EXPLANATORY PAPER

The Technological Knowledge Strand: Technological Systems

ABSTRACT

The purpose of this explanatory paper is to explain understandings of componentry and processes as they relate to a technological system, clarify why and how components are selected and connected and how they allow technological systems to work the way they do. It presents the component descriptor, the key ideas underpinning it, and illustrative examples of these from technology. This paper also suggests possible learning experiences.

STRANDCOMPONENT DESCRIPTOR

Technological systems are a set of interconnected components that serve to transform, store, transport, or control materials, energy, and/or information. These systems exist in the world as the result of human design and function without further human design input. Understanding how these parts work together is as important as understanding the nature of each individual part.

Technological system knowledge includes an understanding of input, output, transformation processes, and control, and an understanding the notion of the “black box”, particularly in terms of sub-system design. Understanding redundancy and reliability within system design and performance, and an understanding of the operational parameters of systems are also included. Specialised languages provide important representation and communication tools and are therefore included to support developing ideas of system design, development, maintenance, and troubleshooting.

KEY IDEAS

Technological outcomes may be referred to as technological products and/or technological systems (see Characteristics of Technological Outcomes for an explanation of why the same outcome could be referred to as both a product and system). However, in this strandcomponent, the focus is on understanding the physical nature of a technological outcome as viewed as a system, and therefore it is componentry and process understandings that are key to this strandcomponent.

Technological systems are defined as a set of interconnected components designed by people to fulfil an intended function without further human design input. This means that while a technological system may include input from people to allow the system to function, this input does not alter the system design, and therefore, intended function. For example, while a person driving a car may apply the brakes (human input to activate the system), the functioning of the brake system (as a technological system) is not reliant on this person’s design input.

People may be involved in making judgments around intended functions through selecting a particular setting for a manufacturing production system; however, once selected, the designed function continues as intended. The judgment, therefore, again exists as an input to the technological system. Similarly, quality control decisions around outputs can also be inputs to the technological system, providing impetus for a changing of operational parameters. Over time, system feedback may lead to a need for the system’s re-design.

The knowledge base underpinning these generic concepts will vary depending on the specific nature of the technological system being explored and/or developed. For example, the understandings required to develop biotechnological systems differ significantly to those required to develop electronic control systems. However, the key concepts underpinning technological systems are those generic concepts that relate to how the inputs are transformed to outputs and what is involved in the control of this. Inputs to technological systems include such things as raw materials, information, and energy.

Outputs from technological systems include the intended outcome of the system. For example, the output of a manufacturing system for Easter eggs is the egg itself. The output of a telephone communication system is transformed and transported information – that is, a voice in another location. The output of a wind-based energy generation system is transformed and stored energy – that is, electricity. However, most technological systems also produce other outputs such as heat and waste products – including pollution. These may be known or unknown at the time of development.

Transformation processes are those processes that occur within a system, to ensure the inputs are transformed into the outputs in a controlled and intended way, without need for additional human design input. Simple technological systems are defined in this context as systems that have been designed to change inputs to outputs through a single transformation. Other systems may involve one or more subsystems. The role of subsystems is to act as a component of a larger technological system in a way that supports that system's overall function. The properties of a subsystem refer to its transformation performance and its level of connective compatibility. The role a subsystem is playing can be established by examining the way in which the inputs change to outputs during that part of the system. Where subsystems exist, effective interfaces are critical for the successful function of the system as a whole.

Control mechanisms within a system are designed to enhance the efficiency of the technological system by maximising the desired outputs and minimising the undesirable outputs. Adjustments to the transformation processes can be a part of a system's design, whereby feedback from any part of the system allows for ongoing responsiveness to input requirements and/or output success, thereby allowing the system to be self regulatory.

Self-regulatory systems are different to intelligent systems. Intelligent systems are those that have been designed to adapt to environmental inputs in ways that change the nature of the system components and/or transformation processes in known and unknown ways to produce hopefully desirable but unspecified outputs.

An exploration of generic concepts, such as redundancy and reliability within a technological system's design and performance, is important in supporting the development of understandings about a system's operational parameters. *Operational parameters* of systems refer to the boundaries and/or conditions within which the system has been designed to function. These concepts are important to understand when establishing the fitness for purpose of technological systems. Ethics play a significant part in the decisions around reliability and redundancy, as improvements in both these areas within a system inevitably comes with associated costs.

The concept of *redundancy* within a technological context refers to the inclusion of more time, information, and/or resources than would strictly be needed for the successful functioning of the technological system. Redundancy may be built into a technological system as a contingency plan to allow room for detecting or tolerating faults before the success of the system is compromised. This concept can be thought of as "allowing a bit extra" or taking a "belt and braces" approach to design, and can be understood at varying levels of complexity. While the inclusion of redundancy options in a system may provide additional capability, often in terms of increasing safety margins, redundancy can also result in over engineering a system by including components that provide no added functional advantage to the system. This form of redundancy is something system designers strive to eliminate as it often impacts on a system's ability to function within agreed specifications; for example, specifications around the cost of production.

An example of simple redundancy measures can be seen in the use of component parts with tolerances higher than those required to make the system fit for purpose. Within complex system design, a broad understanding of redundancy is required to ensure all variables (produced by multiple levels of interconnectedness) are included in decision making.

The concept of *reliability* within this context relates to the probability that a system, or sub-system, will perform a required function under stated conditions for a stated period of time. Reliability is, therefore, a part of that system's overall design and that of its constituent parts. Tolerances for reliability are determined by the specifics of each development and the nature of the output. For example, if the system is designed to result in an output that enhances human safety, reliability tolerances will be more stringent. Reliability as a concept underpins understandings associated with all three types of situations where a technological system no longer functions successfully. These three types being: malfunctioning; a gradual reduction in function caused by ongoing use; and designed failure.

The concept of a *black box* is important in describing technological systems. A black box can be thought of as representing a part of a technological system that is reduced to inputs, outputs, and a hidden transformation process or series of processes. There are advantages and disadvantages in adopting a black box approach when working with and understanding technological systems.

An advantage is that it can provide an opportunity for complex systems to be explored and understood in a holistic sense. It also allows for system maintenance to be undertaken without in-depth knowledge, through the replacement of isolated parts of a system with little to no disruption to the rest of the system. Ease of such replacement would be an inherent part of the system design and would need to take into account such things as the costs associated with the disposal of a part when repair of the part could have sufficed.

A significant disadvantage of black boxing is that the detail is rendered invisible, and, therefore, not available to be understood. This may pose problems in future system modification and/or development. It may also result in a loss of empowerment for the end-user, particularly should any malfunction occur or when troubleshooting or repair work is required.

Technological systems are often represented in symbolic ways to communicate their constituent parts. While there are some generic symbols associated with systems, for example, arrows to denote direction, specialised languages also exist and are central to the development and communication of technological systems. Design concepts of systems can, therefore, be represented using a variety of communication tools (for example, computer software, flow diagrams, web diagrams, 3-D models, etc.) in order to explore and understand relationships between parts of a single system and/or between different systems. Different technology communities often supplement or modify generic symbols as part of more specialised diagrams/representations to communicate system-related details. System-related details include such things as what components would be feasible, layout requirements, and how they would need to be connected.

ILLUSTRATIVE EXAMPLES FROM TECHNOLOGY[5]

Mass production manufacturing systems are an example of technological systems that have had a significant impact in the world. Such technological systems transformed the one-off (and, therefore, craft based) nature of product development and served to change the way labour was managed and perceived in the post-industrial age.

There are four types of manufacturing systems: custom manufacturing, intermittent and batch manufacturing, continuous manufacturing, and flexible manufacturing; all have advantages and disadvantages. Exploring examples of increasingly self-regulatory technological systems allows for insights into the increased sophistication of internal feedback as key parts of a system use data from its own functioning to control and modify its transformation processes.

Black boxing has become a feature of much contemporary design and technological development. It is employed more frequently, because of the complex nature of many sophisticated technological systems, to the point where many complete sub-systems are developed as black boxes. These often become disposable units when a system malfunctions.

The modern car provides an excellent example of a technology that was initially based on highly visible mechanical systems that many lay people could understand and confidently repair. In the past this was a requirement for early cars as they often broke down and garages (and mechanics) were few and far between and New Zealand roads were often isolated and demanding. Drivers, therefore, carried tools and spare parts as a matter of course. In contrast to this, a modern car is more reliable, drivers do not expect it to breakdown, and, if it did, would rarely entertain the notion they could undertake their own repairs. As modern cars become more electronically controlled and managed by a centralised computer system, opening the bonnet exposes a series of carefully integrated black boxes, with the mechanical systems becoming less accessible.

Servicing, troubleshooting, and addressing malfunctions, therefore, have become highly specialised activities

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[5] These are provided for the purpose of increasing teacher background understandings of this strandcomponent; however, they may also be relevant for senior students.

that the majority of lay people would deem outside their capability. In fact, many automotive mechanics would also argue that current levels of black boxing are such that their role has reduced from any form of mechanical intervention, to one of computer-assisted diagnostic work with the purpose of finding and replacing parts; little knowledge being needed of what might be happening within the part at fault.

POSSIBLE LEARNING EXPERIENCES

The learning experiences suggested below have been provided to support teachers as they develop their understanding of the Technological Systems partcomponent of Technological Knowledge, and how this understanding could be reflected in student achievement at various levels. There is no expectation that these would form the basis of any specific unit of work in technology. The learning experiences have been written in such a way as to support student learning across a range of levels. This stance reflects the majority of classrooms where it is expected that students will demonstrate a range of levels of achievement.

Junior Primary (NE-Year 4)

Students could explore a range of familiar technological systems (such as an electric jug, a windup toy, yoghurt maker, television, computer, fish tank, popcorn maker, washing machine, torch, pacemaker, etc.) and identify the components of the system and what it has been designed to do. Teachers could lead a discussion about technological systems and explore what they have in common with, and how they differ from, natural systems, for example, the digestive system, and social systems, for example, the lunch ordering system at school.

The teacher and students could select an example from the familiar systems above and together discuss what the inputs, outputs, and transformation processes are. They could also explore how the system ensures that the transformation occurs in a controlled fashion. In pairs, the students could select their own example and identify its inputs and outputs, controls, and transformation processes. Allowing students to use the systems would aid these explorations, as would being able to pull some apart where appropriate.

As part of class discussions, students could suggest definitions for a technological system to enable them to distinguish technological systems from non-technological systems and begin to explore why the same technological outcome may be referred to as a technological system or a technological product.

Students achieving at level 1 could be expected to:

- identify the components of a system and how they connect to each other; and
- identify the inputs and outputs of a system and that a transformation of some sort has occurred.

Students achieving at level 2 could be expected to:

- describe the change that has happened to an input for the output to be produced in a simple system; and
- describe the role each component has in the transformation of the input to output in a simple system.

Senior Primary/Intermediate (Years 5-8)

Students could identify a number of simple technological systems from different contexts, and represent the parts of the systems using appropriate language tools (including graphical symbols) for the type of system focused on. The systems explored could be categorised by the students as being primarily focused on transforming energy, information, or materials. Students could then explore a more complex technological system that consists of one or more black boxed components, (for example, a security system, manufacturing system, car wash, fermentation system, etc.) and discuss the advantages and disadvantages of not knowing what is happening inside the box.

In order to gain a better understanding of the concept of black boxes and technological systems, students could be involved in making a bread product. As part of their technological practice they are provided with the opportunity to experience a variety of ways of making bread. That is, they could make bread in a traditional way; accessing their own ingredients and carrying out the steps by hand, whereby their design input is necessary for the transformation to occur. In this case, the bread making *is not* a technological system. They could then make bread with a bread-maker, but access their own ingredients. In this case, the bread-maker *is* a technological system – but its system nature can be viewed as a black box as its transformation processes are hidden. Finally, the students could make bread with a bread-maker using a “ready bread mix”. In this case, the bread-maker (a technological system) and the mix (an input into this system) can both be thought of as black boxes. The students could also view a video showing a commercial bread factory and identify technological systems employed in this context.

They could explore the nature of the outputs in all these scenarios and determine the ratio of wanted (bread product) versus unwanted (waste, energy depletion, pollution, etc.) outputs in each case. Ongoing class discussions could be held around the quality and reliability of the end product, and how easy it was for the student to modify the product to allow for different tastes etc., within each method used. Students could complete a PMI (plus, minus, and interesting) analysis of making bread in a variety of ways.

Students achieving at level 2 could be expected to:

- describe type of transformation that occurs within the bread-maker; and
- describe the role each component has in the transformation occurring within the bread-maker.

Students achieving at level 3 could be expected to:

- describe a range of simple technological systems (including a system involved in bread making) using appropriate language tools; and
- explain what a black box is, and give examples of how a black box can be both helpful and unhelpful.

Students achieving at level 4 could be expected to:

- identify an example of a control mechanism within a technological system and explain how it influences the transformation process; and
- describe how the fitness for purpose of the bread-maker was and/or could be enhanced by the use of control mechanisms.

Junior secondary (Years 9-10)

Students could investigate the computer network within their school to identify and explore how it meets both technical feasibility and social acceptability specifications. They could also identify subsystems within the system, establish the transformation and connectivity properties of these, and the interface implications for effective integration into the system. Students could explore the way that the system has been designed so that failure in a particular subsystem is managed to guard against overall system failure and/or damage. This may be by way of alternative paths or shutdown options.

Extensive investigation could be undertaken to uncover the workings of a black box within the identified system. Issues associated with ongoing support and maintenance could be explored and suggestions made for the different levels of expertise required to develop, use, maintain, and repair their school computer systems.

Students achieving at level 3 could be expected to:

- describe their school computer network using appropriate symbols and language to represent its components and connections; and
- identify examples of black boxes within the network and suggest how these may be viewed differently by members of the school community.

Students achieving at level 4 could be expected to:

- identify control mechanisms within the network and explain how they influence different transformations;
- explain how control mechanisms enhance the system’s fitness for purpose as a school network; and
- communicate, using specialised language and drawings, system-related details that would allow others to create a feasible and acceptable network system.

Students achieving at level 5 could be expected to:

- identify all subsystems within the network and explain their transformation and connectivity properties; and
- discuss how the interface between each subsystems allows the network to work together effectively.

Senior Secondary (Years 11-13)

As part of student involvement in the development of an electronic game, they could focus on developing understandings associated with micro-controllers. Undertaking product analysis of a number of everyday appliances allows students to begin to explore the nature of the transformation processes occurring within what was previously the system black box when viewing the appliance as a product. Once these processes are understood, students can practice writing software that would allow for these processes to occur. Exploring a range of components (such as real-time clocks, micro-controllers, pulse-width-modulation blocks, motors, etc.) and the interfaces between them allows students to build up their systems knowledge related to subsystems, redundancy, and reliability that will support their design decisions for the development of their own game.

Students achieving at level 4 could be expected to:

- explain how the fitness for purpose of a particular appliance was enhanced through the use of a micro-controller; and
- communicate, using specialised language and drawings, system-related details to support their development of a feasible and acceptable electronic game.

Students achieving at level 5 could be expected to:

- explain the specialised transformation processes occurring within components that serve as subsystems within an appliance; and
- discuss how electronic interfaces support the integration of subsystems in the development and maintenance of systems.

Students achieving at level 6 could be expected to:

- explain how multiple sub-systems allow for the development of systems with additional features; and
- describe examples of how micro-controllers allow for self-regulation to occur within a system.

Students achieving at level 7 could be expected to:

- explain how reliability was enhanced through the design, development, and maintenance of a particular technological system; and
- discuss examples of designed redundancy and explain why it was deemed necessary to enhance user safety.

Students achieving at level 8 could be expected to:

- explain the impact of energy efficiency and fail-safe on the operational parameters of systems used in familiar appliances; and
- explain the operating parameters of an appliance and the implications of these for its design and ongoing maintenance requirements.