Technology practice: a structure for devoloping technological capability and knowledge in schools

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Abstract
Technology education in New Zealand schools has moved into a new stage with the development of assessment standards for senior students. This raised questions concerning what students should learn at school that would meet the intent of the technology curriculum and equip them to proceed to university degree courses in technology and engineering. Research was undertaken with academic technologists at Massey University to identify a simplified structure of practice and knowledge suitable for New Zealand schools. Seven elements describing technology practice were identified. The first three elements, society, work environment and purposeful action, involved context and methodology. The remaining four elements, organisation, information, resources, and techniques, involved the skills, knowledge and actions of the individual technologist or technology team. The research indicated technologists structured their knowledge into a framework that reflected the subsystems used to break down complex problems and develop solutions. This paper outlines the research and discusses these results.

Keywords: cognitive models, knowledge, technology practice, techniques, teaching and learning, total technology

Introduction

Technology education has become a compulsory subject in New Zealand schools from year 1 (new entrants) to year 10. Currently, new assessment standards for years 11 to 13 are being developed for introduction in 2002. There is an expectation that these new standards will provide a smooth transition for senior school students to first year tertiary qualifications in technology and engineering. This has raised questions concerning what students should learn at school that would meet the intent of the technology curriculum and equip them to proceed to university degree courses in technology and engineering. The *New Zealand Technology Curriculum Statement* (Ministry of Education, 1995) requires teachers to teach technology within a framework of strands, technological areas and contexts (see Figure 1).

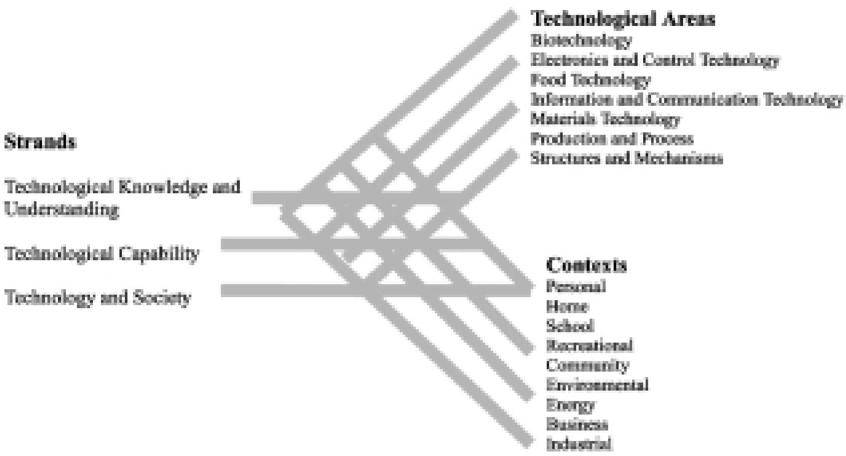

Figure 1 New Zealand framework for technology education (adapted from the New Zealand Technology Curriculum Statement, 1995)

The school sector appeared confused as to what conceptual and procedural knowledge should be taught to meet the requirements of the New Zealand technology curriculum. Research was required to identify and communicate the basic elements and knowledge structures involved in technology practice.

Research Questions

The research aims were encompassed in three research questions: What are the important elements of technology practice? What techniques, knowledge and actions are involved with each element? How can the technological concepts and knowledge involved in technology practice be structured and communicated effectively to technology education teachers and students in New Zealand schools?

Modern paradigms

The literature provided a starting point for the identification of these elements. Society influences technology practice (Mackenzie and Wajcman, 1993; Bijker and Law, 1992; Staudenmaier, 1985; Pacey, 1983). Products are defined by the social milieu in which they are developed and, in turn, influence those that follow. Pacey (1983) proposed three aspects to the social milieu of technologists and their practice - cultural, organisational and technical.

The impact of cultural aspects on American technology practice described by Chant (1989) and the views of Kapp, Bacon and Mumford discussed by Mitcham (1994) provide examples of cultural influences on technology practice. Organisational aspects such as patent and copyright laws, research and development policies, and access to risk capital are examples found in most modern economies (Chant, 1989). Constant II's (1980) account of the development of the jet engine illustrated the cultural, organisational and technical aspects that influenced this development. These aspects were related to the wider society in which practice occurred.

Technologists typically work in an environment that constrains and influences what and how things can be done. Staudenmaier (1985) described this environment as a pervading atmosphere or ambience that has a profound effect on the types of products produced. The available equipment, knowledge, attitudes to risk and innovation, and users of the product all influenced judgements about what was possible and worthwhile, and how it would be developed and produced (Fleck, 1997; Cowan, 1993; Layton, 1993; Bijker and Law, 1992).

Modern technology practice is goal orientated and usually involves a systematic methodology (Ulrich and Eppinger, 1995; Mitcham, 1994; Hughes, 1993; Layton, 1993; Vincenti, 1990). Engineers generally describe the purposeful action as a process involving analysis, synthesis, simulation and evaluation, (Roozenburg and Eekels, 1995), while Product Development Technologists describe four or more stages in the process (Earle and Earle, 1999; Ulrich and Eppinger, 1995). Technologists organise and manage the innovation process to ensure appropriate information is gathered and resources used effectively. They also organise and structure their knowledge to incorporate new information and understandings that can be applied to the practical problem solving context of their practice (McCormick, 1997; Hennessy and McCormick, 1994; Glaser, 1993). Practice that includes all these factors can be referred to as total technology (Earle and Earle, 1999).

A number of models have been developed to illustrate the characteristics of technology for teaching purposes. (Roozenburg and Eekels, 1995; Eggleston, 1992; Kimbell *et al,* 1991; Savage, 1991). These models generally portray a stepwise process of identifying a problem through to the assessment of the proposed solution. The approach is methodological and focused on generally tangible outcomes. Most depict a cyclical or iterative progression through the various steps. The model by Peters, Verhoeven and de Vries (1989) recognised the constraints of the natural world and a societal and cultural context in the conceptual framework for technology practice, a weakness in many of the other models (Layton, 1993). While these models give a general overview of many of the elements involved in technology practice, no one model was seen as communicating all the elements and interactions involved in total technology in a way that assisted New Zealand teachers to organise and plan their technology teaching.

Methodology

Technology has been taught at Massey University for over 30 years, with many of the faculty involved in industrial problem solving and new product and process development. This research involved studying the practice of technologists, and student industry-based projects at Massey University. The elements identified from this research were developed into a model for technology education teaching and evaluated by schoolteachers. The framework for the research involved the first two stages of the product development research method (Earle, 1971; Ulrich and Eppinger, 1995).

The first stage involved knowledge development, model content development and three iterations of model concept development. Insightful observation, conversation and formal discussion techniques were used and outcomes recorded in a research journal over a period of eight months (Kvale, 1996; Anderson,1990). Brainstorming and screening techniques were used with a group of four technologists to develop and evaluate the model concepts.

The second stage involved the model concept verification and evaluation, followed by the final model detailed design. The final model concept was critiqued and verified by an expert panel group of eight senior technologists working in different technological areas. The model elements were then used to describe the technology practice involved in the development of a new pharmaceuticals process and company (Earle, R., 1999; Earle, R., 1997). The total technology practice model concept was then evaluated by 48 teachers using focus group and by a further 39 teachers using a questionnaire (Ulrich and Eppinger, 1995; Anderson, 1990; Gordon and Langmaid, 1988). Individual interviews conducted with six technologists working in different technological areas identified the detailed techniques, knowledge and actions involved in each element.

Results and Discussion

The first stage of the research identified seven elements of total technology. The first three elements, society, work environment and purposeful action, involved context and methodology. The remaining four elements, organisation, information, resources, and techniques, involved the skills, knowledge and actions of the individual technologist or technology team. These will be discussed in turn.

Society

Technologists recognised that their personal concepts and assumptions could affect the final product. They therefore consulted stakeholders throughout the process to reduce any personal bias. An example of this was observed in the development of a board game designed to teach Te Reo Maori (Maori language) where incorporation of cultural values and customs were important to the product's success. The technologists working on this project had to put aside their concepts and gain an appreciation of a different cultural perspective.

Observations of student projects highlighted the constraints of laws and regulations imposed by society on the development of new products. Other societal influences observed were the impact of the economic system on project finance, and the type of marketing system through which the product would be distributed. Table 1 provides examples.

Work Environment

The work environments at Massey University and client companies constrained and encouraged the practice of students and staff. These constraints created a tension between what the technologist would like and what was permissible or available. Students working on industry projects found there were differences between companies in business cultures, organisational systems, technical expertise,

Cultural Aspects	Organisational Aspects	Technical Aspects
Differences between ethnic groups	Capitalist economic system	Available materials and their selection
Beliefs in progress	Patent system	Empirical approaches
Education	Venture capital	Systematic process
Urbanisation	Consumer law	Rigorous and fair testing
Mass consumer society	Safety regulations	Optimisation and efficiency
Conception of beauty and form	Professional engineers' associations	Methodology
Attitudes to creativity and risk	Product quality regulations	Quality assurance Computers

Table 1 Examples of societal influences on technology practice (Gawith 1999:56)

and equipment. The importance of the work environment is evident in industry studies where contexts and atmospheres can encourage creativity and knowledge creation (Leonard and Sensiper, 1998; Nonaka and Konno, 1998; Nonaka *et al,* 1996).

Purposeful Action

It was observed that students learned and applied effective project skills, which enabled them to develop products using planned and effective methodologies. The technologists identified technology as a goal orientated practice that required constant decision making to ensure progression within the constraints of society and the work environment. Figure 2 illustrates the society, work environment and purposeful action elements that promote, constrain, and define technological products.

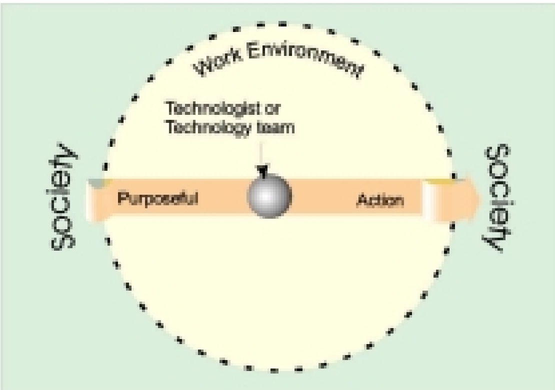

Figure 2 The pervading atmosphere of technology practice (Gawith, 1999:61)

In its broadest interpretation, the purposeful action element involves the recognition and definition of the problem, consultation with stakeholder and user groups (within society), development of concepts and solutions (within the work environment), and evaluation of use and disposal of the product (in society).

The technologist or technology team now became the central focus of the model. Four further elements are centred on technologists themselves.

Organisation

Organisation and management skills were observed as important in developing student capability in technology. Besides organising the process to be followed, technologists must also organise time, people, resources, and relevant information. Figure 3 depicts the elements of practice that focus on the technologist or technology team.

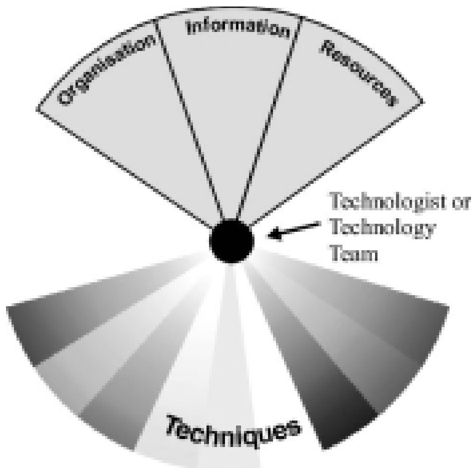

Figure 3 Information, resources, tools and techniques in technology practice

Information

Technologists and students used and adapted information from a number of sources. Some information was technological in origin, while other information was from life and work experience. Knowledge from a range of other disciplines, particularly science, mathematics and social science was used to inform their technological problem solving. It was clear from the research that a technologist's ability depended on a depth of knowledge and information in related subject areas, and an ability to organise this in a technological framework of principles and abstractions that related to the project in progress.

Resources

Resources were utilised or altered in the process of developing products. Optimisation is an important aspect of resource use, requiring knowledge, skill and experience. Table 2 gives examples of resources used by the product development technologists and students. Each resource required the development of theoretical and practical knowledge of application and use (tacit knowledge). Figure 3 adds information and resources knowledge as important elements of technology practice.

Techniques

The techniques used by the technologists were a combination of knowledge and praxis that were adapted and applied in a thoughtful reflective way, then evaluated for suitability and results. The technologists' skill was in the appropriate application of techniques. The choice of technique, when and how it should be used, varied according to the particular problem, the experience and preferences of the technologist, and the context in which it was applied. It was not sufficient to know the techniques in a theoretical sense, students were expected to develop tacit knowledge of their application and use. Figure 3 adds techniques as the final element of technology practice.

Each element of technology practice described above contributed to the development of the total technology practice model. Figure 4 illustrates how the organisation, information, resources and techniques linked to the technologist fit within

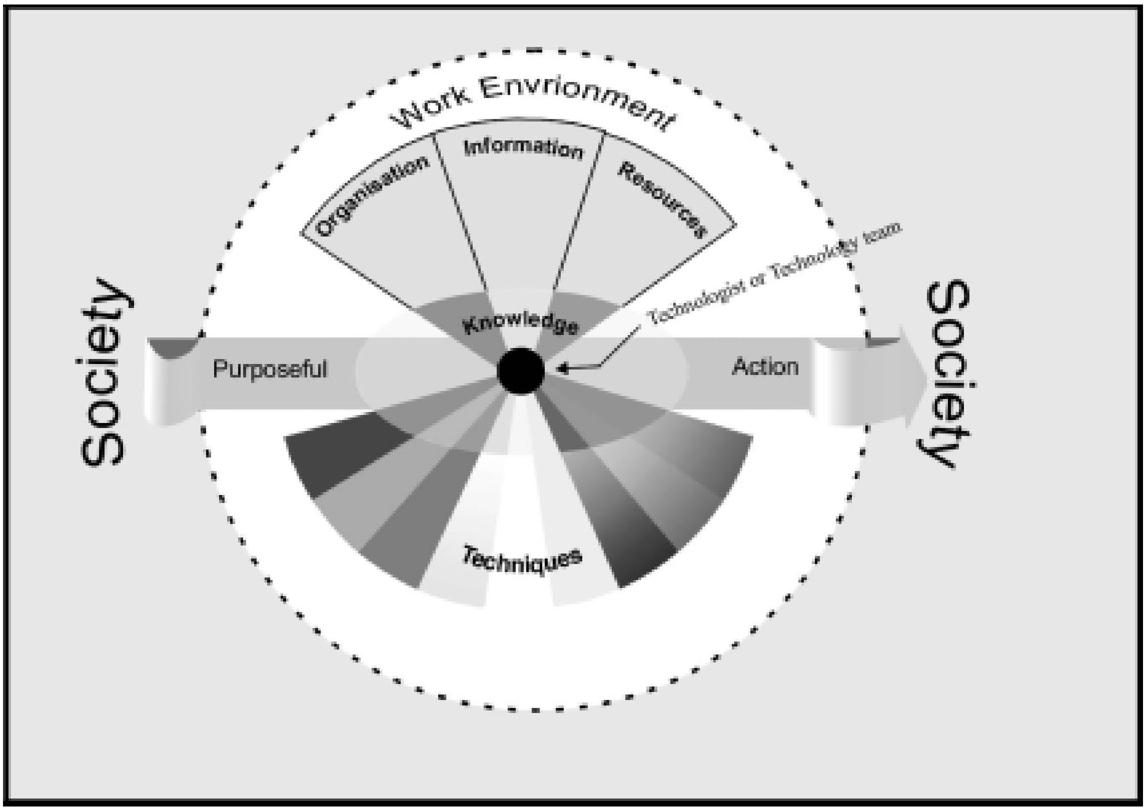

Figure 4 The total technology practice model

the context of total technology. The technologist or technology team achieved their goal by working along the purposeful action arrow in an iterative process, from the identification of the problem to the use and disposal of the product. As they did this, the nature of the techniques, organisation, information and resources changed. Initially they identified the problem, gathering information from stakeholders and specifically the user group. As the process moved to developing concepts and testing prototypes the techniques, organisation, information and resources used were altered accordingly.

The expert panel confirmed that the seven elements in the model represented a simplified concept of total technology practice. There was general agreement that the model conceptualised the interaction between these elements and that together they presented a balanced understanding of total technology practice. As the technologist's knowledge expanded through experience, a greater conceptual and procedural knowledge of each element developed. From this base, the techniques, knowledge and actions involved in each element were identified.

Techniques, knowledge and actions

The research results were combined to develop tables identifying the detail of the organisation, information and resource elements of the model and the common techniques used by technologists in practice. The tables provide a general outline of knowledge, concepts and skills that were common across all the technological areas. Variation in emphasis may apply to some technological areas as students study at higher levels of the curriculum. However, the basic structures should remain the same. Table 2 lists the detail of the organisation, information and resource elements of practice.

Ten categories or *tool kits* of techniques were developed from this research. The concept of tool kits was used to convey the idea of

Organisation & Management	Information	Resources
The process of development	*Context*	*Raw Materials*
Steps in process	Local community/stakeholder attitudes and beliefs	Data
Decision making	Linkages and dependencies	Information
Outcomes	*Working Environment*	Biological
Actions	Goals	Non biological raw materials
Timing	Organisational structures	*Components*
People involved in the project	Technical strengths and constraints	Industrial materials
Communication	*User*	Manufactured components
Decision making	Desired product attributes	*Energy*
Users	*Market*	For processing
Advisors & Researchers	Size and User groups	For transportation
Information	*Technical*	*Capital*
Collecting	Processes	Space
Analysing	Components	Equipment
Communicating	*Raw material*	Tools and instruments
Resources	Availability, Properties, Variation, Environmental impact	Working capital (Money)
Resources needed in process of development	*Statutory*	*People*
Production process	Standards & Regulations	Knowledge
Product launch & marketing	Local body planning	Energy and enthusiasm
Capital	*Formal*	Creativity and risk attitude
Space	Fundamental principles	*Infrastructure*
Equipment	Research reports	Communication
Working capital	*Methodologies*	Energy
	For: Modelling, Simulating., Prototyping	Transport
	For: Managing	
	Past Experience	
	Note books	
	Case studies	

Table 2 Organisation, information and resources elements (Gawith,1999)

Consumer info. Collection	Technical info. Collection	Modelling Prototyping Simulating	Testing	Problem solving
Primary sources Secondary sources *Analysis*	Information search Experimental research *Analysis*	*Abstract* Verbal Graphical Mathematical *Physical* Models Prototypes	Product Testing Safety Testing User Testing Process Testing Environmental Testing Social Impact Testing	Problem Definition Problem Analysis Idea Generation Decision making
Evaluation	**Instrumentalities**	**Management**	**Implementation**	**Information Adaptation**
Context Working Environment Market Production Financial Social and Environmental Impact	Tool Use Machinery Use Equipment Use Instrument Use	Context Project Personnel Information Production Marketing	Production Product Launch	Reclassifying Reorganising Reconstruction of Knowledge Re-evaluating Recontextualising Scientific knowledge

Table 3 Technique categories (Tool Kits). (Adapted from Gawith, 1999:124)

selection from a menu according to the result required, similar to the drop down menus used by computer programs. Table 3 identifies the technique toolkits and suggests an outline of their content.

Knowledge structures

McCormick (1997) and Glaser (1993) identified the need for an organised body of conceptual and procedural knowledge, in order for students to be effective problem solvers in technology. Technologists interviewed in this study confirmed the importance of an organised body of knowledge. These technologists identified a wide range of techniques and conceptual knowledge used in their practice. Many of the techniques were common across the technological areas. A significant outcome from this phase of the research was the way in which these technologists appeared to construct their knowledge around the subsystems involved in their practice. Table 4 gives examples of subsystems identified from the research.

Subsystems organised technologists' accumulated tacit knowledge and codified, or formal, scientific knowledge in the most effective structure for practical problem solving and application. These knowledge structures were developed through

Technological Areas	
Process Technology Examples: Food Technology Biotechnology Materials Extraction Chemical Technology	Production Technology Example: Manufacturing
Subsystem name	
Unit Operations Examples: Separation Mixing Size reduction Heat transfer Transport Fluid flows	Process Function Examples: Cutting Forming Casting Extruding Weaving Joining Finishing

Table 4 Subsystems for technological areas

experience and used to frame the problem in a way that allowed systematic investigation and experimentation. Further research will be required to identify and adapt the subsystem structures for other technological areas identified in the New Zealand curriculum.

Without a generic structure of technological knowledge and practice, it is likely that students will find it increasingly difficult to relate technology practice and transfer knowledge and understanding between the technological areas identified in the curriculum as they move through school and on to university. Teachers who evaluated the model found it communicated the concepts and elements of total technology practice well, and helped them understand modern technology practice. They considered the model most useful as a tool for structuring teaching, and technology unit planning.

Conclusion

This research identified the important elements of technology practice and provided a simplified, ordered and generic conceptual framework for the development of knowledge important in technology practice. The elements and the way they interact can be communicated in the form of a structured model of total technology practice. The model provides a useful tool for communicating technological practice, knowledge and understanding, and for structuring teaching units in technology education. The development of knowledge is central to modern technology practice and is based on knowledge of fundamental principles, practical application and tacit and conceptual knowledge of each element identified in this research. Technologists appeared to organise this knowledge into conceptual structures associated with the subsystems involved in their practice.

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