

# Electronics and Control Technology

— *Mike Forret*

Technology has been, and continues to be, central to the survival and success of the human species. It allows humans to cope successfully, despite their physical limitations, with environmental conditions that would otherwise be overwhelming. Furthermore, humans are unique among animals in the complexity of the tools they have created and use to manipulate, reshape and control their environment.

Once reliable control of a situation is achieved, humans often seek to automate that control, so that they are freed to do other things. This automation may be carried out by people, by other animals, but particularly now, by systems designed by humans to monitor the environment, detect changes and respond to those changes according to predetermined algorithms. The systems need not be electronic, but in the late twentieth century, electronics, both by itself and in combination with other systems, for example, electro-mechanical and optical systems, is the key to much modern technological control. Other forms of control use mechanical systems which depend on moving parts of mechanisms, and hydraulics and pneumatics which depend on fluid and air pressure, respectively; but these will not be discussed in this chapter. Some follow-up sources are provided at the end.

## **Attitudes to electronics**

Attitudes and values play an important part in the messages, directly and indirectly, that young learners receive. In considering attitudes to electronics, it pays to remember that modern electronics has evolved in less than one lifetime. Children are growing up in cultures permeated by electronic systems and devices that were not available to the previous generation.

Until recently, there was no requirement to learn electronics and control technology in the New Zealand school curriculum. Apart from isolated pockets of teaching based on the enthusiasm of individual teachers, there is very little direct learning of electronics in New Zealand primary or secondary schools. The learning of electronics is located in tertiary vocational training programmes. Thus, few school students learn about electronics and few school teachers have experience in teaching it.

Lack of experience with electronics (other than using its products) has contributed to a commonly held view of electronics as out of the control and intellectual grasp of the average person; the domain of the engineer, programmer and enthusiast with his or her special aptitude. This need not be true, but teachers' and parents' lack of experience with electronics is in danger of denying young learners access to the mainstream of modern technology.

## **What is electronics?**

The fundamental 'raw materials' of electronics are moving electric charges. Electronics is therefore the technology of manipulation and control of electric current. It involves the design and construction, explanation and understanding of the basic tools of this manipulation, electronic components, and of devices and systems constructed from these components as solutions to broader technological problems.

An integral part of understanding electronic technology is the realisation that electronics did not suddenly appear as the result of one individual's brilliant idea, it evolved (and continues to evolve) through numerous interconnected events, practices, ideas and inventions driven and directed by personal and cultural values and choices, a point made clear by Noble (1991).

... technology bears the social 'imprint' of its authors ... there is always a range of possibilities or alternatives that are delimited over time – as some are selected and others denied – by the social choices of those with the power to choose, choices which reflect their intentions, ideology, social position and relations with other people in society.

(Noble, 1991: 14)

The design and construction of each new artefact generates new intellectual, as well as practical, possibilities. New artefacts provide not only new entities to work and build with but also new entities to think with, which, in turn, generate new ideas and artefacts.

Thus (electronic) technology evolves through a process of generating and testing. New ideas, physical or intellectual, are generated then tested and selected on value, with selections forming the basis for further generation and testing. This feedback loop is the heart of a technological design cycle and is also the basis of adaptive human behaviour, that is, learning.

### Origins of electronics

The following sections provide a brief historical overview of the development of electronics and control technology within the rapidly changing technological environment of the twentieth century and this is followed by a description of some of the central ideas in these technologies.

#### *Early electronics: the vacuum valve*

An important event in the evolution of modern electronics was the construction of a thermionic, vacuum diode in 1904 by J.A. Fleming and a triode in 1906 by L. de Forest (see Williams, 1978). Triode 'valves' could not only detect radio signals but also amplify them (make them larger), making it possible to use loudspeakers instead of earphones. This new-found ability to amplify small electrical signals opened up numerous developmental possibilities and valves quickly became the central components of research and development in communication technology.

What characterised these new devices was the utilisation of free electrons, that is, electrons that were emitted from, and free of, the metal. Designers and engineers working with these devices, that manipulated the behaviour of free electrons, were known as electronic (rather than electrical) engineers and the technology became known as electronics.

Early electronics was almost entirely concerned with communication. Radio in particular advanced quickly, to be soon followed by telephony, radar and computer applications. Much of the early development work in electronics was empirical, relying on practical knowledge of the physical behaviour of devices and components. By the 1940s electronics had grown into a major industrial activity and the shortcomings of the vacuum valve, its size, fragility, relatively short working life and high power consumption were hampering further development, and there was a strong market-pull for an alternative.

#### *Early semiconductor electronics: the transistor*

The intense research and development made urgent by the Second World War, and its successes in the areas of radar, communications, aircraft design and nuclear weapons, all served to bring science (but not technology) into the limelight. Within the buoyant post-war environment there were many British and American research groups working on semiconductor materials. These materials, which could be made to conduct if they had certain impurities added to them, were being studied to see if the action of a valve could be produced within a solid.

This research led, in 1947, to the demonstration by J. Bardeen and W. Brattain of Bell Laboratories (U.S.A.) of a semiconductor device called a point-contact transistor that could amplify electrical signals. On the basis of this success W. Shockley, also from Bell, proposed the possibility of a transistor made of a single piece of germanium and in 1950 he, M. Sparks and G. Teal succeeded in creating such a device. Despite initial production problems, efficient techniques for producing semiconductor devices in large numbers were developed. During the 1950s a transistor-based electronics industry grew rapidly.



### *Miniaturisation: the integrated circuit*

Advances in both manufacturing techniques and the theoretical understanding of semiconductors culminated in the introduction, in the early 1960s, of the integrated circuit, a technique whereby all the components of an electronic circuit could be manufactured simultaneously on the same semiconductor 'chip', rather than being manufactured separately and connected later. Integrated circuits, or ICs, allowed complex circuits to be miniaturised and manufactured quickly and efficiently. The advantages of the integrated circuit were manifold. They were small, light, robust, versatile, reliable, required very little power to operate and were cheap to produce in quantity. ICs quickly took over as the fundamental 'building blocks' of the electronics industry.

### *Digital electronics: computers, telecommunication and the information age*

The Russian success with Sputnik in 1957 prompted an American response that boosted the electronics industry even further. From the 1960s on, electronics, in the form of digital integrated circuits, grew more rapidly than any other technology in history. Digital electronics, the foundation of modern information technology, became the design medium of choice for virtually anything that operated electrically, or that could be controlled electronically. The development of modern electronics and particularly the ubiquitous microprocessor, has generated new forms of technology such as information engineering, artificial intelligence, systems and network theory and applications, photonics and control and automation.

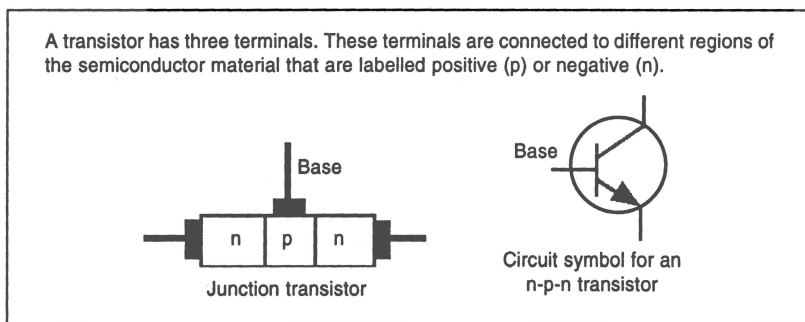
These developments have generated not only new devices and systems but also completely new ways of thinking. In information engineering a machine is no longer a converter of energy but of information. As Wiener put it, 'From one standpoint we may consider a machine a prime mover, a source of energy ... a machine for us is a device for converting incoming messages into outgoing ones' (Wiener, quoted in Hirschhorn, 1984: 37). With this way of thinking the fidelity, reliability and speed of transfer of messages, abstractly represented by

electrical signals (variations in current and voltage), become the main considerations, not the dimensions or structure of physical devices.

### Central ideas in electronics and control technology

Before considering electronics education and its implementation, this section provides a brief introduction to some of the key ideas in electronics and control technology. The transistor is an essential component of this technology and its structure is described in Figure 14.1.

**Figure 14.1: Structure of the transistor**



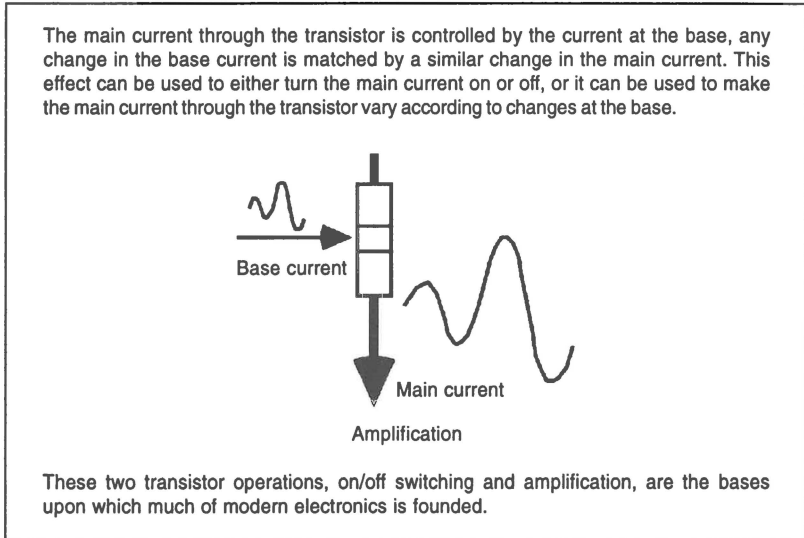
### *The transistor as amplifier*

In many electronic devices the detected electrical signal (variations in current and voltage) is too small to directly operate and control output devices. For example, the small electrical fluctuations caused by the movement of magnetic tape over the 'reading head' of an audio or video recorder are too small to be of direct practical use. Amplification allows these small electrical variations (electrical signal) to be made larger while maintaining the integrity of the original variations.

In this way small electrical signals can be made large enough to operate devices such as loudspeakers while faithfully reproducing the originally detected signal (Figure 14.2). Electromagnetic waves, for example, such as radio, TV and radar (or microwave) transmissions,

that are fundamental to our modern communication systems, produce very small electrical changes in the ariels and antennae that detect them. Without amplification these tiny changes would remain unusable and modern wireless communications would not be possible.

**Figure 14.2: Functions of the transistor**



### *The transistor as switch*

A transistor can be used as a switch (Figure 14.2) – one that is turned on and off electrically. Such a switch has a number of important advantages. Having no mechanical parts to wear out, it can last almost indefinitely, and as it does not rely on physical motion (in a mechanical sense), it can be turned on and off extremely quickly. Also, the solid-state construction allows a transistor and other semiconductor devices, to be made very small, thus using much less material in the manufacturing process. Being small and requiring only a very small voltage change at the base to turn it on or off also means that the transistor uses very little energy to operate.

*Analogue circuits: continuously variable current*

Most environmental changes (for example, light, heat, sound, motion) are usually analogue, that is, they change continuously not in discrete units. Many devices designed to detect these changes (for example, a microphone) also produce continuous changes, usually (directly or indirectly) in electric current. Devices that operate on a continuously variable current of this type, perhaps amplifying the current but maintaining its continuously changing character, are called analogue circuits and systems.

*Digital circuits: on or off*

Digital circuits and systems operate by detecting whether a switch is on or off. In such circuits 'on' is recognised by a particular current or voltage level and 'off' is recognised by a lower level (usually zero). Levels between the recognised on and off levels have no effect, for example, a simple domestic light switch is either on or off. It cannot be partly on, whereas a light dimmer control is an analogue device and allows a continuously variable output.

One of the great advantages of digital circuits is that both the basic elements of logic (true and false) and the digits of the binary number system (1 and 0) can be represented electronically by a switch; the presence or absence of a voltage or current. Binary numbers and logic states can be represented and stored by electronic switches. For example, three switches that are in turn, on, on and off, might represent the binary number 110.

A stream of electrical pulses in sequences that represent binary numbers, which in turn represent letters and numbers, can transport information along electrical wires or via electromagnetic radiation through the atmosphere. Electronic circuits combine these streams of pulses to perform numerical and logical calculations. The ability of digital systems to store, process and efficiently transmit data is the basis of the modern information age.

The word digital derives from 'digit' meaning number. Words like 'bit' meaning a binary digit (1 or 0), 'nibble' a 4-digit or 4-bit binary number and 'byte' an 8-bit binary number, are now part of the language

and culture of digital electronics and computing. One mega-byte means one million bytes, or one million 8-bit binary numbers.

*Modularisation: different levels of generality*

What constitutes an electronic 'component' varies depending on the perspective adopted. At a fundamental level, an individual electronic element such as a resistor or transistor could be considered a component; at another level an integrated circuit might be considered a component; and at yet another level (a complex systems level), a computer might be considered a component of a larger system or network.

This modularisation, or 'black-boxing', provides a powerful technique by which to progressively increase the complexity and sophistication of electronic (or other) systems while limiting the intellectual (and physical) demand of keeping track of individual smaller components. Black-boxing is as much an intellectual process as it is a physical one. A recently formed 'module' provides not only a new entity to build with but also a new entity to think with.

A systems approach analyses design structures in terms of inputs, how they are acted on by a processor and the subsequent outputs. The flow of data from one part of the system to another and how data are handled are the main considerations not the behaviour of the innumerable smaller parts that make up each module. Many electronic and control systems are too complex to be usefully thought about in other than system terms.

*Computers*

There is not space here to trace the development path of the modern computer but issues already covered in this chapter underpin its evolution in the following ways:

- electronic switches (transistors) can represent binary numbers;
- binary numbers can represent, through programming languages, or codes, other numbers and letters;
- binary information can be stored as the ons and offs of transistors, either temporarily or permanently;

- integrated circuits make it possible to store and process large amounts of data on a small chip; and
- computers are most usefully thought about in system terms.

The heart of the modern computer is its ability to store its own instructions (program). Programs are stored permanently on ROM chips (Read Only Memory) or dynamically on RAM (Random Access Memory).

The internal ROM of a computer is permanent and holds the instructions that the computer will need regardless of the eventual application programs it may run. These instructions enable it to communicate with the screen, keyboard and disk drive as well as organise and manage the instructions that are input when an application (wordprocessor and so on) is loaded for use. It is the computer's internal management and housekeeping system.

When an application is started the instructions that make up the application are stored temporarily in the computer's RAM. When the machine is turned off or the application is shut down, these instructions are removed from the memory. All data are stored and communicated within the computer as electronic ons and offs representing binary numbers, which in turn represent other numbers and letters.

The keys to modern computing are the programs, the codes that interpret the patterns of ons and offs produced by mouse clicks, key strokes and so on, process the signals and produce the required output effect.

### *Feedback: control, automation and adaptable machines*

The idea of feedback is a simple yet powerful one. In order to achieve or maintain a goal, it is necessary to sense what is happening, check to see if it is in keeping with the desired goal and, if not, make changes towards the goal. Changes alter what is sensed and what is sensed causes changes to be made. This is therefore a continuous process, or loop, that is constantly adjusting and readjusting to environmental changes.

In an electronic feedback system a sensor of some kind detects environmental changes such as temperature, light, sound, or motion, usually as a change in current. The detected change is compared to a

reference (or goal) and if it does not match then signals are sent to output devices to make changes that bring the system back within desired limits. A common feedback system is the thermostat control of a domestic heater that senses the temperature of a room and turns the heater on or off to maintain a preset temperature. In more complex systems, that have multiple sensors and control a range of output devices, the decision-making and switching is usually controlled by a microprocessor (dedicated minicomputer).

Feedback-based systems are central to modern automation, robotics and artificial intelligence. The notion of feedback is, therefore, central to modern electronics both in terms of the function of particular circuits and as a design principle that reflects the nature of technology itself.

The heart of such systems is, of course, the program that makes the decisions. The development and testing of the processor's program is a crucial part of the design and construction of control systems.

### **Electronics education**

Within the over-arching aims of the technology curriculum, the aim is to help learners become fluent in electronics and control, become confident and competent in using the language, ideas, skills and techniques of electronics and control to solve technological problems. Learners should be encouraged to examine the relationship between society and developments in electronics and control technology and to consider the personal and social effects (and affects) of particular developments. It is important that learners are able to critique these developments from a position of understanding both of the technology involved and the technology-society relationship.

In the same way that one cannot learn to read, write or ride a bicycle without actually doing it, so it is with electronics and control. Learners need to practise electronics and control technology in order to develop the intellectual and practical skills necessary to become fluent in this technology. Knowing *that* a particular circuit diagram represents a transistor, lamp, resistor, light-dependent resistor and battery, is not the same thing as knowing how to connect the circuit correctly, even less is it the same as the practical and intellectual skill of using such a circuit to design and construct a practical burglar alarm.

In the earlier part of this chapter some of the main ideas of electronics and control were described. While it is always problematic to list areas of knowledge and understanding in such a rapidly changing field (in the future it is possible that we will be more concerned with photonics – circuitry that operates on light rather than electrons – than with electronics), the following list may help to summarise the main ideas.

Electronics and control technology would include knowledge and understanding of:

- the influence of personal and cultural values in determining the nature and direction of technological development
- the nature and development of electronic technology in the past, present and possible future
- a range of electronic devices and systems and their application in a variety of contexts
- an electric circuit and what is needed to make it operate
- the meaning (electrically) of off and on
- series and parallel circuits
- resistance, current and voltage and their relationship
- circuit symbols and diagrams
- computer commands used to control a device (robotics)
- flow and system diagrams
- a range of electronic components, their function and use
- the difference between analogue and digital circuits
- the transistor used as a switch
- the transistor used as an amplifier
- the concept of feedback, in general and in electronic circuits
- integrated circuit production
- integrated circuits – logic gates, operational amplifiers, timers and microprocessors
- logic symbols and diagrams
- analogue-to-digital and digital-to-analogue conversion
- data storage and transmission in analogue and digital forms
- binary code conventions, assemblers, compilers and interpreters
- structured computer programming
- instrumentation and virtual instrumentation
- printed circuit board (PCB) diagrams and circuits.



### *Links with other curriculum areas*

Knowledge and understanding of electricity is central to developing capability in electronics. Early practical experiences with electrical circuits provide a basis for developing knowledge and understanding in both science and technology. Experiences in constructing and manipulating circuits soon lead to curiosity and ideas about how and why circuits behave as they do (see Osborne and Freyberg, 1985 and Cosgrove, 1995). Understanding the science ideas of current, voltage, resistance, electromagnetism and waves, and their relationship to each other, provide the electronics technologist with powerful explanations for electrical phenomena and with the confidence to reliably predict the behaviour of electrical circuits. Chemistry and atomic and quantum physics also have strong links with electronics through the materials technology of semiconductor manufacturing techniques.

Information and communication technology is intimately related to electronics and control through the electronic foundation of modern telecommunications and automation.

Mathematics is a fundamental language of science and technology. Many science and technology ideas and relationships are expressed mathematically, and in programming too fluency in mathematics is central.

Technological action brings together a range of skills and knowledge and within any context for technology education there is much potential to integrate a number of curriculum areas. Actual opportunities for integration will depend on the context chosen but strong links with science, mathematics, information and communication technology, materials technology and social studies are usually present.

### **Implementing electronics education**

Developing a successful classroom programme for electronics and control technology is itself a technological activity and will develop through a process of planning, implementation, ongoing evaluation and refinement, in other words, by doing it. Also, like other technologies, it will develop within the constraints and possibilities of a particular situation. Schools will have to select experiences and contexts (perhaps from the technology curriculum document) that are suitable for their

learners and for the resources they have available. There is, therefore, no formula for implementation but there are suggestions and ideas.

In general, the aim is to provide learners with:

- a supportive, non-threatening and stimulating environment;
- as many relevant experiences as possible;
- opportunities to try things out for themselves;
- opportunities to reflect on and discuss, their own and others' ideas; and
- opportunities to test and explore the validity of their ideas.

These general principles can be very effectively achieved in a context of technological problem-solving and exploration.

The following are suggestions and outlines intended to provide a framework for developing electronics and control. They are organised in three broad and overlapping areas of schooling, the first few years at school, late primary – early secondary, and senior secondary.

As schools begin introducing technology education many learners will initially have little or no experience with electronics and control technology. Achievement expectations will need to be tailored accordingly. Many senior secondary courses will have to be aimed, in the first instance at least, at a level well below level eight of the curriculum document, with similar adjustments for younger learners. Not until a cohort of students has experience of technology education throughout their schooling, will the higher levels of achievement outlined in the curriculum document be a realistic expectation.

### *First few years at school*

#### *A possible context – Morse code*

To help learners gain experience with simple circuits they can be challenged to make a Morse code sender. They can learn Morse code and practise using their circuits to send messages to each other. As well as helping to focus on the nature of an electric circuit and the operation of a switch, this activity also helps to focus thinking on methods of communication and on codes in particular. Morse code is not unlike the binary code used in digital electronics and although this need not be

raised formally with learners at this stage, the idea is embedded in the activity.

Learners can be challenged to extend their message senders so that they are able to send messages to more than one place, either simultaneously or alternately. This quickly brings up ideas of series and parallel circuits and learners can decide the advantages and disadvantages of each for their designs. Circuit ideas can be recorded, initially as drawings and later using standard circuit symbols – another code or language (see Cosgrove, Osborne and Forret, 1989).

The Morse Code sender challenge could also be tackled by using computer control. For example, Lego light bricks, linked to a computer with Logo installed, can be turned on and off by typing simple commands on the keyboard. Learners can devise sets of Logo commands to send Morse letters and numbers (see Cosgrove and Schaverien, 1994).

Part of the investigation can be to find out who Samuel Morse was and why he needed a code. When did he invent the code, how and where did he use it and what difference did it make? The role of telecommunications, generally, and its impact on our lives can be explored.

### *Late primary–early secondary*

#### A possible context – environmental control

An environmental control system for a greenhouse might include designing and constructing systems to monitor and control, the level of light, the temperature and soil moisture. This task might well be approached by allocating different parts of the system to different groups, for development, and later integrating the parts to form the complete system.

The project could include working from the outset to a design brief, considering the economic and environmental advantages and drawbacks of automating a greenhouse, and the development of a cost–benefit analysis. Issues of efficiency, optimisation and reliability would also be important considerations.

One group might work on developing a temperature control system that uses one or more thermistors (resistors whose resistance changes with temperature) to monitor the temperature at different points in the

greenhouse and turn on or off a heater (perhaps modelled by a lamp), or open or close skylights (perhaps modelled by a motor operated in forward or reverse), or both of these, depending on conditions.

Another group might develop a circuit that monitors light levels using light-dependent resistors (LDRs) and controls the opening and closing of shutters (again modelled by a motor).

Yet another group might develop a circuit to monitor soil moisture (the resistance of soil decreases as it gets wetter), turning on a sprinkler system (a motor could model the pump) when the moisture level gets too low.

Each of these systems could be developed separately and would involve research, planning, designing and testing, as well as management of time and resources both human and physical.

Later, consideration could be given to how all of these systems could be integrated to form a complete environmental control system.

Integration of these systems through the development of a computer control program to monitor the output of the various sensors and handle the switching on and off of pumps, heaters and so on could be studied either as an ongoing part of the development described above, or as a separate project altogether.

### *Senior secondary*

#### *A possible context – a computer interface*

Learners might design and construct a computer interface for use in school practical work, perhaps for a data logger designed to log levels of light or sound. This would involve designing and constructing the interface itself as well as developing suitable computer software to store, process and display the data from the interface, perhaps providing spreadsheet and graphing capabilities.

Students would prepare a design brief and make decisions (after appropriate testing) as to which sensors (transducers) would be most suitable for the design purpose. Consideration would need to be given to Digital to Analogue Conversion (DAC) and Analogue to Digital Conversion (ADC) requirements and suitable connections for input devices and to the computer.

Students would have to take into account industry standards for computer interfaces and software development. Initial circuit prototyping and development could be done using a software package such as Electronic Workbench, before moving to actual components and printed circuit boards.

The project would involve prototyping and testing of circuits and software, including consideration of the user friendliness of the software and aesthetic and ergonomic characteristics of the final hardware product.

The design project could well be tackled with a team approach, each part of the team being responsible for a different aspect of design and development. This raises issues of time and resource (physical and human) management.

Part of this study might be to investigate the impact of electronics and control technology on the modern industrial workplace, perhaps looking at changes in the types of work, skills and management techniques needed in a post-industrial information age (see Hirschhorn, 1984), comparing and contrasting with those of the mechanised industrial age and considering implications for the future of currently developing electronic and control technologies.

### **Students' responses to learning electronics**

It is perhaps appropriate to leave the final words of this chapter to three sixth form students as they reflect on their experiences of working on a circuit design problem. The following are brief extracts from an extended interview with these students.

- MF What do you think you got out of doing this? You told me it was fun and you enjoyed the challenge, but apart from the enjoyment of the challenge what else, if anything, did you feel you got out of this?
- St.1 Perseverance, being able to have a problem you couldn't do and actually working through and solving it and being able to, because quite often you get a problem you can't do it, you tell the teacher and they help you with it, but with this one it was actually up to us to solve the problem.

Later

- St.1 It's a very good way of learning it, lot better than sitting down and being told a list of components and how they work, you actually found out practically and that puts it in your brain a lot easier. You can think back to what problems you had and how you solved them, so you know how the part works.
- St.2 ... I mean, like, we all now know what happens when you put two transistors in the circuit, how sensitive it gets, we would never have got anything like that if we were just taught out of a textbook, it's all experience.
- St.3 Also, no one knowing the answer was good and going to the teacher would have been the easy way out. A few hints here and there and you are almost there but this way we had to do it all ourselves.

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### *Industry Training Organisation*

Electro-technology Industry Training Organisation (ETITO), Manukau Road, P.O. Box 24469, Royal Oak, Auckland.

Contact Mary Barry, tel: (09) 625 1591, fax: (09) 625 159 free phone: 0800 501 558.

### *Polytechnics*

Many Polytechnics throughout New Zealand are involved in industry training for the ETITO. Information on these courses and the institutions involved is available from the ETITO.

### *Industries*

Once again the ETITO is a source of information about companies throughout New Zealand that are involved in electrotechnology.

### *Universities*

Auckland, Waikato, Massey, Victoria, Canterbury and Otago universities all have physics departments that are involved in electronics. In addition Auckland and Canterbury also have electrical engineering departments and Massey has a Production Technology department.

### *Professional associations*

#### **Institution of Professional Engineers New Zealand (IPENZ)**

IPENZ is on the World Wide Web at <http://www.ipenz.org.nz/>. It includes a showcase of innovative engineering in New Zealand and links to other international engineering sites. IPENZ has branches throughout New Zealand and the head office is, P.O. Box 477, Wellington, New Zealand.

#### **The Institution of Electrical Engineers (IEE)**

The U.K. Institution of Electrical Engineers is on the World Wide Web at <http://www.iee.org.uk/>. This Web site provides access to a wide range of useful technical, professional and educational material,



including the comprehensive collection of IEE publications that includes the magazine *Electronics Education*. Information about publications and other information on the IEE can be obtained from: IEE, P.O. Box 96, Michael Faraday House, Stevenage, Herts. SG1 2SD, U.K.. Tel: +44 (0)1438 313311 Fax: +44 (0)1438 742792 E-mail: [webmaster@iee.org.uk](mailto:webmaster@iee.org.uk)

#### The Institute of Electric and Electronic Engineers (IEEE)

The U.S.-based IEEE has a comprehensive Web site at <http://www.ieee.org/> providing wide range of electronics related information, resources and connections. Check out the IEEE bookstore. The IEEE can be contacted at, IEEE Customer Service, 445 Hoes Lane, P.O. Box 133, Piscataway, NJ 08855-1331, U.S.A.. Tel: +1 (908) 981-0060 Fax: +1 (908) 981-9667 E-mail: [customer.service@ieee.org](mailto:customer.service@ieee.org)