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3. TRANSFERRING KNOWLEDGE VERSUS KNOWLEDGE THROUGH TECHNOLOGY EDUCATION

What's the Difference?

INTRODUCTION

In this college,
Useful knowledge
Everywhere one finds,
And already,
Growing steady,
We've enlarged our minds.[1]

These lines come from a Victorian comic opera that lampooned university study generally and women's higher education in particular. A hundred and thirty years later it still points up current distinctions between different types of knowledge and hints at what type of knowledge is more valued. The "Classical" education of the time had little if any technical or scientific tuition, but the author was only mildly satirical realising that "Useful knowledge" was something that the Victorians valued highly. Steam engines and railways, bridges and tunnels were the physical manifestation of a "can-do" ethos of the age which placed practical utility to the fore and often demonstrated that technological knowledge led while scientific explanation followed rather than vice versa. Gaining such practical and technical know-how was recognised as needing more than a reliance on a simple "rule-of thumb" craft-based apprenticeship model, and Mechanics Institutes had been established by the start of Queen Victoria's reign in most of Britain's major industrialised towns to provide more formal adult education in a range of vocational subjects. Many became the forerunner of some famous current Universities such as Herriot-Watt University in Edinburgh, Birkbeck College in London, and University of Manchester Institute of Science and Technology (UMIST), now part of the University of Manchester. But what of today? What is the relationship between the useful knowledge that is particular to technology and situated in the context of learning about technology, and what is its relationship to the knowledge transferred from other domains, particularly science, which is exploited in technology education?

H.E. Middleton & L.K.J. Baartman (eds.), Transfer, Transitions and Transformations of Learning, 23-37.

One often hears people, especially politicians, referring to "science and technology" as if science and technology were a single activity inseparably linked. The aims and processes of science, however, are fundamentally different from those of technology and the links between them are not as formal as many people think. Maybe the confusion is because science is seen, erroneously, as necessarily underpinning technology – providing the foundation to develop "useful knowledge." Disappointingly, the confusion is also present in the school curriculum where, in simple terms, science is often seen as "theory," that is, "know-why," and technology as both practical, that is, "know-how," and in some way dependent on science. To consider knowledge transfer from other subject domains that may be exploited in technology education, particularly science, we must first clarify our understanding of "science" and "technology," and how science knowledge is "exploited" in learning technology; and vice versa how technology is used to advance science.

This chapter considers:

- the distinction between scientific knowledge (knowledge usually gained through studying science) and technological knowledge (knowledge usually gained through studying technology);
- the relationship between science and technology using examples from history. When knowledge transfer has been important and when it has not;
- the common ground between science and technology;
- designing and problem solving as key areas of knowledge used and learnt in technology which have wider application, and technology as a lead subject for learning "affective" knowledge; and
- systems thinking both in science and in technology, and "black boxes" – designing electronic systems as a technological process.

THE DISTICTION BETWEEN SCIENTIFIC AND TECHNOLOGICAL KNOWLEDGE

> Technology is about creating artefacts and solving problems, while science is primarily about describing and explaining phenomena in the world. (Noström, 2011)

Young people want to know *why* something is the way it is or *how* something works; they seem to want answers to two sorts of questions. One type of question seeks knowledge of the "knowing how" variety – how a thing works, how it is used, how it is possible to improve the function of something or the way something is done, or how to create something which has a new purpose. This is technological knowledge. It is the practical knowledge of application, that is, know-how or more formally the *operating precepts*. The other type of question seeks knowledge of the "knowing why" variety – why the world is the way it is, first to help us understand the rules that confirm generally accepted agreement about what we know, and second to help us rationalise the experience of our senses. This type of knowledge is called scientific knowledge. It considers the whys and wherefores of the operating precepts, that is, the science of the know-how, or more formally the *operating aetiology* (Clarke, 1982). Thus the baking of a cake by following a recipe uses operating precepts; mix this with that in these proportions according to these instructions and there you have it – a birthday cake. Understanding the chemistry of why particular ingredients, when mixed in particular proportions, produce the result they do is the operating aetiology – and you do not necessarily need that kind of knowledge to bake a cake!

However, scientific knowledge would be useful in improving the design of the cake. If we consider the birthday cake as a food product, then we could draw on knowledge of food additives to improve the cake's shelf-life or reduce its sugar content. A knowledge of nutrition would enable us to produce similar party food which is just as much fun but healthier to eat.

The press cliché is that we live in a "technological age." Some would say that all should have an understanding of the workings of what we use, yet most of us lead perfectly satisfactory lives on the basis of knowing how rather than knowing why. One can know *how* to drive a car without having much idea of *why* the engine and all its control systems do the job they do. Similarly, a motor mechanic (or a TV engineer and numerous other "serving" people) can mend engines without any knowledge of gas laws, combustion principles, materials properties, or other scientific knowledge of the "knowing why" variety.

The level of "knowing why" needs to be appropriately matched to the needs for the "knowing how" for them together to be useful knowledge for creating appropriate products.

TECHNOLOGY BEFORE SCIENCE?

Science has been in the school curriculum for a long time yet the subject of technology is a relative newcomer. In many countries technology in the curriculum fights for its survival as curriculum designers have perhaps tended cling to the belief that science education provides a more appropriate preparation for students intending to follow careers in industry and that without a thorough understanding of scientific principles there can be little progress in the various fields of application.

The assumption that science knowledge always precedes technology knowledge can be challenged through some wide-ranging examples (see Plant, 1994). How to refine copper has been known since ancient times, millennia before the concept of oxidation was understood. Around 1795 the Paris confectioner Appert devised a method of preserving food by heating it (to kill bacteria) and, without delay, sealing it in a container. The idea caught on, and a cannery using tins was already functioning in Bermondsey in 1814 when Louis Pasteur proposed a "theory of bacterial action." England became the "steam workshop" of the world in the 18th century following the invention of the first commercial steam engine by Thomas Savery and Thomas Newcomen at the end of the 17th century (Bronowski, 1973). Their knowledge of how to design steam engines spread as "know-how" across Europe and to North America. Yet the concept that heat was a form of energy able to do work came later. Later still Sadi Carnot, an officer in the French Army, became preoccupied with the concept of heat engines but it was years before his findings influenced steam engine design. The science of thermodynamics followed from the intellectual challenge to understand the operation of better steam engines. The principal point is that technology is more than the application of fully understood scientific knowledge; a point acknowledge by the economist Nathan Rosenburg:

> It is knowledge of techniques, methods, and designs that work, and that work in certain ways and with certain consequences, even when we cannot explain exactly why. It is […] a form of knowledge which has generated a certain rate of economic progress for thousands of years. Indeed, if the human race had been confined to technologies that were understood in a scientific sense, it would have passed from the scene long ago. (Rosenburg, 1982, p. 143)

Technologists today use a host of ideas and "rules-of thumb" that are helpful but not scientifically sound. Examples include the idea of a centrifugal force, heat flow (like a fluid), and the notion that a vacuum "sucks" (see Noström, 2011). For example, heat flow in science is often conceptualised using the kinetic theory of molecular motion. This is of limited value in technology where heat flow related to conductivity (or even "U values") and temperature difference is usually much more useful in practical situations. In order to use a particular idea for practical action, it is sometimes the case that a full scientific explanation is unnecessary and too abstract to be useful knowledge:

> [Reconstruction of knowledge] involves creating or inventing new "concepts" which are more appropriate than the scientific ones to the practical task being worked upon. … Science frequently advances by the simplification of complex real-life situations; its beams in elementary physics are perfectly rigid; its levers rarely bend; balls rolling down inclined planes are truly spherical and unhampered by air resistance and friction. Decontextualisation, the separation of general knowledge from particular experience, is one of its most successful strategies. Solving technological problems necessitates building back into the situation all the complications of "real life", reversing the process of reductionism by recontextualising knowledge. What results may be applicable in a particular context or set of circumstances only. (Layton, 1993, p. 59)

In technology, if the knowledge is useful then it continues to be exploited until it is no longer of use. In science, a concept that is not "correct" in that it does not match experimental results or related theory is discarded. However, rejection of certain scientific ideas such as phlogiston, the caloric theory of heat, and acceptance of energy as quanta took many years!

It is obviously true that new technologies have arisen from scientific discoveries. Microelectronics is founded on the "blue skies" fundamental science of semiconductors and similar fundamental research has led to

- improved knowledge of the intrinsic properties of materials such as lightweight alloys, carbon fibres, and plastics;
- the development of new types of superconductor, the laser, and other electronic devices; and
- high yielding, disease-resistant crops through an improved understanding of the scientific basis of genetics.

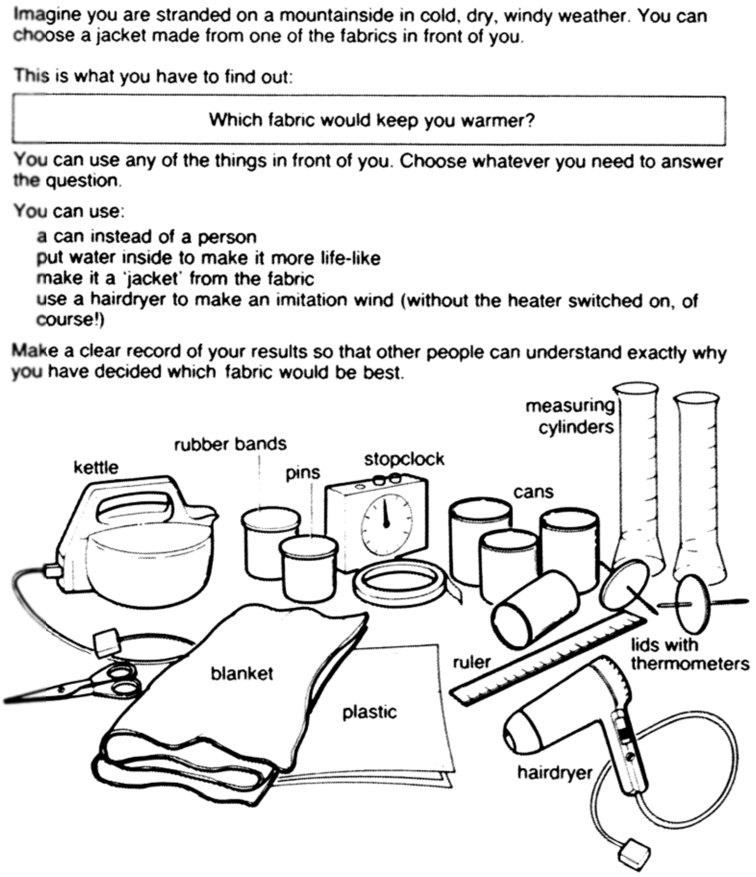
There is a link between scientific discoveries and new or improved technologies, and technology *can* stimulate new directions for science too. Space research is an example of this. Technological developments, for example rockets that can launch the Hubble Space Telescope and the Curiosity Mars Rover – technological achievements in their own right – can promote new challenges for science by revealing new features of the universe.

COMMON GROUND BETWEEN SCIENCE AND TECHNOLOGY

As we have seen, science does not need to precede technology but technology can be stimulated by the findings of science. Indeed, in response to today's economic demands there is pressure to structure scientific research with the specific purpose of stimulating technology, and hence a nation's wealth. Of course, the "laws of nature" as formulated by science set particular constraints within which all technological activity has to take place. For example, the second law of thermodynamics suggests that the building of a perpetual motion machine is futile despite inventors' persistent efforts to "break" the law! Other constraints may be economic, human skill and imagination, cultural influences, resource availability and so on. Furthermore scientific discoveries can suggest new products such as lasers and nuclear magnetic resonance imaging in medicine. Conversely, as illustrated above, technology does make a contribution to science in several ways. Examples include providing the stimulus for science to explain why things work in the way they do. The contribution of technology is especially evident in the way scientific concepts are deployed in technological activities.

It is useful to make a distinction between concepts which are directly related to knowing how (i.e., technological concepts as defined above) and concepts related to knowing why (i.e., scientific concepts). It is very difficult to make hard and fast distinctions between these two types of concepts, but consider the following examples. An electron is a concept, a fundamental atomic particle; science is able to describe its mass, charge, and other properties. In these terms the concept of an electron has no obvious practical application and is an example of a "knowing why" concept. On the other hand a light switch is a technological concept for it has been designed for the particular purpose of switching on and off a flow of electrons. It is a "knowing how" concept.

To see how the concepts are deployed in teaching science and technology, take the concept of *insulation* (a technological concept), which has relevance to understanding *conduction* (a scientific concept) of electricity and of heat. In the context of a science lesson, a teacher might involve children in exploring *electrical* *conduction* through simple experiments, for example, by using an ohmmeter to compare the resistance of a variety of materials, or using a simple circuit and noting the effect on the brightness of a lamp when different materials are placed in series with the lamp. In a study of *heat conduction* students might be encouraged to plot temperature/time graphs that compare the rate of cooling of a beaker of hot water wrapped around with different materials. Very often such a science activity would be placed within an "everyday" context (see Figure 1). The aim, in a scientific sense, is to find out the property of the material. This would lead on to the idea that if there is a lot of trapped air, then that material is a good insulator as it stops convection. However, as Murphy (1991, 2007) notes, some students (particularly girls) are distracted by this technological context. The important first step in this science lesson is to strip away the context to set up a comparison



Imagine you are stranded on a mountainside in cold, dry, windy weather. You can choose a jacket made from one of the fabrics in front of you.

This is what you have to find out:

Which fabric would keep you warmer?

You can use any of the things in front of you. Choose whatever you need to answer the question.

You can use:

a can instead of a person
put water inside to make it more life-like
make it a 'jacket' from the fabric
use a hairdryer to make an imitation wind (without the heater switched on, of course!)

Make a clear record of your results so that other people can understand exactly why you have decided which fabric would be best.

Figure 1. Investigating the "best" material for a mountaineer's jacket.

experiment between differently lagged beakers; yet some students will wish to stick with the real problem presented and make a little “jacket.” After all, that is what was asked for, not some abstract experimental method. Rather than making the science lesson “real” and meaningful, the context has provided a serious distraction.

This is an example how knowledge that is important for a science lesson is not the totality of the useful knowledge for a technology lesson. In technology such an understanding of suitable material properties would be an important factor to consider, but it would not be the only criterion. In addition, the students would need to consider non-scientific factors such as cost and availability, water resistance and toxicity, strength and flame-proofness, and colour and density of the insulating materials that might be used. So, whereas scientific knowledge of heat conduction would contribute to the design process, a range of other factors could also influence the choice of insulating material, such as its appropriateness to a given cultural context. Further, suppose scientific experiments in a country with few “advanced” material resources show that the stripped and powdered bark of a local tree, or the cotton-like seed heads of a local plant, would make a suitable low-cost heat insulating material. Why then should the technologists in this country use a hard-to-obtain and costly imported insulating material when the collection and preparation of this indigenous material also provides local employment? These wider considerations that are grounded in know-how and the value systems of the people using the technology are an important aspect of technological design activities.

In summary, science often has a contribution to make to enhancing design and technology projects. However, teachers need to be clear about what that contribution may be, and plan to teach it to students. It is also important to realise that in designing and making, scientific understanding is but one contributory factor among many competing concerns. Although scientific ideas *can* enhance projects, it is possible, in fact usual, for a student to conduct complex technological activity without first exploring and understanding all aspects of the science involved.

OTHER USEFUL KNOWLEDGE DEVELOPED IN TECHNOLOGY CURRICULA

Affective Knowledge and Values

Technology cannot be divorced from other dimensions of human thinking and behaviour since the beliefs and values of individuals and communities are influenced by, and exert pressure on, technology itself. In technological activities it is just as important to involve students in making value judgements about the *human*, or rather *humane*, dimensions of technology as it is to focus solely on technical details about the functioning of the technological product. Given that the *purpose* of technology is to respond to certain sorts of need, students should be expected to find answers to questions such as:

- Whose needs are to be met?
- Who has identified the needs?
- Are proposals for a particular technological development acceptable to the individuals and communities who are to use or be influenced by the development?

Decisions about various technological *processes* are affected by a range of criteria, each of which depends on different kinds of values. For example, materials used may be in short supply or come from environmentally sensitive regions of the globe; new construction projects may disturb or destroy wildlife, and so on. Evaluations of the *products* of technological activities are subject to decisions about fitness for purpose, cost effectiveness, possible health hazards, and so on. People's values affect every stage of the technological process from decisions taken about whether to embark on a particular innovation, through the process of development, to the acceptability of the subsequent product. The clarification of values is a responsibility of all engaged in technological activities and it has a central role to play in the affective dimension of a student's education.

The different *social* meanings attached to technology are nowhere more evident than in the use of the terms *high technology* and *intermediate technology*. The former is used to describe large-scale, capital-intensive technologies such as microelectronics which use a highly skilled workforce; and the latter is used to describe small-scale (Schumacher, 1973), labour-intensive technologies advocated for small communities that capitalise on local skills and resources which are at the community's disposal. It is of course quite possible that relatively high-technology electronics may be *appropriate* in small communities (e.g., those in remote areas), but this leads to issues about control of technology and economic power. It is these influences that make design and technology rich in educational terms. The interpretation of what is needed, how it is to be done, and who is to benefit should be made explicit and debated in order to question the value judgements that underlay any assumptions about a course of action.

Problem Solving

Discussions about technology as a vehicle for the teaching of problem solving sometimes become emotionally charged. Over the years, those proposing different technology curricula have used this argument as a principal way of advocating that technology should have an enhanced status in the school curriculum because a general ability to solve problems is central to satisfying human needs. Glaser (1984), Hennessy and McCormick (2002), and Layton (1993) all suggest that learning is heavily influenced by the context in which it occurs. McCormick (2006) in particular suggests that this is to be expected if one takes a sociocultural view of learning, where knowledge is the result of the social interactions in which it occurs and is inseparable from them.

Students do not easily transfer their ability in a particular activity from one learning "domain" to another. Technology teachers have assumed that if students are taught to investigate the factors influencing the design decisions for making one product, for example a moisture sensor, then they will be able to transfer those techniques to consider the different design decisions for, say, batch food production. The evidence is that students do not easily transfer their understanding across these different contexts and require considerable support from their teacher to help them do so (McCormick, 2006). Barak (2007) agrees that no all-purpose problem-solving method exists, but has set out a set of series of what he calls “strategies, schemes and heuristics” that would help teachers and their students to start with a framework for considering various possible problem-solving techniques. Murphy and McCormick (1997), however, caution that such strategies become an “algorithm” which sometimes teachers and students follow rather slavishly. Problem solving within a specific context is not confined to learning in technology; many people are able to add up effectively when shopping in a supermarket but find a similar sum set in a maths lesson very difficult (Lave, 1988).

There is a close association in a particular context between the conceptual knowledge associated with the particular problem and an understanding of what action needs to be done to tackle that problem (procedural knowledge). People think within the context in which they find themselves – “situated-cognition.” Murphy (2006) and Murphy and McCormick (1997) suggest that when students are presented with problems in unfamiliar contexts they tend to use everyday knowledge to tackle them.

Designing

Although problem solving is seen as central to the teaching of technology, “designing” is sometimes considered as so important that it is separated out – as in “technology and design” – perhaps for extra emphasis, as in most of the school technology curricula around the world students engage in designing to some extent. Mawson (2003), working in New Zealand, sets out the particular emphasis on the “design-make-evaluate” process there and in many other countries. He also notes the widespread criticism of how such an artificially linear “design process” is taught in schools, drawing on a wide range of research studies in Australia, Canada, and England and going back very many years. For example, Archer (1973) advocated design to be developed to a level which merited scholarly consideration, and Eggleston (1992) agreed about its importance:

> At the heart of the matter is the design process. This is the process of problem-solving which begins with a detailed preliminary identification of a problem and a diagnosis of needs that have to be met by a solution, and goes through a series of stages in which various solutions are conceived, explored and evaluated until an optimum answer is found that appears to satisfy the necessary criteria as fully as possible within the limits and opportunities available. (p. 18)

Eggleston, therefore, sees design as a special form of problem solving, and just as is the case with problem solving discussed above, many have criticised the simplistic models that were promoted when technology (or *design* and technology!) was first introduced into schools as a more scholarly activity than the former craft-based subjects. Initially such criticisms manifested themselves in the search for alternative models which better described what people engaged in a design activity actually did. This search for the "holy grail" of a supposedly correct description of the design process might have been seen as imposing order on what is necessarily a complicated and iterative process. That some countries wish to do this is to be able to assess and give students credit for the *process* of technology rather than just the end product that they make. However, this desire to assess builds in a level of unfortunate artificiality – even game playing – that is unacceptable to many learners. For example, when evidence of ideas is judged through a portfolio of drawings and notes, it is not unheard of for a student to be advised (after they have completed their final made artefact) to go back and invent some more "initial ideas"!

Mawson (2003) advocates that prior to any introduction of a perceived need, students need to be exposed to the context within which the task will be based:

> During this exploration of the general knowledge, relevant information, and social attitudes relating to the particular context, children should also be given an opportunity to explore the range of materials available to them when working towards their solution. (p. 123)

As was plain from Murphy's (1991, 2007) example of the mountaineer's jacket above, not only does the context shape students' ideas and thoughts about their emerging design, so does the opportunity to engage in their work alongside others. The opportunities for such collaborative work, however, are often not offered to students in the individualistic common "design-and-make" technology education paradigm common in many countries.

Systems Thinking

"Systems thinking" is a process of considering interacting elements in terms of overall function rather than a concentration on the individual component parts; looking at the whole building, as it were, rather than the individual bricks. Systems thinking is important in both science (particularly biology) and technology. In biology, examples of organs working together to perform a certain task include the digestive system, blood circulation system, and nervous system. Such systems are present in all mammals and in all cases they can be considered as a functional block that does a job – but with component parts. For the blood example, components are the heart, blood, and blood vessels; for the nervous system, the brain, spinal cord, and peripheral nerves. The approach to first aid is also systemic, as is triage, the process of determining the priority of patients' treatments based on the severity of their condition, dealing with bleeding and breathing problems before taking action on broken bones. In technology, the design and use of electronics systems is an example of the value of using know-how rather than know-why in technological activities in the classroom (see Banks & Barlex, forthcoming). In technological activities, students are expected to have a clear idea of what they want the electronics systems to do; it is a goal-oriented approach that is an essential ingredient of the successful use of electronics in designing and making activities. Rather than focusing on any scientific understanding of the way in which the individual devices and circuits work, the emphasis is on the functional aspects of the electronic devices and circuits that the students are to use. Students should be expected to ask questions such as:

- What do I want my electronics system to do?
- What operating conditions, for example, power supply requirements, does it need to work?
- Will the device stand up to rigours of use in its intended environment?
- How much will it cost to make and run?
- What characteristics of this device are better for this design than other similar devices?
- Will it be safe and easy to use?
- Can the components needed be obtained easily?
- Will it be acceptable, culturally and economically, to the people in the community in which it is to be used?

To a technologist, meeting these functional and contextual criteria are as important a consideration as knowing why the electronic devices used work in the way they do. The emphasis on *function* and *context* rather than *theory* and *fundamentals* may be misleading, seeming to lack opportunities for rigorous thought. However, the design and assembly of circuits and systems for specific purposes requires knowledge and understanding at the operational level. These operating precepts are just as demanding intellectually as the operating aetiology used by science to explain concepts such as electrical conductivity and potential. An example or two will make these points clearer.

An *electronics system* can be represented by three linked building blocks as shown in Figure 2. It is an assembly of functional electronic *building blocks* that are connected together to achieve a *particular purpose*, for example, sounding an alarm when smoke is in the air. Examples of *input* building blocks include switches, for example, mechanical and semiconductor types, microphones, and light-dependent resistors. *Processor* building blocks include amplifiers, comparators, oscillators, and counters. *Output* building blocks include light-emitting diodes, seven-segment displays, loudspeakers, and meters. Thus, the *input* building block of a smoke detector would be a smoke sensor. Its *processor* building block might comprise a comparator to switch on an audio frequency oscillator when the smoke level detected by the sensor has reached a pre-set danger point, followed, perhaps, by an amplifier. The detector's *output* building block would be a small loudspeaker or piezoelectric device to generate an audio

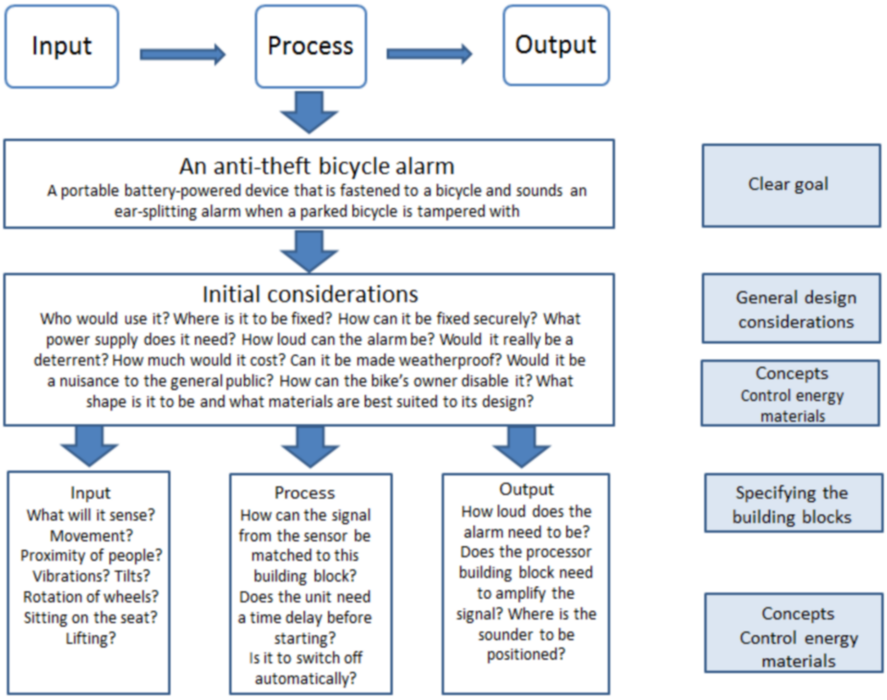


Figure 2.The linked building blocks of an electronic system and some of the technological criteria and concepts to be considered.

frequency sound when signals are received from the oscillator. Students quickly learn to associate a circuit board with a particular "job." For example, a 14-year-old student would easily solve the problem of making a "rain alarm" by linking a moisture detector (*input*) to a buzzer (*output*) by using a transistor switch (*process*).

Such black boxes can also be used to make more complex devices. Design decisions are based on how the product is to be used and students are constrained by their specification criteria, not by a lack of understanding of why the circuit functions. A *detailed* knowledge at the component level is unnecessary. Let us assume that a student is aiming to design and make an anti-theft warning device to clip onto a bicycle and provide an ear-piercing sound if the bicycle is about to be stolen, that is, it is a portable device to be used by an individual. First and foremost, there needs to be a clear specification of what the system is to do (see Figure 2). Second, there needs to be a consideration of the environment in which it is to be used, not just the physical environment (e.g., wet, dusty, hot, cold, or dry), but the human environment, too:

- who is to use it;
- what is it to look like – its shape, colour, size and so on;
- how it is to be used, for example, whether fixed to the wheels, handlebars, or forks;
- how much it is to cost to make and to sell; and
- whether the user needs to have any technical skills to use it.

Only after these criteria are established through appropriate research is it possible for the student to select the functional building blocks that will enable a prototype system to be made which meets the criteria. There are several concepts which arise in this analysis of need. For example, in terms of *energy* there is a consideration of the power supply requirements. In terms of the *process*, a student will need to consider how the device can control the sound long and loud enough to alert attention. Is it to have an automatic cut-out? What is to be the operating principle of the sensor which first detects the movement of the bicycle? In terms of *materials*, cost, ruggedness, waterproofness, and design of the casing for the unit and similar considerations for the components need to be tackled.

When it comes to the manufacture of the anti-theft bicycle alarm, however, the technical factors to be considered are more than simply selecting appropriate input, process, and output devices; plugging them together; and expecting the system to work. What is most often missed in designing electronic systems is the need to consider the requirements that enable each building block to respond to the signal it receives and send an appropriate signal to the building block that follows it. The concept being highlighted here is called *matching*. This is more complex, but at a basic level, students are able to use computer software which will give the design for a printed circuit board combining the contributory functional blocks.

Systems thinking can sometimes make simple ideas more complex. Consider the example of a flush cistern in a toilet where the ballcock regulates the level of the tank. If a variety of technologists are asked to draw a systems diagram of a cistern, they will probably produce very different diagrams. Similarly, when asked to identify the input to a simple burglar alarm as shown above, students sometimes identify the input as "electricity" or "the battery" (McCormick & Banks, 1994). However, when building up complicated electronic devices, considering them as a collection of functional blocks in terms of input, process, and output functions can very much simplify the learning of electronics. Just as a first aider does not need to know about the chemical triggers needed for the beating of the heart, a technologist does not need to know about the detailed working of an integrated circuit, or even a transistor, in terms of the physics involved, just how to use it in a range of circumstances. A systems thinking approach in both cases gives the necessary overview and provides the necessary useful knowledge for the task in hand.

CONCLUSION

When we consider transferring knowledge from other domains versus knowledge acquired through technology education, we have seen that we need to keep in mind the important differences in terms of purpose and intent. Technology has often been considered a portfolio subject which just transfers useful knowledge from other areas, and indeed sometimes technology is merely seen as "applied science." In this chapter, however, we have seen that whereas technology is founded in human need to change the environment, science is in understanding the whys and wherefores of the world around us. The *know-why* of science is a fundamentally different goal from the *know-how* of technology. Science knowledge and understanding will often contribute to project work in schools, but it is necessary to keep in mind the sometimes limited extent of such knowledge which is actually required and the other useful knowledge such as designing and systems thinking that is also required. The contribution of science needs to be set against the other dominant factors such as *sustainability*, *aesthetics*, and *appropriateness*. But as Plant (1994, p. 29) reminds us:

> it is also important to recognise that science has a part to play in stimulating technological activities. First, by revealing new frontiers to spur technological inventiveness. Second, by using the vocabulary of science for providing convincing explanations of the behaviour of technological devices. Third, in the provision of convincing explanations of the behaviour of technological devices. Lastly, in the provision of resources for the constraints on technological processes.

Even though technology often resorts to the language of science to describe how the technology works, technological practice is steeped in the culture and social values of the society which uses it. It is indeed very much more than applied science. Not only has technology education its own subject-specific knowledge in design processes, problem-solving techniques, and systems thinking, such useful knowledge can be transferred, used, and applied elsewhere. The goal-directed nature of technology in leading to an appropriate product makes it a first-rate vehicle for using and creating knowledge. The knowledge transfer is a two-way street.

NOTES

[1] Gilbert and Sullivan's *Princess Ida* Act 2 – first performed 5 January 1884.

REFERENCES

Archer, L.B. (1973). *The need for design education.* Paper presented to DES conference N850, Horncastle. Mimeo. London: Royal College of Art.

Banks, F., & Barlex, D. (forthcoming). *Linking science, technology, engineering and mathematics in the secondary school: The STEM teachers' handbook*. London: Routledge.

Barak, M. (2007). Problem-solving in technology education: The role of strategies, schemes & heuristics. In D. Barlex (Ed.), *Design and technology for the next generation* (pp. 154-169). Whitchurch, UK: Cliffe & Company.

Bronowski, J. (1973). *The ascent of man*. London: BBC Publications.

Clarke, M. (1982). Technology and knowledge. *Journal of Further and Higher Education, 6*(2), 3-18.

Eggleston, J. (1992). *Teaching design and technology*. Buckingham, UK: Open University Press.

Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist, 39*(2), 93-104.

Hennessy, S., & McCormick, R. (2002). The general problem-solving process in technology education. Myth or reality. In G. Owen-Jackson (Ed.), *Teaching design and technology in secondary schools* (pp. 109-123). London: Routledge/Falmer.

Lave, J. (1988). *Cognition in practice*. Cambridge, MA: Cambridge University Press.

Layton, D. (1993) *Technology's challenge to science education*. Buckingham, UK: Open University Press.

Mawson, B. (2003). Beyond 'the design process': An alternative pedagogy for technology education. *Intentional Journal of Technology & Design Education, 13*(2), 117-128.

McCormick, R. (2006). Technology and knowledge. In J. Dakers (Ed.), *Defining technological literacy* (pp. 31-47). New York: Palgrave.

McCormick, R., & Banks F. (1994). *Study guide E650: Design and technology in the secondary curriculum.* Milton Keynes, UK: The Open University.

Murphy, P. (1991). Gender differences in students' reactions to practical work. In B. Woolnough (Ed.), *Practical science* (pp. 131-143). Buckingham, UK: Open University Press.

Murphy, P. (2006). Gender and technology: Gender mediation in school knowledge construction. In J. Dakers (Ed.), *Defining technological literacy* (pp. 219-237). New York: Palgrave.

Murphy, P. (2007). Gender & pedagogy. In D. Barlex (Ed.), *Design and technology for the next generation* (pp. 236-261). Whitchurch, UK: Cliffe & Company.

Murphy, P., & McCormick, R. (1997). Problem solving in science and technology education. *Research in Science Education, 27*(3), 461-481.

Noström, P (2011) Engineers' non-scientific models in technology education. *Intentional Journal of Technology & Design Education* (On-Line First). DOI 10.1007/s10798-011-9184-2

Plant, M. (1994). How is science useful to technology? Course Booklet for E886. Milton Keynes, UK: The Open University.

Rosenberg, N. (1982). *Inside the black box: Technology and economics*. Cambridge: Cambridge University Press.

Schumacher, E. E. (1973). *Small is beautiful*. New York: Harper and Row.

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