of trouble matching red or brown backgrounds for camouflage".

Example 2 from log:

CURRENTS FLOWING THROUGH WIRES OF DIFFERENT LENGTHS AND DIAMETERS

Patterns found from table of data: "Pattern one is that the longer the wire the smaller the current". "Pattern two is that the bigger the diameter the bigger the current".
Law 1: Doubling the wire length halves the current
Law 2: Doubling the wire diameter quadruples the current.

N.B. In these two examples we can see how BIOLOGICAL systems have a lot of variability and PHYSICAL systems do not.

In this last project example you will notice that putting data in logical order makes the patterns easier to see. Just look at the first two results: by holding length constant at 10 cm and doubling the diameter, the current was four times larger. The other pattern can be seen by looking at the two results in the second and third lines, where the diameter is held constant.

It is also useful when labelling the column to put in the units at the top, in brackets, to save repeating them all the way down.

3.53 DISPLAYING DATA

Often it is not easy to work out trends or patterns in the data from just the table of results, and so you will very often need to display data graphically. This kind of display allows us to judge at a glance possible links between our variables: how the friction changes with block area, how average temperature changes over several years, how the number of bacteria growing depends on type of toothpaste used, etc.

Nearly all projects will have a clear display of results or data in graphic form at the end, to summarise what has been found out and to draw conclusions from. There are several different types of graphic display to choose from, depending the type of data which your observations produced.
Some common types of graphic display are listed below with explanations:

Vertical 'bars' or rectangles are used to represent numerical and non-numerical data. ('Numerical' means definite number values used on an axis, "Non-numerical" means using labels such as "colour", "type" etc which have no number associated with them).

Bar graphs can be used simply to display data or to show trends, laws or patterns and are used a lot in geography and biology (e.g. number of fish caught in each month of the year).

Data points are shown with crosses and connected with a line as in (a) or (b) or (c). Joining one point with the next by a line as in:

(a) is correct if there is no gradual change detected e.g. number of car crashes on each day of the week. (Not used much with Physical Systems).

(b) is called a Line of Best Fit which shows the average line for the points and is used where there is a gradual change from one point to the next e.g. stretching a spring by adding equal weights (used a lot with physical systems).
(c) is also an average line where there is a **gradual change** from one reading to the next, but the pattern is not a straight line (used a lot with physical systems).

This is called a curve of best fit and would be found, for example, with the temperature readings each minute when something is cooling down.

Line graphs are usually only used with numerical data. They can show trends, laws or patterns.

---

**Pie Chart**  
The fraction of the circle shown for a particular key represents the fraction of the whole sample. *e.g.* in geography to show how the whole population is composed of different fractions with different ethnic origins. Pie charts are used mainly for the classification or display of data and not for finding trends.

---

**Cartoon Chart**  
Each cartoon represents a particular number of those articles *e.g.* each cartoon man represents 1000 soldiers and each aeroplane cartoon represents 100 U.S. fighters, etc. Cartoon charts are used just to display data or possibly to show trends.
Each set of data is plotted as crosses but not joined with a line or a bar. Scattergrams are used to show the variation in readings or data e.g. people’s ages plotted against their times to run 100 metres.

Scattergrams display lots of individual observations and can be used to discover trends or patterns but not laws.

Picture plots are used to show the positions of items in an area and sometimes, as with cartoon graphs, the numbers of them e.g. Shows where trees are found where flowers are found etc.

Picture plots are often used in biology, geography etc. to display data and sometimes to show trends.

There are various other kinds of ways of representing data graphically in books or newspapers, but they will only be slight variations on the ones shown above.

When you have your experimental data tabulated you must then choose the best way to represent the data graphically for easy display. This section should help you with your choice.
Summary of best methods of displaying data

✓ = Yes  X = No

<table>
<thead>
<tr>
<th>Numerical</th>
<th>Non Numerical</th>
<th>Display</th>
<th>Trends or Patterns</th>
<th>Laws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pie Chart</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Cartoon Chart</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Picture plot</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Bar Graph</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Scattergram</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Line graph</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Don't forget that all graphs should have a TITLE which tells us what is being shown or plotted and each axis should be LABELLED correctly.

PSE#10

3.6 CONCLUSIONS

Drawing Conclusions from the data collected in your experiments is the most important part of the whole project - this means saying what you found out from interpreting your results.

Any conclusions that are drawn should refer back to the hypothesis that was made earlier on (see section 3.2) so that you will be able to say that either

(a) the hypothesis was shown to be correct (confirmed) or
the hypothesis was shown to be incorrect (refuted). There will sometimes be an experiment where results do not show if the hypothesis is confirmed or refuted - in this case all that we can say is that the results are **inconclusive**.

This may occur due to various reasons, such as: the experimental design being poor, inaccurate measurements or difficulty with being able to control the variables. These kinds of inconclusive results often occur with measurements on biological or human systems in problems like "Why a sudden growth in the number of killer wasps?" or "Do violent videos produce violent behaviour in people?". The hypotheses here may seem very logical but confirming them with research measurements may be extremely difficult. How would you measure "violent behaviour" accurately? Could Donald Duck hitting Mickey Mouse on T.V. be classed as a violent video?

As we have said, if data are presented in some graphical form it is easier for us to take it in and detect any trends, although nowadays computers can be programmed to do this much more efficiently than humans can. In cases where there is a lot of
variability or uncertainty the computer can express conclusions in the form of probabilities. We often see this on T.V. with weather predictions: "Southland has a 40% chance of rain today," etc.

We should try to give as much information in our conclusions as we can, which means trying to state a law rather than a trend if possible but, as we have seen, with biological systems this may be difficult.

Example 1

A conclusion from this graph could be "as you get older, you also get taller"

However, this conclusion is not really detailed enough for anyone to predict a person's height at a particular age. There is enough detail in the results graph which could be used for a better conclusion. For instance: When a baby is born it is about 30% of its final adult height. By the age of 2 a baby will have reached about half of its final height. Final height is reached by about 15 years of age and doesn't change much after that age.

These are much detailed and useful conclusions and ones which will allow us to make better predictions as they describe the system more fully. We could probably even work out a mathematical equation from the curve into which we could put a baby's height and then predict its adult height. This would give us an exact law. However, we must always be
aware of any limitations in our conclusions, or factors which stop us from using our predictions too widely in other areas. For instance, the height results were only for ONE person and not for a whole population. We might also have problems in using the curve to predict the height of boys or even different races so we must be careful and try to see limitations or defects in our own work. This will be discussed more fully in the next section on Evaluation.
Example 2

Shown below is a graph made from the results of an experiment on a Thermistor called TH5 whose resistance was measured with a digital meter at different temperatures.

The conclusion could be drawn from the graph that "As the temperature rises, the thermistor resistance goes down". A much more detailed conclusion found from studying the results more carefully and using a calculator would be "For every 10°C rise in temperature, approximately, the resistance value is halved".

This is an example of an exponential fall.
Example 3 (Difficult)

Shane took some results whilst at the Ammonia Production Plant in Taranaki and recorded them in a table. He noted how many cubic metres of ammonia gas were produced from the same volume of nitrogen and hydrogen in the reaction tank for different temperatures and pressures.

<table>
<thead>
<tr>
<th>TEMPERATURE (°C)</th>
<th>PRESSURE (ATMOSPHERES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td>1.91</td>
</tr>
<tr>
<td>200</td>
<td>1.56</td>
</tr>
<tr>
<td>300</td>
<td>0.86</td>
</tr>
<tr>
<td>400</td>
<td>0.32</td>
</tr>
<tr>
<td>500</td>
<td>0.11</td>
</tr>
</tbody>
</table>

CUBIC METERS OF AMMONIA PRODUCED

With these results, we can see quite a complex situation occurring apart from (a) a rise in pressure producing more product and (b) a rise in temperature producing less product.

We have a 3 variable system here (Temperature, Pressure and Volume of ammonia) and to test the link between any two of them we must hold the other independent variable constant as we would do in an experiment. For instance, to see the effect of...
temperature on volume we hold the pressure constant in our minds by only looking at the first column under "25 atmospheres". Here we can see that the temperature rises from 100° to 500°C the amount of ammonia falls from 1.91 m³ to 0.11 m³ - a reduction by 17x.

If we now look in the last column under "400 atmospheres" we can still see a reduction in volume from 1.99 to 0.97 m³ but this amount of reduction is only about 2x.

This conclusion could be stated in non-mathematical language by saying:

As the temperature rises the volume of ammonia produced falls (an INVERSE relationship) but this percentage decrease becomes less as the pressure increases.

(NOTE the method of controlling variables in a table by only looking at one column or row of results at a time).

3.7 EVALUATION

Evaluation or appraisal means making decisions and giving your opinions on how good the experimental methods were that were used. This is the final stage of your project, where you look back critically on your own work and comment on the good and bad aspects, what worked well and what didn’t and say how your methods or measurements could have been improved. We try to think of everything when we design the experimental Fair Tests and do preliminary experiments, but we always run into unforeseen complications of some kind due.
to things like: unknown variability, inaccuracy of measuring instruments or some independent variables present which we hadn't allowed for.

In your Project Report you will need to discuss the problems which you found and how you overcame them - as well as giving an overall constructive criticism of your work and how well you met your original aims.

Look at the Limitations of your results in your final conclusions and point out why, perhaps, they might not apply in a different situation:

e.g. 1. "Although these running shoes were found to be best for road running, it is possible that they may not be so good on the track".

e.g. 2. "Although the Energizer battery lasts longest with small currents, it may not last as long as others when large currents are drawn".

e.g. 3. "Although Ultrabright toothpaste is best at preventing tooth decay it does cost more than the other toothpastes tested".

e.g. 4. "Although cedar seems to absorb slightly more water than rimu, there is a large variability in results, even for the same kind of wood - which makes it difficult to draw any definite conclusions".

Having discussed your experimental conclusions and their limitations the final task is to relate these to the original hypothesis. It doesn't really matter if that hypothesis was wrong, as at that time there may not have been enough evidence to go on, but what is important is that your conclusions are based on sound experimental methods and measurements.
It is also good practice, as a final discussion of any research work, to finish by making suggestions as to how your methods could have been improved if you could do it all again - knowing what you know now.

**EVALUATION PROCESS**

- **CONSTRUCTIVE CRITICISM**
  - **METHODS** → ADEQUATE/INADEQUATE
  - **RESULTS** → ACCURATE/INACCURATE
  - **CONCLUSIONS** → HYPOTHESIS CONFIRMED/REFUTED; LIMITATIONS STATED

*PSE#12*
DESIGN-AND-MAKE PROJECTS

Water good sport!

Hovercraft racing may not be on the curriculum at most schools, but the girls at St Paul's Way School in East London have taken to this watery sport. And the members of the only all-girl team on the racing circuit built their hovercraft with their own fair hands. “They don’t mind getting dirty,” says Dave Ensor, the teacher who’s turned them into a slick team of racing dynamos.

With his (and a technician’s) help, the girls, aged from 11 to 14, built their hovercraft from scratch in the school workshop. The craft, which travels on a cushion of air, can reach speeds of up to 40mph on land and water. “Like all forms of racing, it can be dangerous,” says Dave. “But it’s controlled danger. The project has been a very educational experience and also an enormous confidence booster for the girls.”

These schoolgirls can reach speeds of 40mph in their craft.

The outcome of a Design and Make type of project is to produce a device (or invention) which does something useful and applying scientific knowledge to design problems is called TECHNOLOGY. We have already discussed how to decide on what project to do by looking at the NEEDS of different sets of people: your parents, the disabled, drivers,
the housewife, music lovers - in fact any group of people who require devices with particular specifications. Specifications state exactly what you want a device to do.

You might start off choosing a project by talking with people and finding out their particular needs. Mothers wanted to be able to take their babies with them in the car with greater safety and so the Baby Seat was invented, people wanted to be able to talk to each other over long distances and so the Telephone was invented, in the 1950's children suffered from Poliomyelitis and so a Vaccine was developed for it.

In each case a NEED existed in the first place for a particular group of people and the specifications for the device were decided upon, then different ideas were trialled before coming up with the final solution. Some specifications for the baby seat might be -

MODEL BABY
Comfortable for the baby.
Safe in a crash.
Easily removed from the car.
Not too expensive.
Not too heavy etc.

**PSE#13**

### 4.1 ANALYSIS

To produce design specifications you need to analyse the design problem in detail - this analysis could take the form of a series of QUESTIONS about the finished article and some ideas about their answers. e.g. Baby Seat

1. What will it be made of?
2. How will it be anchored onto the seat?
3. What size does it need to be?
4. How will the baby be held in?
5. What weight should it be?
6. What should the maximum cost be? ....... etc.

For each of the analysis questions there will be several alternative solutions to choose from where decisions have to be made as to the best answer.

e.g. Steel is strongest but it is too heavy.
Plastic is lightest but difficult to work with and not very strong.
Wood is strong, light, easy to work with and cheap - so my solution to Q.1 is that it will be made of wood with foam padding.

This method of asking questions and considering
DEVELOPMENT OF A SOLUTION TO A DESIGN AND MAKE PROBLEM

IDENTIFY NEED

DECIDE ON SPECIFICATIONS

SEVERAL DESIGN SOLUTIONS

PROTOTYPES

TRIALS AND APPRAISAL

ADVANTAGES/ DISADVANTAGES

BEST SOLUTION

MODIFICATION

DEVICE

MEETS SPECIFICATIONS

YES

FINAL SOLUTION
lots of possible answers is a good way of analysing the problem and coming up with possible solutions. It also stops you from jumping at the first solution which occurs to you. Remember to consider the advantages/disadvantages linked with each solution.

After looking at possible designs for the seat some prototypes or trial devices would need to be made to try out - firstly with model babies in simulated car crashes - and then with real babies in everyday situations. By getting advice or feedback from the consumers or a group who are going to use the device, modifications can be made to improve it.

This process of trial, criticism and feedback is called APPRAISAL - reporting on the good and bad points. Finally the device which has been developed will be tested to see how well it meets the original design specifications.

The problem solving flow diagram shown need not be followed exactly, as things could occur in a slightly different order, but basically the idea is that after trying something out we criticise, learn by our mistakes, take advice and redesign. This is the problem - solving method used for all types of scientific projects, whether they be Experimental or Design - and Make.

The most important part of the whole process is the design of the solutions to the problem and this is probably where most creativity will be called for. However, it is no good being creative if your ideas cannot be put into practice.

It could happen that the project will fail to meet specifications for two reasons:

1. You do not have enough experience with materials or equipment to know what is or is not possible.
2. You may not have the skills (or money) to make the device to the specifications given.

This is where your previous EXPERIENCE comes in - if you have worked in a laboratory or workshop, know how to solder, cook, file, weld etc. then you will be much more aware of how things could be done and what is not possible for you to do although you must be prepared to be confident in yourself and adventurous enough to take on new skills.

The Information input comes from your knowledge of science and relates to the APPLICATION Criterion of CREST. If, for instance, you know from your science lessons that one connection on a light bulb must be connected to the + and the other to the - of a battery and that there must be a complete circuit then you could build that into your design. If you didn't have that scientific knowledge then the original design could be faulty.

4.2 INPUT

A large amount of Input at the design stage is vital if the device is going to work properly at the end.

You will need to RESEARCH THE TOPIC thoroughly to gain as much information and as many ideas as possible. This could mean doing a wide variety of things such as:
This is how many solutions are found to difficult problems in our world; by thinking LATERALLY and drawing together a variety of ideas from different areas in science and technology. Real-life problems in technology need input from many different areas - take, for example, the invention of Artificial Hip Joints: a knowledge and expertise in biology, physics, chemistry and engineering all had to be brought together for a solution to the problem of putting metal ends on to bones.

Does anyone ever have enough knowledge skill or experience for a project?

The answer is NO:- Even the top scientists working for NASA will not have all the individual abilities necessary to put a person into space - but they will know where to get advice and expertise from. Proposals would be drawn up and then input from engineers, chemists, biologists, statisticians or tool makers would show them what could or could not be done or how ideas would have to be modified.
For you, in your project, this help would come from your CONSULTANT or from your Supervising Teacher, family members or friends.

So in your Design-and-Make project you will have to get as much input as possible in terms of knowledge and expertise, by reading or asking people for advice. Skills which you do not have may also have to be learnt from someone else, perhaps, or developed by constant practice - and this is where students who have had a lot of experience at working with their hands (or programming) will do better.

For all levels: Bronze, Silver or Gold CREST you will need to consult with someone for advice to see what is possible in those first design solutions.

PSE#14
4.3 TRIALLING AND APPRAISAL

You have decided on a Design - and - Make problem, you have researched and gained as much input as possible and drawn up several possible solutions to the problem which your advisors think are all O.K. Ideally, you should make up simple versions or "mock-ups" of your designs (PROTOTYPES) now and try each one out, but this may not be possible. It might be too expensive or time consuming to make prototypes of all of your design solutions and so, at this stage, your may have to make a decision as to which seems best. Again, ask people's opinions on this - and then make your prototype for trialling.

For example:
Fiona wanted to make an egg timer with an accuracy of about 10 seconds for her "study of time" project.

She had three main design ideas for this:
1. Using sand falling through a tube into a jam jar.
2. Using an electronic circuit where a buzzer went off.
3. Using water running out of a jar where a light went off when it was empty.

Fiona drew up a list of the advantages and disadvantage of each design to help her decide on the best one.

<table>
<thead>
<tr>
<th>Design</th>
<th>ADVANTAGE</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SAND</td>
<td>Easy to make. Not accurate.</td>
<td>Have to keep looking at it. Can't alter the time easily.</td>
</tr>
</tbody>
</table>
Because Fiona didn't feel happy with electronic circuits and the sand timer could not be used easily for different timings, she made a decision to produce a prototype of her water timer device.

Can you see how her device would work?

While water is still in the top tank the lamp would stay on but it would go off once all the water had run out.

The ball-bearing acts as a valve and prevents the water from running out of the hole until the magnet is placed over it and lifts it up. The electric pump is used to fill the top tank up to the correct time line before the timer is used.

To make her prototype, Fiona didn't bother with the ball-bearing valve, the pump or the lamp circuit but just made up the tanks from washing up liquid bottles and plastic tubing. The main things she wanted to find out was the size of the hole where the water ran out and levels in the top tank to give the required times.

This is what a prototype is used for - to try our ideas out on a simple form of the device, find out the problems and to set some values. In this
case, the values she needed were sizes and volumes, but the following examples give some idea of other kinds of factors which could be researched by a prototype trial.

Separate parts of the devices or programs are all trialled separately, evaluated to see how well they work and modified, if necessary. Finally, the separate parts are fitted together to make the complete device from the proper materials as a final solution. The device will then be given an appraisal or evaluation to see how well it meets the design specifications.

Here are some examples of how prototypes were used in the development of projects:

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>PROTOTYPE DETAILS</th>
<th>FACTOR INVESTIGATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-theft trailer lock.</td>
<td>Trial version. Made up from thin tin plate.</td>
<td>Can it be removed without bending?</td>
</tr>
<tr>
<td>Automatic plant waterer.</td>
<td>Lemonade bottle with valve.</td>
<td>Does the valve design work?</td>
</tr>
<tr>
<td>Multiple-choice Biology questions program.</td>
<td>Trial of Menu procedure part of program only.</td>
<td>Any bugs in the Menu selection?</td>
</tr>
<tr>
<td>4 - tumbler door lock</td>
<td>Make a 1 - tumbler lock from wood.</td>
<td>Is position of tumbler correct for key?</td>
</tr>
<tr>
<td>Fireproof night-dress.</td>
<td>Doll dressed in rough design and exposed to flame.</td>
<td>How easily will it ignite?</td>
</tr>
<tr>
<td>Burglar alarm</td>
<td>1 transistor light switch made up on prototype board.</td>
<td>How far away could the light be for it still to work?</td>
</tr>
</tbody>
</table>
In the case of the Fiona's Water Timer the final product was an attractive system made of perspex and plastic tubing which was evaluated by her family and other cooks to see how useful it was and how easy it was to use. Design specifications like "Being able to give the correct time within 10 seconds" and "Lack of leaks" were also checked.

**RECAP ON THE DESIGN - AND - MAKE METHOD**

1. Decide on design specifications
2. Build prototypes to trial each separate part of the system
3. Make modifications
4. Build whole device
5. Evaluate
This chapter focuses on the final stage of any project where you have to communicate important facts to other people - what you did, how you did it and what you found out.

Ideas can be presented to others in two ways - visually or orally - and the skills involved could be very important ones for you to develop in later life.

For Science Fair the skills involved in creating a visual impact are the most important ones, although it would also be important, if your project were selected to go through to the Zonal Final, to talk effectively and be able to explain efficiently to the judges the essential details of your project work.

With CREST you may be asked by your teacher, once you have done some investigations, to give an oral presentation (talk) to the class to see your progress so far. In the Silver and Gold CREST award work being able to explain your ideas in words becomes an important part of your assessment.
5.01 VISUAL PRESENTATION

Because of the limited space available for Science Fair exhibits your visual message must be put over very concisely and in a way which immediately grabs the attention of the viewer. Have a look at some advertising posters to see how the use of colour and layout around a central theme does the job of catching the eye.

Try to be creative in the way you use your display boards to put over your ideas with impact. Apart from graphics, photos, posters and colour you may choose to have some 3 dimensional artwork or models as your centre of attraction. People find displays more interesting if they are INTERACTIVE i.e. there is something for them to alter or experiment with themselves within your display - like buttons to push, equipment to adjust or inputs to make on a computer. With hundreds of exhibits on display the time available to view each of them is limited and so the main points of your project which you want to get across must be laid out concisely and in some logical order which is easy and quick to follow, from left to right, perhaps something like this:
Nowadays, with graphics or word-processing computer software available the production of neat, artistic writing for display work is easier. All the more detailed methods, results and findings can be shown in your Project Report and Log for people to read if they are really interested and want to find out more about the work you did in greater depth.

5.02 ORAL COMMUNICATION

One of the most important personal skills which practical project work allows you to develop is one of expressing yourself verbally (in your own words). For the Science Fair projects and CREST higher awards this is a particular skill which forms part of the assessment criteria - that ability to be able to communicate with your teacher, Assessor, Consultant or Science Fair judge.

**ROLE OF THE INTERVIEW IN SCIENCE FAIR**

The opportunity for judges to talk with the exhibitors is a most important part of the Science Fair. Not only does it give each exhibitor an opportunity to describe her or his work, but also it allows a discussion with senior teachers and practicing scientists and gives judges close insights into the exhibitor's design, development and understanding of the project itself.

Essentially, however, the project must stand on its own; it must convey to the viewer the purpose, methods, results and conclusions of the particular investigation. The exhibitor will not always be on hand to explain, describe, discuss any areas which are unstated or unclear. Thus the purpose of the interview is to interpret and explain rather than expand.

Having examined the project without the exhibitor being present the judges now have the opportunity to check.
Standing up and giving a talk to others may seem a bit worrying to you at first but you will find that when you study and become an "expert" in a particular project topic this becomes a whole lot easier; you become enthusiastic about what you have done and found out and will want to tell everyone about it.

When Archimedes, the Greek, discovered the Flotation Principle whilst having a bath one day, he wanted so much to tell someone about this that he ran down the street in the nude yelling "Eureka!" (which means 'I've found it!')
- That's how this creative, experimental work gets you!

For any formal talk about your work you will need to prepare yourself well beforehand by making short notes on the main points which need mentioning. You could put these on to cards to use during the talk as memory-joggers.

Try to limit the amount of time for which your audience is just listening to you by making use of some kind of visual aid:

- GRAPHICS ON THE BLACKBOARD
- POSTER DIAGRAMS
- APPARATUS DISPLAY
- OVERHEAD PROJECTOR TRANSPARENCIES
- PROJECTED SLIDES OR PHOTOGRAPHS

These are all useful to make your talk more interesting.

Remember that you are performing, so you will need to keep your voice clear, loud and reasonably slow in pace.
Avoid too many long words which people might not understand and finish off your oral presentation with a summary of the main points again on some kind of visual display.

Not all of these things come easily to everyone, but you will find that the more talks of this kind which you give the better you get at it - and a rehearsal in front of your friends or family beforehand can build up your confidence (try tape-recording your talk.)

The same hints which have been given above would also be helpful in the one-to-one talks, or interviews which you may have with Science Fair judges or CREST assessors - except that you will have to rely on your memory more for these, rather than Display Aids and Summary Cards.

### 5.2 THE PROJECT REPORT

The Project Report is the method by which you communicate exactly what you did and what you found out to other people who may be interested - such people as the General Public, Science Fair judges or Supervising Teachers and Assessors for CREST.

The report does not need to be lengthy: in fact, it would be a disadvantage if it was too long and contained unnecessary things, but you should include such things as: ideas, stages of development, methods and outcomes in the project (no more than 5 hours should be spent).

For CREST it is enough that your write-up is neat and tidy but if you are submitting a project for Science Fair you will need to give more thought and effort to your display work as extra marks are awarded for an eye-catching presentation which will grab people's attention.
The CREST Project Log will contain all the small details, working notes, observations, letters, photos and times spent on everything that was tried, but all of these are not required for the Report. Just stick to a summary of the main work which was done, the results and the conclusions reached. The Log could be attached to the end of the Project Report, if necessary.

For a Science Fair display a detailed Project Report is not so important but such things as observations, letters, background information, etc. should be attached in a Log Book to add extra detail which is too much for the main display.

It is far easier for assessors or judges to follow the progress of a project if the Report is laid out neatly with headings to guide them, but the main thing they will be looking for is whether the agreed criteria for good science have been met - and this involves brainwork and organisation, rather than artistic abilities in the case of CREST.

Before writing your Project Report just check over your project notes and Project Log to see that you have completed everything which is required. PSE#15 contains two checklists for the two kinds of projects (Experimental and Design - and - Make) which ask you questions about your project. If you are able to put a tick for 'yes' to every question then you should have done the PERFECT PROJECT!

5.21 REPORT HEADINGS

It is helpful, in leading an Assessor through your report, to put headings at the beginning of each section which explain what each part is dealing with. The following headings might be useful in organising the report.
TITLE PAGE

This is the outside cover page for your report which contains your name and CREST Registration Number (for Silver and Gold) together with the Project Title in the centre.

ACKNOWLEDGEMENTS

Under this heading you should write a list of all the people who helped you throughout the development of your project. These could include Consultants, family members, teachers, friends or any firms which you contacted for advice.

INTRODUCTION AND PROJECT OUTLINE

In this section you should discuss the problem which you tried to investigate and its importance (i.e. need). You should outline some of your first thoughts on solutions and what the AIM of the project was.

PLANNING

Here you would set out your plan of attack: objectives, what you needed to find out, what preliminary experiments or trials had to be done and a list of alternative approaches which you considered. Identify some of the constraints which you thought might have prevented you from reaching your objectives.

PROJECT

Here you simply put down exactly what you did, what problems were encountered and how you overcame them - in a logical sequence as things happened.
Write your results here, what happened, observations made, data recorded and how well things worked. Tables, graphs, results would all be put in this section.

CONCLUSIONS

This section basically tells what you found out - the meanings of your results. In an Experimental Project this is the section where you test the hypothesis to say whether it is supported or refuted. In a Design - and - Make project you would report on whether the device/program met the design specifications.

It is here that you give your evaluation i.e. opinions of how successful your work was in overcoming the problems of producing the device or problems encountered in the experimental work. Include a self assessment of your methods and competence together with some ideas for improvements or alternative ways things could be done in the future.

A few lines as a summary would be good here to draw together all the main methods and findings of the project again - just to remind the reader once more.

APPENDIX

For the final part of the report you should list all the books, pamphlets, articles magazines etc. which you used to refer to for input to your project i.e. references.