

1.1 Overview of the chapter

Chapter 1 starts with a brief introduction regarding the fledgling status of technology education, which was the catalyst for this study. This is followed by a description of the background and problems relating to the lack of understanding of the nature of technology in South Africa, and constitutes the rationale for and purpose of this study. The research questions and an explanation of key terms, which inform the context of the study, follow. The research design and methodology, which include the knowledge claim (philosophical assumptions), are dealt with prior to the delineation of anticipated/preliminary research limitations and outline and organisation of the study, which conclude this chapter.

1.2 Introduction

The advent of technology education¹, nationally and internationally, has posed challenges different from those experienced in regard to the other learning areas. In contrast to the other learning areas which have, at least for particular components, a well-founded subject philosophy, there is as yet no established subject philosophy for technology education (Ankiewicz, De Swart, & De Vries, 2006:117-118). Technology education is in fact still a fairly new subject globally without a large research base and a well-established culture of classroom practice (Mawson, 2007:253).

The importance of a philosophy of technology is acknowledged by De Vries (2005b:8) who notes that it can, *inter alia*, provide a conceptual basis and proper understanding of technology and help identify a research agenda for educational research in technology education.

1.3 Background, rationale and purpose

The purpose of technology education in South Africa is, according to the Department of Education (DoE) (2002:4), to contribute towards learners' technological literacy, which the DoE defines as "the ability to use, understand, manage, and assess technology" (DoE, 2002:66). This purpose is to be achieved through an integration of the three learning outcomes stated in the Revised National Curriculum Statement (RNCS) for grades R-9 (schools) for technology: technological processes and skills, technological knowledge and understanding, and technology, society and the environment (DoE, 2002:5). An integration of these learning outcomes embodies technological practice in keeping with

¹ For the purpose of this study the terms *technology education* and *technology* are used interchangeably. Also see section 1.5.2 for an explanation of the use of the term *technology*.

the current sociological understanding of technology and technological developments (Compton, 2004:10).

Since present day schooling, however, is still obsessed with content and the premise of fragmentation as a requirement for the curriculum (Slabbert & Hattingh, 2006:702), content is parcelled in 'compartments', which causes various problems in respect of technology education. The discomfort South African teachers experience as a result of the generally low capacity in terms of content knowledge and cognitive and manual skills related to the pedagogy of technology (DoE,2003:31), exacerbates the situation.

To build capacity, educators need to begin to understand technology whilst progressing to knowing how to "do" technology, and how to facilitate learning in technology (DoE, 2003:31). Developing and implementing technology learning programmes to develop technological literacy requires a sound understanding of technological practice, the nature of technology and technological knowledge (Compton, 2004:17).

Mitcham (1994:154-160) identifies four ways through which technology can be conceptualized and better understood. Technology as

- knowledge (epistemology as a field in philosophy);
- activity (methodology as a field in philosophy);
- object (ontology as a field in philosophy); and
- volition (teleological, ethical and aesthetic, as fields in philosophy (De Vries, 2005b:7)).

For the purpose of this study, the focus is on technology as knowledge (epistemology), due to the emphasis in the RNCS (DoE, 2002) for technology on knowledge. The prominence of knowledge in the policy document suggests that knowledge should take centre stage in the training of learners and teachers in technology. Herschbach (1995:32) notes that the recognition of the centrality of knowledge leads to conceiving technology as more than artefact, technique and process. In addition, it makes little sense to talk about curricular strategies until the epistemological dimensions of technological knowledge have been determined (Herschbach, 1995:32). Rowell, Gustafson, and Guilbert (1999:39) argue that the pedagogical implications for technology education arise from the epistemological debate about the nature of technological knowledge. Also, since it is impossible to undertake a technological activity without technological knowledge and the utilisation and transformation of other knowledge bases (Jones, 2003:89), an inquiry into 'technology as knowledge' seems appropriate.

Pavlova (2005:127) notes that the importance of knowledge and the understanding of technology are identified as an area of concern by a number of authors. Yet, the epistemology of technology is by no means a fully developed area (De Vries & Tamir, 1997:7; Gibson, 2008:3). In the absence of an established subject philosophy for technology education, one can draw on the philosophy and history of engineering, as well as design methodology for insights into technological knowledge (Broens & De Vries, 2003:459-460). Authors from these disciplines provide frameworks which offer various views on technological knowledge.

- Vincenti's (1990:208-225) framework for engineering knowledge was derived from an analysis of aeronautical history cases and includes the following categories of engineering design knowledge: fundamental design concepts, criteria and specifications, theoretical tools, quantitative data, practical considerations and design instrumentalities (Vincenti, 1990:208). In addition to the categories of knowledge, Vincenti (1990:229) also identifies seven knowledge-generating activities: transfer from science, invention, theoretical engineering research, experimental engineering research, design practice, production and direct trial.
- Ropohl's (1997:68-70) framework offers a philosophical view on technological knowledge. His categories of knowledge are technological laws, functional rules, structural rules, technical know-how and socio-technological understanding.
- De Vries's (2003:13-14) framework is derived from technological practice/development and includes the categories of functional nature knowledge, physical nature knowledge, means-ends knowledge and action knowledge.
- Bayazit (1993:123,126) presents a framework from a designer practitioner's point of view and classifies designers' knowledge into two main groups, procedural and declarative knowledge. In addition, Bayazit (1993:126) also identifies design normative knowledge and collaborative design knowledge.

Although engineering, philosophy of technology and design methodology provide frameworks through which technology can be conceptualized, in order to be useful in an educational context, they need to be validated by educators, and data needs to be gathered from students in order to begin to develop an idea of the form of technological knowledge (Compton, 2004:17). Compton (2004:14) emphasises that:

It is essential that we acknowledge that technology education cannot expect to "operationalise" frameworks from technology into technology education without clearly exploring the fitness of doing so ...

Against this background, the problem that has been identified is the lack of existing frameworks in technology education through which technology can be conceptualized. Although one can draw on frameworks from other established disciplines, one needs to engage with such frameworks to determine their usefulness in a technology education context.

The purpose and significant contribution (thesis) of this study therefore, is to investigate the usefulness of a framework derived chiefly from professional engineers to describe the nature of technological knowledge in an attempt to contribute towards the understanding of this relatively new learning area.

1.4 Research questions

The following research question is therefore to be addressed:

How useful to technology education is the conceptual framework of knowledge derived chiefly from and used by professional engineers?

The term *useful* is used as an adjective in this context to mean “being of use” (Tulloch, 1995:1734). If the conceptual framework is found to be useful, it can be used to enhance the understanding of technological knowledge in technology education. The conceptual framework can also be used to evaluate technology learning programmes to determine the extent to which all the knowledge types in technology is represented in those learning programmes.

One way of establishing the usefulness of the conceptual framework, is to determine the frequency to which students engage in the categories of technological knowledge and knowledge-generating activities that make up the conceptual framework, during technological designing and making tasks (i.e. capability tasks). Furthermore, by determining the relationship between the extent to which students make use of the categories of technological knowledge and the knowledge-generating activities in two content areas, one can get insight into the way various knowledge types are used in two different content areas. This can, for example, show if the knowledge contained in one content area significantly favours the categories of knowledge above the knowledge contained in the other content area.

Consequently the sub-questions are:

- what is the frequency of categories of technological knowledge used by education students when they design and make an artefact?
- what is the frequency of knowledge-generating activities drawn upon by education students when they design and make an artefact?
- what is the relationship, if any, between the categories of technological knowledge used in two different content areas in technology education?
- what is the relationship, if any, between the knowledge-generating activities drawn upon in two different content areas in technology education?

1.5 Explanation of key terms

1.5.1 The term technology

The etymology of the term *technology* is “discourse or treatise on an art or the arts” (Harper, 2001c). It comes from the Greek word *tekhnologia* (*technologia*) which means systematic treatment (Tulloch, 1995:1603). The root *tekhnō*, combining form of *teckhnē* (*techne*) refers to art, skill, craft, method and system (Harper, 2001b). The root *logos* refers to word, speech, discourse and reason (Harper, 2001a). Herschbach (1995:32) notes that the meaning of the root *logos* also includes argument, explanation, and principle, but believes that its meaning is more relevant to “reason” – Technology, thus, encompasses reasoned application.

1.5.2 The use of the term technology

Mitcham (1994:143) notes that the term *technology* has, in current discourse, narrow and broad meanings, which roughly corresponds to the ways it is used by two major professional fields, viz. engineering and social science.

1.5.2.1 Engineering

The use of the term *technology* in the engineering field is restrictive (narrow). The engineer, according to Mitcham (1994:146), is not so much one who actually makes or constructs as one who directs, plans, or designs: engineering as a profession is identified with the systematic knowledge of how to design useful artefacts or processes. The term *technology* with its cognates is reserved by engineers mainly for more direct involvement with material construction and the manipulation of artefacts (Mitcham, 1994:147). Vincenti (1990:14) notes that the word “organizing”, for which we can also read “devising” or “planning”, distinguishes engineering from the more general activity of technology, which embraces all aspects of design, production, and operation of an artefact.

1.5.2.2 Social science

For social scientists the term *technology* has a much broader meaning than in its engineering context: it includes all of what the engineer calls technology, along with engineering itself (Mitcham, 1994:149). De Vries (2005b:11) takes this broader meaning of the term technology to refer to :

... the human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, various kinds of natural (material, energy) and cultural resources (money, social relationships, etc.).

De Vries (2005b:11) distinguishes engineering from technology in that engineering entails professionals called ‘engineers’ carrying out the human activity described above. Also, engineering and technology differ because in the latter the user perspective is included, and not in the former.

1.5.2.3 The use of the term *technology* in this study

For the purpose of this study the term *technology* will, in line with its use by other scholars in the field (Ankiewicz et al., 2006:118-119; De Vries, 2005b:11-12), be used in the broad sense as described above. The term *engineering* will also be used in the same broad sense and the use of the terms *technology* and *engineering* will be led by the literature referred to in that particular case.

The definition of technology stated in the RNCS (DoE, 2003:4) informs the meaning of technology for this study:

the use of knowledge, skills and resources to meet people’s needs and wants by developing practical solutions to problems, taking social and environmental factors into consideration.

1.5.3 The design process

The design process is the backbone outcome for the technology learning area in South Africa. The design process is a creative and interactive approach used to develop solutions to identified problems or human needs. Its associated skills, which form the different phases of the design process, are to investigate, design (to develop ideas), make, evaluate and communicate (DoE, 2002:6).

1.5.4 The project portfolio

A project portfolio is a systematic and organized collection of a learner’s work. It entails the comprehensive documentation of the notes on the process that was followed in

developing solutions. It also includes findings, successful and unsuccessful ideas, data, pictures, drawings, and so on (DoE, 2002:65).

1.5.5 Technological activities

The technological activities (tasks) relevant to this study are capability tasks, resource tasks and case studies.

1.5.5.1 Capability tasks

Capability tasks involve the designing and making a product that works (Barlex, 2000). These projects are conducted over a longer period of time using the design process, i.e. investigating, designing, making, evaluating and communicating as prescribed by the DoE (2003:6).

1.5.5.2 Resource tasks

Resource tasks, also known as focused tasks, are short practical activities used to encourage pupils to think and help them acquire the knowledge and skills they need to design and make competently (Barlex, 2000). Resource tasks are used to teach learners the knowledge, understanding and skills likely to be required in designing and making assignments (Barlex, 1998:147).

1.5.5.3 Case studies

Gerring (2004:342) defines the case study as an intensive study of a single unit² for the purpose of understanding a larger class of (similar) units. Case studies are true stories about design and technology in the world outside the classroom (Barlex, 2000). The DoE (2003:34) avers that case studies are useful to develop some of the investigation assessment standards and some of the evaluation assessment standards of learning outcome 1, and all of the technology, society and the environment assessment standards of learning outcome 3.

1.5.6 Project- and problem-based learning

The South African DoE (2003:26) proposes that the operational approach to teaching technology should be project-based. Project-based learning is a comprehensive approach to classroom teaching and learning that is designed to engage students in the investigation of authentic problems. Within this approach students pursue solutions to non-trivial problems by asking and refining questions, debating ideas, making predictions,

² A unit connotes a spatially bound phenomenon, e.g., a nation-state, revolution, political party, election, or person, observed at a single point in time or over some delimited period of time (Gerring, 2004:342).

designing plans, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artefacts (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991:369,371).

Savin-Baden (2003:17) notes that project-based learning is seen by many as synonymous with problem-based learning because both are regarded as student-centered approaches to learning. Savin-Baden (2003:17), however, disagrees and suggests a number of distinct differences between the two approaches, some of which are listed in table 1.

Table 1: Differences between project-based and problem-based learning (Savin-Baden, 2003:18)

Project-based learning	Problem-based learning
Students are required to produce a solution to solve the problem.	Solving the problem may be part of the process, but the focus is on problem management, not on a clear, bound solution.
Input from the tutor occurs in the form of some type of teaching during the lifespan of the project.	The focus is on students working out their own learning requirements. Some problem-based learning programmes require lecturers to support the students rather than to direct the learning.
Students are usually involved in the choice of project (sometimes from a predetermined list).	Students may choose problem scenarios from practice although the problems are usually provided by staff. What and how they learn is defined by the students.
Often occurs towards the end of a degree programme after a given body of knowledge has been covered, that will equip the students to undertake the project.	Problem-based learning is not usually premised on the basis that students have already covered required propositional knowledge. Rather, students themselves are expected to decide what it is they need to learn.
Is often seen as a mechanism for bringing together several subject areas in one overall activity at the end of a course.	Works from the premise that learning will necessarily occur across disciplinary boundaries, even at the beginning of a course.

Notwithstanding the differences listed in table 1, Barron, Schwartz, Vye, Moore, Petrosino, Zech, et al. (1998:277) propose an approach using problem-based learning as a scaffold for project-based learning. They argue that project-based learning experiences are frequently organized around a driving question or problem that serves to organize and drive activities which in turn result in artefacts or products that address the driving question (Blumenfeld et al., 1991:371), yet believe that too frequently, the question that drives a project is not crafted to make connections between activities and the underlying conceptual knowledge that one might hope to foster (Barron et al., 1998:273,274). In their (Barron et al., 1998:277) proposed approach, a relevant problem-based challenge can serve as a scaffold for more open-ended projects. They (Barron et al., 1998:278) note that an advantage of pairing problem-based and project-based activities is that students are likely to develop flexible levels of skills and understanding.

Project-based and problem-based learning symbolize an integrative approach to learning, since they draw on a number of learning theories while at the same time acknowledging the importance of learning through experience (Savin-Baden & Major, 2004:29).

1.5.7 Collaborative and cooperative learning

Savin-Baden and Major (2004:73) regard collaborative learning as probably the most common form of learning in regard to the problem-based approach. Collaborative learning is a pedagogy that has at its centre the assumption that people make meaning together and that the process enriches and extends them (Matthews, 1995:101). Dillenbourg (1999:5) describes collaborative learning as a situation in which particular forms of interaction are expected to occur among people, to trigger learning mechanisms, although there is no guarantee that the expected interactions will actually occur.

Similar to collaborative learning, cooperative learning can be described as a group learning activity organized so that learning is dependent on the socially structured exchange of information between learners in groups, in which each learner is held accountable for his or her own learning and is motivated to increase the learning of others (Olsen & Kagan, 1992:8).

The difference between cooperative learning and collaborative learning, according to Savin-Baden and Major (2004:74), is that cooperative learning involves small group work to maximize student learning. Also, cooperative learning tends to maintain traditional lines of knowledge and authority whereas collaborative learning is based on notions of social constructivism (Savin-Baden & Major, 2004:74).

1.5.8 Constructivism and social constructivism

Constructivists believe that knowledge is not an absolute, but is rather constructed by the learner based on previous knowledge and overall views of the world (Savin-Baden & Major, 2004:29). The constructivist views the mind as a builder of symbols – the tools used to represent the reality of the one who has knowledge. External phenomena are meaningless except as the mind perceives them – reality is personally constructed and personal experiences determine reality, not the other way round (Cooper, 1993:16). Constructivism posits that understanding comes from interactions with the environment, cognitive conflict stimulates learning, and knowledge occurs when students negotiate social situations and evaluate individual understanding (Savin-Baden & Major, 2004:29).

Both sociology and psychology have, however, undergone a transformation from views of constructivism centred on the private or personal, subjective nature of knowledge construction, to views centred on their social, inter-subjective nature (Au, 1998:299; Mehan, 1981:73). Au (1998:299) points out that these newer views are generally called *social constructivism*, according to Mehan (1981:71), the principle that states that social structures and cognitive structures are composed and reside in the interaction between people. As Gergen (1985:270) states: “ knowledge is not something people possess somewhere in their heads, but rather, something people do together”.

1.6 Context of the study

The study involved undergraduate Bachelor of Education (BEd) students at the University of Pretoria who selected design and technology as an elective subject. Novice teacher education students were selected specifically, despite evidence in the literature that indicates that there are several advantages to using “experts” in the field as opposed to novices (this issue is further discussed in section 3.5). The reasons for the choice of novice teacher education students are:

- The question of who the “experts” are in technology education is problematic, since technology is a relatively new learning area internationally and even more so in the South African curriculum. As a result of the newness of this learning area, the vast majority of practising technology teachers in South Africa do not have formal training in technology education, but were generally sourced from subjects such as home economics, woodwork, metalwork and industrial arts (Van Niekerk, Ankiewicz, & De Swart, forthcoming). Current technology teachers therefore do not have the relevant academic background in terms of the technology content areas, design process and the methodological approach to technology education. In addition, most of these teachers were not trained in outcomes-based education

(OBE) (Potgieter, 2004:210), which underpins the South African education system (DoE, 2002).

- Technology students at the University of Pretoria, on the other hand, are trained in technology education according to the most recent policy requirements and it is assumed that they are able to design and implement learning programmes successfully. Since they are the educators who will be teaching their “newly” acquired knowledge to learners, it made sense to describe technological knowledge according to *what* they know and *how* they know it.

Design and technology at the University of Pretoria is a 64 credit³ subject presented in four periods of fifty minutes each over a period of three years⁴, and is structured as follows:

Table 2: Design and technology course structure

Year	Module code	Content	Term	Credits	Time (weeks)
1	JOT 151	Conceptual framework	1	5	7
	JOT 152	The design process	2	5	7
	JOT 120	Design 1	3 + 4	10	14
2	JOT 210	Design 2	1 + 2	10	14
	JOT 220	Processing	3 + 4	10	14
3	JOT 310	Electrical systems and control	1 + 2	12	14
	JOT 353	Mechanical systems and control	3	6	7
	JOT 354	Structures	4	6	7

In addition to the modules listed in table 2, all the students who select design and technology as an elective are also required to attend the methodology of technology course (JMC 300) in the third year of study. Design and technology, as an elective, will enable the students, on completion of their BEd degree, to teach technology in schools from grade R to grade 9.

The design and technology course structure, shown in table 2, was conceptualised and developed by two lecturers responsible for the curriculum development of this elective subject at the University of Pretoria. One of the two lecturers has a background in graphic communication, design methodology, and design cognition. She teaches the first year modules (JOT 151, JOT 152 and JOT 120), as well as JOT 210 in the second year. The

³ 64 credits entail 640 hours (contact and non-contact time) to be spent on the module.

⁴ The fourth year is designated for research, methodologies and a six-month school-based internship period.

second lecturer, also the researcher of this study, teaches the third year modules (JOT 310, JOT 353 and JOT 354). He has a technological background in industrial instrumentation and process control. Both lecturers are full-time, permanently appointed academic personnel in the faculty of education at the University of Pretoria. The module JOT 220 is taught by a part-time, contract-based lecturer with a physics and chemistry background.

This study focuses on two capability tasks from two different technology content areas for third year design and technology students, JOT 353 (systems and control) and JOT 354 (structures). These two content areas were selected specifically because they are part of the last two modules of the students design and technology training. The rationale for this choice was based on the assumption that at this stage the students had, at least, a basic understanding of the learning area (e.g. how to utilize the design process), as the study investigates the extent to which these students engage in the different categories of knowledge derived chiefly from professional engineering, when they design and make technological artefacts during capability tasks. In addition, this study also investigates the knowledge-generating activities drawn upon by these students in completing the abovementioned capability tasks.

It is important to note that the capability tasks were performed in a constructivist manner during non-contact time⁵. The reason is that a blended project-based and problem-based approach was followed to optimise the students' cognitive engagement and to develop more flexible levels of skills and understanding, as suggested by Barron et al. (1998:277-278). Students' identified needs and artefacts therefore differed from one another and the solution to their problems was thus unique. Each student required different knowledge at different phases of the design process, which due to time constraints, could be realised only if the students worked in a constructivist manner during non-contact time.

Contact time was reserved for activities such as lecturing, resource tasks and case studies. These activities focused exclusively on providing the students with the necessary content knowledge pertaining to the assessment standards of learning outcome 2, i.e. knowledge and understanding of systems and control, and structures. This knowledge formed the basis for the knowledge used by the students in the capability tasks under

⁵ It is assumed that all the third year design and technology students, although they had no previous engagement in the content of systems and control, and structures, were competent in following the design process independently as it formed part of their formal first and second year training.

discussion. It is acknowledged, however, that the students could also have constructed their own knowledge based on knowledge acquired elsewhere.

1.6.1 JOT 353

JOT 353 is a seven-week, six credit, third term module that deals with the content area of systems and control. The capability task required the students to design and make an educational toy comprising at least two different mechanical components, e.g. gears, pulleys, levers, etc., and an electrical circuit. At the end of the module, students had to submit the educational toy, as well as a comprehensive project portfolio, which were assessed and graded to constitute part of their final semester mark.

Refer to the detailed description of this module in chapter 3 (section 3.6.1).

1.6.2 JOT 354

JOT 354 is another seven-week, six credit, fourth term module that covers the content area of structures. During this module the capability task required the students to design and make a structural artefact based on and selected from their individual learning programmes created in JMC 300: the methodology of technology course. As part of their JMC 300 module, all students had to create a complete learning programme for a phase⁶ of their choice. Learning programmes had to include all three content areas in each grade, viz. systems and control, structures, and processing. Since the technology teaching strategy is project-based, students had to specify a contextualised project as a capability task for each content area in each grade. Students acted as programme developers since they were not required merely to select a capability task from a pre-existing set, but had to contrive relevant projects, which would address the assessment standards for each grade as specified in the South African NCS.

In the JOT 354 module, students were free to choose any project from any grade specified in their JMC 300 course that related to the content area of structures. They then had to design and make the artefact as a capability task for JOT 354. At the end of the module, students had to present the structural artefact and a comprehensive project portfolio documenting the process followed to design and make it.

Refer to the detailed description of this module in chapter 3 (section 3.6.2).

⁶ The RNCS is divided into three phases from grades R - 9: The foundation phase (grades R – 3), the intermediate phase (grades 4 -6) and the senior phase (grades 7 – 9).

1.7 Research design and methodology

The strategy of inquiry that governed this study is based on a combination of quantitative and qualitative research. The rationale for using this design is that the quantitative data and qualitative data are needed for different purposes:

- The quantitative data in this study was used to determine the frequency of technological knowledge used and the knowledge-generating activities drawn upon by the students when they design and make an artefact. It was also used to establish any relationships between the categories of technological knowledge and knowledge-generating activities measured in the two different content areas. This data is suited to make generalisations in terms of frequencies and relationships, but is lacking in terms of context and applied examples.
- The qualitative data was used to inform *what* knowledge the students used and *how* they used it to complete the capability tasks. In addition to providing context, the qualitative data provided the opportunity to find examples of knowledge in the students' project portfolios, of the different knowledge-generating activities and to classify them into relevant categories of knowledge. The foregoing was omitted from the quantitative phase due to the complexity of the conceptual framework and the risk that the students might not be able to conduct such a complicated classification.

The quantitative data (QUAN) took priority, since most of the research questions of this study could be answered during this phase of the design. The quantitative data was collected and analysed first and was obtained by means of a questionnaire completed by the students on completion of the capability tasks at the end of each of the modules.

The qualitative data (qual) entailed a content analysis of the students' project portfolios. It involved a search for examples in the students' project portfolios to substantiate the students' responses to the questionnaire and also to inform *what* knowledge the students used and *how* they used it during the completion of the capability tasks. A detailed description of the research design, methodology and instruments will be provided in chapter 3.

The knowledge claims for this study is based on pragmatic assumptions (Creswell, 2003: 11-12,20). The implications of this knowledge claim for this study are:

- that the study draws from both quantitative as well as qualitative assumptions without committing to one system of philosophy and reality;

- the freedom to choose the methods, techniques, and procedures that best meet the need and purposes of this study. Pragmatism posits that the understanding of the problem is more important than the method used to study the problem;
- research always occurs in social, historical, and other contexts; and
- truth is what works at the time – it is not based on a strict dualism between the mind and a reality completely independent of the mind (Creswell, 2003:12).

1.8 Research limitations

The limitations acknowledged by this researcher include:

- the contextual scope of this study: this study was conducted using one group of undergraduate students from one university only, who selected technology education as an elective subject;
- the focus of this study is limited to technological knowledge in a South African education context – other views on knowledge are not addressed;
- only a limited number of students participated in the research. This is a limitation since it restricts the possibility to make quantitative generalisations. Refer to section 1.6 for an explanation as to the motivation for selecting these students;
- the sample was not identical since not all the students were present in both modules. This could have resulted in experimental mortality and is therefore a limitation of this study. Section 3.7.1 explains this in more detail; and
- it is accepted that the activities that were performed during contact time had an influence on the way students engaged in technological knowledge when they conducted the capability tasks. It is, however, a limitation of this study that it was not possible to determine the extent of this influence, since the students did not explicitly indicate what knowledge was acquired by themselves or by means of the classroom activities.

1.9 Outline and organisation of the study

Table 3 presents the outline and organisation of this study.

Table 3: Outline and organisation of the study

Chapter	Chapter heading	Chapter outcome
1	Prelude to the enquiry	To call attention to a void in technology education and to point out some of the pedagogical implications of this void. The chapter also sets the stage for the rest of the study.
2	Literature study	Provides an overview of the relevant literature and investigates frameworks from other established disciplines.
3	Research design and methodology	Describes the research design, methodology and instruments that were used in this study and presents the conceptual framework.
4	Data and results of the quantitative phase	Presentation, analysis and discussion of quantitative data.
5	Data and results of the qualitative phase	Presentation, analysis and discussion of qualitative data.
6	Epilogue	Reflects on the quantitative and qualitative findings, answers research questions and includes conclusions and recommendations.

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2.1 Overview of the chapter

This chapter presents a review of the literature pertaining to this study. It starts by taking a look at knowledge in general and offers some definitions in an attempt to describe the term *knowledge*. After critiquing an epistemological view of knowledge from a technological perspective, the nature of technological knowledge is explored. This is followed by an acknowledgement of the role of indigenous knowledge in the South African curriculum in general and in technology specifically. The relationship between science and technology, seemingly the starting point for many discussions on technological knowledge, is addressed next. This is followed by views on learning in order to inform how we might draw on and use knowledge, and includes an account of the transfer of knowledge. The remainder of this chapter explores four frequently cited frameworks that provide different views on technological knowledge from different disciplines in the field. A combination and adaptation of some of the items in these frameworks provides the conceptual framework for this study, as discussed in the next chapter. A summary of the literature review concludes the chapter.

2.2 Knowledge

The proliferation of terms used to designate knowledge constructs in the literature often seem to duplicate, subsume or contradict one another (Alexander, Schallert, & Hare, 1991:315). The term *knowledge* is therefore not easily or well defined (Gibson, 2008:5). Scheffler (1999:1-2) offers three reasons to explain why defining the term *knowledge* is so complex. First, the range of meaning of the everyday concept of knowing is very wide, it includes familiarity with things, places, persons, and subjects, competence in a variety of learned performances and possession of ostensible truths on matters of fact as well as faith, the fallible items of science and everyday experiences, as well as the alleged certainties of mathematics and metaphysics (Scheffler, 1999:1). Secondly, Scheffler (1999:1-2) notes that the concept of knowing is related in important ways to other fundamental and complex ideas. One form of knowledge can therefore influence or be influenced by the existence of another (Gibson, 2008:5). Finally, attributions of knowledge are not simply descriptive of bodies of lore or types of experience; they express our standards, ideals, and tastes as to the scope and proper conduct of the cognitive arts. They reflect, for example, our conceptions of truth and evidence, our estimates of the possibilities of secure belief and our preferences among alternative strategies of investigation (Scheffler, 1999:2).

Aside from the aforementioned complexities regarding the definition of the term *knowledge*, it still needs to be described, since this study purports to investigate knowledge in technology education.

2.2.1 Definitions of knowledge

Alexander, Schallert and Hare (1991:317) state that for researchers in the field of cognition, knowledge refers to an individual's personal stock of information, skills, experiences, beliefs and memories. This knowledge is "always idiosyncratic, reflecting the vagaries of a person's own history" (Alexander et al., 1991:317). Cognitive psychologists describe the structure of knowledge in terms of two types of knowledge, conceptual and procedural knowledge (McCormick, 2004:24). Procedural knowledge is simple "knowing-how-to-do-it" knowledge while conceptual knowledge is concerned with relationships (links) among "items" of knowledge, e.g. in the area of gearing, the relationship between the change of speed and torque (McCormick, 2006:34). Similarly Bzdak (2008:36) points out that philosophers sometimes distinguish between two kinds of knowledge: *knowledge-that* and *knowledge-how*. Knowledge-that, e.g. knowing that $1 + 2 = 3$, is sometimes referred to as propositional, declarative or factual knowledge. Knowledge-how, e.g. knowing how to ride a bicycle, is sometimes referred to as applied, practical or procedural knowledge, or simply as know-how (Bzdak, 2008:36). Ryle (1960:40-41,134) made the observation that *knowing-how* is not belief-based and not prepositional, as *knowing-that* is.

Scheffler (1999:1-2) postulates that the term knowledge, in educational contexts, is frequently intended to embrace both the accumulated skill and lore pertaining to the technological control of the environment, as well as those intellectual arts and experiences whose value is intrinsic. In this context, knowledge marks the whole content of our intellectual heritage, which education is concerned to pass on to succeeding generations (Scheffler, 1999:2).

In the field of epistemology most debates revolve around the short description of knowledge as "justified true belief"⁷ (Alexander et al., 1991:317; De Vries, 2005b:30). Audi (2003:333), however, argues that the suggested account of knowledge as *justified true belief* seems to be both too broad and too narrow: a person can, for example, be hallucinating and therefore have a justified true belief which is not knowledge, because when truth is subtracted from what appears to be knowledge, what remains is not

⁷ Plato's account of knowledge has been loosely interpreted as taking knowledge to be "justified true belief", but this was, however, never endorsed by Plato (Audi, 2003:220).

knowledge, but belief. The suggested account of knowledge as justified true belief is, then, too broad (Audi, 2003:220,222,333). On the other hand, it might be too narrow if there is knowledge without justification, e.g. a person who by virtue of a stable cognitive capacity, unerringly computes difficult arithmetic results with lightning speed, but is unaware of the success and is not (initially) justified in believing the answers (Audi, 2003:225,333).

A sound conception of knowledge, according to Audi (2003:251), is “a true belief based in the right way on the right kind of ground⁸”. Only once we have beliefs directly grounded in one of the five sources of non-inferential knowledge and justification - namely perception, memory, consciousness, reason, and secondary but indispensably, testimony, are we in a position to extend whatever justification and knowledge we then have. Justification or reliability, or both, may be essential to explain this concept adequately. This conception of knowledge leaves a great deal unexplained, but should be helpful in seeking a full account (Audi, 2003:251,331,334).

De Vries (2005b:30) agrees with Audi (2003:333) that the original definition of knowledge as “justified true belief” is not sufficiently accurate. De Vries (2005b:30) says that various philosophers have tried to “repair” the definition by adding more conditions, but there is still no generally accepted definition, and some philosophers even say that the description of knowledge as justified true belief must be abandoned.

Similarly, De Vries (2003:15; 2005b:31) dismisses the account of knowledge as “justified true belief” in regard to technological knowledge and argues that it is not appropriate for defining technological knowledge, because it does not do justice to all types of technological knowledge. Broens and De Vries (2003:459) regard this account of knowledge as indicative that the focus of epistemological discussions is more on propositional⁹, descriptive knowledge¹⁰ than on knowledge with a normative¹¹ nature, such as prescriptive knowledge. They (Broens & De Vries, 2003:459) hold that since technological knowledge in many cases has normative aspects, most epistemological literature does not approach the issue of the nature of technological knowledge adequately.

⁸ *Justified belief* might be conceived as *well-grounded belief* (Audi, 2003:251).

⁹ A proposition is the content of a statement about something, for example “today it rains” is a proposition, but so is “tomorrow it will rain” (De Vries, 2005b:30).

¹⁰ Knowledge that describes things as they are. See section 2.2.2 for a detailed description.

¹¹ Knowledge about norms for the design of the product. It includes preferences, values, tastes and attitudes (Bayazit, 1993; Broens & De Vries, 2003:460). Also see section 2.4.4 for a detailed description.

Other reasons, identified by De Vries (2005b:31-32), for the inadequacy of the abovementioned account of knowledge as a fitting description of technological knowledge, include:

- knowledge that can be expressed in propositions fits well with the justified true belief account of knowledge, but “knowing-how” is knowledge that cannot be expressed in propositions. Skills needed in technology are an example of knowing-how knowledge (De Vries, 2005b:31-32); and
- another part of technological knowledge that cannot be expressed in propositions is what Ferguson (1992:41-42) calls “the mind’s eye”, the locus of our images of remembered reality and imagined contrivance. Visual thinking can be successful to the extent that the thinker possesses an adequate array of sensual experiences, converted by the mind’s eye to usable visual information (Ferguson, 1992:42). The sketches and drawings that result from such visualizations contain a richness of knowledge that is unable to be expressed entirely in propositions (De Vries, 2005b:32).

The distinctive nature of technological knowledge is clear from the foregoing and it therefore requires specific attention. This will be achieved by exploring some typologies.

2.2.2 Technological knowledge

Ihde (1997:73) describes several dimensions of technological knowledge. They are:

- *knowledge about technologies* is the engineer’s or technician’s knowledge, the knowledge of how a machine is made and how it functions (Ihde, 1997:73). Knowledge about technologies, according to Pavlova (2005:139), is aimed at understanding technology, its nature and relationship between person, society and nature. It is based on theorizing technology from different disciplines, including philosophy of technology and is closely related to values and ethical issues in the abovementioned relationship (Pavlova, 2005:139);
- *theoretical technological knowledge* is the knowledge of the physical, chemical or electrical laws and principles that allow any given technology the capacity to do what it does. This is the scientist’s or scientific engineer’s knowledge (Ihde, 1997:73); and
- *knowledge through technologies* is a special kind of *praxical* or use knowledge that runs through a wide range of human actions. It is “constructed” through the use of instruments that are technologies. Ihde (1997:74) argues that what makes, for example, modern science *modern* is its embodiment through technologies, i.e. instrumentation. Technologies are *relativistically* transformational and whatever

knowledge we gain through them reflexively transforms the world we discover through them and the embodied beings we are through using them (Ihde, 1997:74).

Pavlova (2005:139) also recognise knowledge *within* technology: It includes knowledge about objects and processes: students should be able to design and make products, analyze them and use and maintain them. Knowledge of processes includes the processing of different materials, simplified design processes, maintaining, using, and so on, that should be considered in different domains, e.g. artisan skills, technical maxims and technological and scientific theories. The main aim of this dimension of knowledge is its application and its links to particular technologies (Pavlova, 2005:141).

Vincenti (1990:198), writing about engineering¹² knowledge, suggests that for epistemological discussion, the classification of engineering knowledge according to its nature may be more fundamental than according to its purpose for production or design. The nature of engineering knowledge is described in terms of descriptive, prescriptive and tacit knowledge.

- *Descriptive knowledge* describes things as they are. It is knowledge of fact or actuality and is judged in terms of veracity or correctness. Descriptive knowledge is synonymous with “knowing that” or knowledge of how things are (Vincenti, 1990:197,237). Herschbach (1995:34) describes descriptive knowledge as “statements of fact which provide a framework within which the informed person works”. This includes knowledge such as material properties, technical information and tool characteristics.
- *Prescriptive knowledge* prescribes how things should be to attain a desired end. It is knowledge of procedures or practice and is judged in terms of effectiveness or degree of success or failure (Vincenti, 1990:197). Herschbach (1995:35) believes that prescriptive knowledge is the result of successive efforts to achieve greater effectiveness. It leads to improved procedures and is subject to change as greater experience is gained.
- *Tacit knowledge* refers to implicit, wordless and pictureless knowledge, and is acquired from individual practice and experience. It is inexpressible, but that does not mean that it is any the less knowledge (Vincenti, 1990:198). According to Herschbach (1995:35-36), tacit knowledge is a personal and subjective knowledge

¹² For the purpose of this study the term *technology* will be used in the broad sense to include everything the engineer calls technology, along with engineering itself. The terms *technology* and *engineering* will be used loosely and the use will be led by the literature referred to in each particular case (refer to section 1.5.2 in chapter 1).

that is learned primarily by working side by side with an experienced technician or craftsman.

Herschbach (1995:34) agrees with Vincenti's (1990:197-199) descriptive, prescriptive and tacit knowledge that describe the nature of engineering knowledge. In addition, Herschbach (1995:39) emphasizes the importance of including all three forms of engineering knowledge for instructional purposes and Herschbach (1995:33) observes that it is through activity that technological knowledge is defined: "It is *activity* which establishes and orders the framework within which technological knowledge is generated and used". Technological activities help make explicit to learners how knowledge is generated, communicated and used to analyse and solve technological problems. Through technological activity students are helped to perceive, understand and assign meaning (Herschbach, 1995:39).

Hitt, Ireland, and Lee (2000:233-234) differentiate only between explicit and tacit knowledge. Concepts related to explicit knowledge are "know-what", "objective knowledge", "predisposition knowledge" and "declarative knowledge", and terms such as "know-how", "subjective knowledge", "personal knowledge" and "procedural knowledge" are used to describe the tacit dimension of knowledge (Hitt et al., 2000:234).

Although Alexander et al. (1991:323) recognise declarative¹³ and procedural knowledge, they add "conditional knowledge" and argue that when we know something (be it content, language, or otherwise), we can know not only factual information about it (declarative knowledge) but also how to use such knowledge in certain processes or routines (procedural knowledge). We can also understand when and where this knowledge will be applicable (conditional knowledge). They (Alexander et al., 1991:323) emphasise the fact that these three types of knowledge are distinct; the acquisition of knowledge in one form does not automatically and immediately guarantee knowledge in the other forms.

2.3 Science and technology

The starting points for many discussions are the critique of the position which identifies technology with applied science (Pavlova, 2005:132). The phrase "science and technology" has been used so often that it gives the impression that these two learning areas must somehow be mutually inclusive. This is confirmed by Frey (1991:1) who notes

¹³ Declarative knowledge is the collection of knowledge about functions, materials, shapes, and manufacturing processes, and about non-technical aspects of a design (economic, social, juridical, etc.) (Broens & De Vries, 2003:457). Also see section 2.4.4 for a detailed description.

that the link between science and technology is so commonplace that it is often assumed that they share a common methodology, symbol system (mathematics and language) and community of practitioners. Frey (1991:1) states that “this misconception about the nature of science and technology and about the relationship between them can be misleading at best and fatal at worst, for technology education”. Educators may find that technology education is equated with science or competes with science programmes. In either case the distinctive character of technology is misunderstood (Frey, 1991:1).

A possible reason for this misconception might be that the epistemology has focused on science and specifically on physics. It has therefore willingly adopted the commonplace that technology is “applied science” (Ropohl, 1997:66). According to De Vries (1996:7) this opinion indeed functioned as a paradigm for the philosophy of technology for some time, and it suggests the existence of a straightforward path from scientific knowledge to the technological product.

Frey (1991:7) expresses his concern regarding the relationship between technology and science in terms of the location of the claim for knowledge. Conventional thinking often classifies technological knowledge in the same knowledge base as science or as a subsidiary to science. This can lead to the notion that technology does not have distinct cognitive content or that science generates knowledge that is used in technology as is, hence the belief that “technology is applied science” (Frey, 1991:7). This science-technology model suggests that science is the wellspring of innovation and that scientific discovery implies technological invention: technology is thus the responsive activity of applied science (Faulkner, 1994:427).

Recent scholars of technology, however, reject the view that technology is applied science and insist that technology is a cognitive system consisting of a separate body of technological knowledge (Faulkner, 1994:432-434; Frey, 1991:7; Herschbach, 1995:31-33; Layton, 1974:40; Vincenti, 1990:225-229). Layton (1974:31) focuses on two critical assumptions which accompany the theory that scientists generate new knowledge which technologists apply. The first is that technological knowledge is essentially identical to natural philosophy and the second is that scientists have produced this knowledge since 1800. These two assumptions lead to the absurd deduction that prior to 1800 technology involved no knowledge at all. In addition, De Vries (1996:7) points out that recent literature suggests that technology actually preceded science. In fact, Ihde (1997:79) holds that the “advance” of scientific knowledge is dependent upon the development of technology knowledge. Ihde (1997:73) argues that much, if not most, scientific knowledge is

technologically dependent - it is constructed through the use of instruments which *are* technologies.

De Vries (2003:17) writes that nowadays “most philosophers of technology accept the idea that technological knowledge is different from scientific knowledge”. Layton (1974:40) holds that “the difference is not just one of ideas but of values; “knowing” and “doing” reflect the fundamentally different goals of the communities of science and technology”. Layton (1974:40-41), however, acknowledges the fact that technology and science might influence each other on all levels. He (Layton, 1971:578) refers to the “symmetric” relationship between science and technology, i.e. information can be transferred in either direction.

Another important distinction pointed out by De Vries (2005a:149) is that technological knowledge possesses a normative component not found in scientific knowledge. For scientific knowledge truth is the ultimate condition. For knowledge of norms, rules and standards as a type of technological knowledge this condition is problematic, since the norms, rules and standards often refer to things that do not yet exist, but are still to be designed or made. Therefore, effectiveness (not truth) is the condition here. The making of judgments about effectiveness is a prominent characteristic of technological knowledge that makes it distinct from scientific knowledge. These judgments also apply to ethical and other values in regard to technological project work (De Vries, 2005a:149).

The foregoing section illuminated the view that technological knowledge is different from scientific knowledge. Philosophical arguments about the relationship between science and technology seem to be standard in debates about the nature of technological knowledge. These debates, according to McCormick (2006:31), are important in order to clarify the nature of technological knowledge, however, during these debates knowledge tends to be seen as an object to be passed around and which will find its way into a learner’s head. Although this might be a legitimate view of how learning relates to knowledge, it is only one view (McCormick, 2006:31). The next section will therefore explore views of learning in order to inform ways in which we might draw on and use knowledge.

2.4 Knowledge and learning

McCormick (2006:44) calls attention to the significance of taking views of learning as a starting point to understand the nature of knowledge. McCormick (2006:31) points out the tendency to see learning as a process that operates on the “content” of *what* is to be learned and that content is seen to be independent of *how* it is learned. Contemporary

theories of learning have important implications for how we see knowledge and how we structure and support student learning in the technology classroom (McCormick, 2006:31).

2.4.1 Contemporary views of learning

Bredo (1994:23) illuminates two current views of learning: the symbol-processing (or computational) and situated approaches.

- The *symbol-processing approach* has been dominant in both psychology and education (Bredo, 1994:23). The mind, according to this approach, is seen as a manipulator of symbols. These symbols are learned and stored in the memory through a knowledge-construction process, i.e. learners make meaning from experiences; when confronted with a problem a person searches the memory for symbols to represent the problem and then manipulates them to solve the problem (McCormick, 2006:32). Thinking and intelligence are seen as akin to a computer performing formal operations on symbols. Research, according to this view, has generally focused on the kind of tasks that are familiar to academics and other professionals, e.g. logical deductions, disease diagnoses, mechanical fault finding and scientific discovery (Bredo, 1994:23). In the symbol-processing view, according to Bredo (1994:24), the mind is generally conceived to be “inside the head”. The educational equivalent of this assumption is a passive “spectator” approach to knowing, which views it as separate from doing (Bredo, 1994:30).
- The foregoing approach has, however, lately been challenged by those advocating a *situated approach* based on the everyday practices of “just plain folk”; where the mind is not “inside the head”, but an aspect of person-environment interaction itself (Bredo, 1994:23-24). The situated approach is represented by a group of theories stemming from the socio-cultural tradition. A common feature of this view of learning is the role of others in creating and sharing meaning. Rather than seeing learning as a process of transfer of knowledge from the knowledgeable to the less knowledgeable, a situated view is concerned with engagement in cultural authentic activity (McCormick, 2006:32-33). Bredo (1994:32) notes that work on situated cognition has emphasised the inseparability of cognition and context. The situated approach assumes great context sensitivity and great contingency because interpretation and meaning vary with context. Knowledge is viewed as inseparable from the activities by which it is acquired and tested and from the practices of the community of fellow language users (Bredo, 1994:32). Glaser (1999:99) agrees that cognitive activity in and outside school is inseparable from cultural milieu. McCormick (2006:33) avers that “inter-subjectivity” (or mutual understanding) between participants arises from shared understanding based on a common focus

of attention and some shared presuppositions that form the basis of communication. From this view of situated learning comes a central focus on collaboration (between peers and others) and problem solving (McCormick, 2006:33).

Although the two approaches are contrasted as different ends of a spectrum, Bredo (1994:32-34) recommends a balance between the two approaches, rather than the dominance of one or the other, or their total divorce. This would involve both respecting their differences and using these differences to common effect.

2.4.2 Transfer of knowledge

Alexander and Murphy (1999:561) describe the term *transfer* as “the process of using knowledge or skills acquired in one context in a new or varied context”. Three kinds of transfer are recognized by Simons (1999:577), namely transfer from prior knowledge and skills to new learning, from new knowledge and skills to new learning situations (learning now preparing for later learning), and from new knowledge and skills to applications in work and daily life (learning for practice).

Stevenson (2004:7) believes the question of the utilization of technological knowledge can be examined as a question of transfer, arguing that the technology knowledge acquired in one context can be utilized in a different one. A case in point is the question of how learners can be prepared for new systems, materials and processes that have not yet been invented (Stevenson, 2004:7).

Authors from different theoretical backgrounds have, however, taken a very negative position by more or less dismissing the possibility of transfer (De Corte, 1999:556). Hatano and Greeno (1999:645) point out that a majority of investigators of transfer believe that the application of previous learning to new problems in new situations is rare. This disappointing phenomenon was also observed by authors such as Stark, Mandl, Gruber, and Renkl (1999:591) who note that learners have considerable problems in successfully applying the knowledge they acquire through traditional instruction to relevant problem situations in realistic settings. In fact, some socio-cultural researchers share the view that according to the situated cognition perspective, knowledge and skills cannot transfer, because they are so strongly embedded in and tied to the context in which they are acquired (De Corte, 1999:556).

McCormick (1999:126) asks whether transfer is not “the wrong metaphor” and proposes (McCormick, 1999:127) that when students learn some mathematical or scientific idea, they need to strip out the context and “see” the science or mathematics, since the salience (the technical term) lies in the science concepts, equations, etc. On the other hand, the practical situation has salience located in the features of the context, and learners need to come to understand where the salience is. He (McCormick, 1999:127) therefore avers that learning the salience, and not transfer, should be the focus.

Recognizing the poor history of transfer, Hatano and Greeno (1999:645-646) report that transfer studies often lead to new instructional attempts to enhance the acquisition of knowledge so that transfer can occur more often. These attempts are based on the presumption that the failure of transfer is attributed to an incomplete acquisition of knowledge by the student (Hatano & Greeno, 1999:646). Alexander and Murphy (1999:571) recommend a domain-specific perspective regarding the problem of transfer. Dispositions toward transfer require a rich and cohesive body of domain knowledge, a well-honed strategic repertoire, as well as a personal investment in or identification with an academic domain (Alexander & Murphy, 1999:571). Volet (1999:640) suggests that active participation in authentic learning activities and mindful, shared regulation of learning may help students decontextualize their knowledge about learning, and develop metacognitive strategies to read culturally and educationally different learning situations.

De Vries (2005b:45) shows that one of the characteristics of technology is that it involves a variety of knowledge domains. Design problems call for knowledge of technical data, knowledge about what customers want, what legislation allows, financial knowledge, and many other aspects (De Vries, 2005b:45). Since engineers do not have the specialized expertise of all those aspects, they have to “borrow” (transfer) knowledge from other disciplines and integrate it with their own knowledge (De Vries, 2005b:45). Vincenti (1990:229), for example, recognizes scientific knowledge as a source of engineering knowledge (as discussed in section 2.3). This transferred knowledge often entails reformulation or adaptation to make it useful to engineers (see section 2.5.1).

2.5 Frameworks of knowledge in technology

Four frequently cited frameworks for technological knowledge will now be explored to form an idea of the content of technological knowledge. The authors of these frameworks hold different views of technological knowledge deriving from different disciplines in the field: Vincenti (1990) provides a framework from an engineering perspective, Ropohl’s (1997) framework offers a philosopher’s view, De Vries’s (2003) framework is derived from the

'dual nature of technical artifacts' philosophical-theoretical framework and illustrated by technological practice, and Bayazit (1993) presents a framework from a designer-practitioner's point of view.

2.5.1 Vincenti's framework

Vincenti's (1990:208-225) framework for engineering knowledge was derived from an analysis of aeronautical history cases. It should be noted that Vincenti's (1990:207) framework contains only design-related knowledge, and not production-related or operation-related knowledge, which is a limitation of the framework.

Vincenti (1990:199) describes engineering knowledge and the activities that generate it as "rich and complex", viewing such knowledge as not only to be motivated and conditioned by design, but also by production and operation. Vincenti's (1990:199) perspective coincides with Layton's (1974:37+38) belief that technology must be seen as a spectrum, with ideas at one end and techniques and "things" at the other, with design as a middle term. The "things" Layton (1974:38) refers to are the artefacts that need to be designed and made; the outcomes of technology.

The classification of engineering design knowledge into categories is a complicated matter and Vincenti (1990:207) cautions that any detailed analysis of engineering knowledge runs the risk of divorcing such knowledge from engineering practice. In addition, Herschbach (1995:33) points out that it is because of this link with a specific activity that technological knowledge cannot be easily classified into categories or codified like scientific knowledge.

Vincenti (1990:208) lists six categories of engineering design knowledge which are linked not only to design, but to production and operation as well.

- *Fundamental design concepts* must be part of engineers' knowledge, even if they only exist implicitly in their minds. This knowledge can be acquired by engineers in the course of growing up - even before they start their formal engineering training. At some stage, however, these concepts have to be learned deliberately to form part of engineers' essential design knowledge. These concepts consist first of all of the "operating principle" of the device in question, in other words, how the device works. Secondly, these concepts must encompass the "normal configuration" of the device, i.e. the general shape and arrangement that are commonly agreed to best embody the operational principle. According to Vincenti

“the operational principle and normal configuration provide a framework within which normal design takes place” (Vincenti, 1990:208-211).

- *Criteria and specifications* are required to design a device. A designer must have specific requirements in terms of the device: the qualitative goals for the device must be translated to quantitative goals in concrete technical terms. This means that the people responsible must have knowledge of technical criteria regarding the device and its use, and they must be able to assign some form of numerical values or limits to those criteria. Vincenti (1990:211) states that “the criteria themselves – the essential key to engineering specification – constitute an important element of general engineering knowledge”. Such criteria often draw on the theoretical tool, quantitative data and pragmatic judgement (Vincenti, 1990:211-213).
- Engineers use a wide range of *theoretical tools* to accomplish their design task. These include intellectual concepts for thinking about design, as well as mathematical methods and theories for making design calculations. Intellectual concepts provide the language for articulating the thought in people’s minds. They are used by engineers not only in quantitative analysis and design calculation, but also for the qualitative conceptualizing and reasoning before and during their engagement in such quantitative activities. The mathematical methods and theories vary from elementary formulas for simple calculations to complex calculative schemes (Vincenti, 1990:213-216).
- *Quantitative data* is needed for the physical properties or other quantities required in the formulas. Vincenti (1990:216) distinguishes two types of knowledge and hence, two types of data, namely descriptive and prescriptive knowledge. Descriptive knowledge is knowledge of how things are. Descriptive data therefore includes data such as physical constants, properties of substances, strength of materials, etc. Prescriptive knowledge, on the other hand, is knowledge of how things should be to in order to obtain the desired result. Prescriptive data refers to data or process specifications (for example, safety factors) that manufacturers issue for guidance to assist designers and other workers (Vincenti, 1990:216-217).
- *Practical considerations* are important, since some knowledge can be learned mostly in practice rather than through training or textbooks. People carry this knowledge in their minds more or less unconsciously. Such knowledge does not lend itself to theorizing, tabulation or programming into a computer and it is hard to find it written down. The practice from which it derives includes not only design, but production and operation as well (Vincenti, 1990:217-219).

- *Design instrumentalities* must be part of engineers' knowledge, since in addition to the analytical tools, quantitative data and practical considerations, engineers need "know-how" to carry out a given task. The instrumentalities of the process include the procedures, ways of thinking and judgmental skills through which it is conducted. It empowers engineers to effect designs where the form of the solution is clear at the outset, and to also seek solutions where some element or novelty is required (Vincenti, 1990:219).

Procedures include structured and optimization procedures, although Vincenti (1990:220) acknowledges that engineers are seldom truly able to optimize. Instead they are mostly engaged in "satisficing"¹⁴ procedures.

Ways of thinking are related to the mental processes the designer follows. Such thought processes can be illustrated and taught to young engineers and are part of the shared body of knowledge. This includes what Ferguson (1992:41-42) calls "visual thinking". Aids to visual thinking include sketches and drawings, both formal and informal ones that engineers make on place mats at the luncheon table and on the backs of envelopes (Vincenti, 1990:220-221).

Judgmental skills refer to the skills required to seek out design solutions and to make design decisions that range from highly specialized technical judgments to broadly based considerations. Knowledge of how to exercise judgmental skills are mostly tacit (Vincenti, 1990:222).

Vincenti (1990:207) notes that some items of knowledge are clearly distinguishable and others are not, also that the divisions are not entirely exclusive, since some items of knowledge can embody the characteristics of more than one category. Also, they are probably not exhaustive – although the major categories are presumably complete, the subsections within most likely are not.

In addition to the categories of knowledge, Vincenti (1990:229) also identifies seven knowledge-generating activities which contribute to the categories of knowledge, i.e. activities from which engineers derive their knowledge. Vincenti (1990:10) examines the growth of knowledge over time and reflects on why and how the knowledge was obtained. The seven knowledge-generating activities are:

¹⁴ *Satisficing* is a term described by Vincenti (1990:220) as "not the very best solution, but one that was satisfactory"

- *Transfer from science*, a transfer of knowledge from theoretical science often entails reformulation or adaptation to make the knowledge useful to engineers. Although engineering design is an art, it is an art that makes use of knowledge from developed and developing science. This does not, however, mean that science is the sole or major source or that engineering can be regarded as applied science (Vincenti, 1990:229-230).
- *Invention* is a source of the operational principles and normal configurations that underlie normal design. Contriving such fundamental concepts is by definition an act of invention even if one comes upon them by chance. It is an elusive and creative enterprise that produces these fundamental concepts (Vincenti, 1990:230).
- *Theoretical engineering research* entails knowledge produced by engineers through theoretical activity, mostly in academic institutions and research laboratories. Theoretical research in engineering has much in common with theoretical research in science. Both are systematic and conceptually demanding and often mathematically complex. Differences are embedded in the goals, aims, priorities, attitudes, etc. of the research (Vincenti, 1990:230-231).
- *Experimental engineering research* is a major source of quantitative data and requires special test facilities, experimental techniques, measuring devices, etc. Since quantitative data of some kind is essential to design in any field, so also is the experimental research from which it stems. Experimental research provides more than design data as it also produces analytical concepts and ways of thinking (Vincenti, 1990:231-232).
- Day-to-day *design practice* not only makes use of engineering knowledge, it also contributes to it. Contributions to fundamental design concepts, theoretical tools and quantitative data are indirect, e.g. practice reveals problems and needs that demand research in order to generate such knowledge, while contributions to criteria and specifications, practical considerations, and design instrumentalities are more direct, e.g. a design criterion of general applicability (Vincenti, 1990:232-233).
- *Production* is another source of design knowledge and can, for example, reveal that a material is too thin and too large, which can lead to cracking, or it can reveal that a machine is too large, which limits the operating space on the floor. This kind of knowledge contributes to the category of practical considerations. Production experience can also contribute to, for example, the formulation of tables of

thickness of sheets suitable to use with rivets of varying sizes in different types of flush riveting (quantitative data) (Vincenti, 1990:233).

- *Direct trial* is related to testing. Engineers normally test the devices they design. Likewise, the consumers who buy these devices put them to use in everyday life. Both kinds of direct trial provide design knowledge. The engineer, for example, applies tests to establish whether the device is able to achieve its goals, does what it is meant to do, or complies with the technical specifications. If the device falls short in any of the tests, recommendations can be made to correct the shortcomings or offer suggestions for redesign. Similarly, customers can provide feedback about the everyday operation of these devices. Do the devices, for example, live up to their expectations and are these the results they envisaged when they bought the devices (Vincenti, 1990:233-234)?

Vincenti (1990:235) presents a summary in tabular format, to show which knowledge-generating activities contribute to the various categories of knowledge. Table 4 represents this summary.

Table 4 Vincenti's (1990:235) summary of knowledge categories and knowledge-generating activities

Activities Categories	Transfer from science	Invention	Theoretical engineering research	Experimental engineering research	Design practice	Production	Direct trial
Fundamental design concepts		X	X	X			X
Criteria and specifications			X	X	X		X
Theoretical tools	X		X	X			X
Quantitative data	X		X	X		X	X
Practical considerations					X	X	X
Design instrumentalities			X	X	X	X	X

The Xs in table 4 indicate the knowledge-generating activities that contribute to the relevant categories of knowledge. It should be noted that Vincenti (1990:235) indicates only the immediate contributions, e.g. theoretical research provides an immediate source of theoretical tools and indirect influences are omitted. Also, as pointed out earlier, an item of knowledge can belong to more than one category: a theoretical tool or an item of quantitative data, for example, can at the same time be part of a technical specification (Vincenti, 1990:234-235).

2.5.2 Ropohl's framework

In a philosophical effort to classify technological knowledge, Ropohl (1997:67-71) identifies five categories of technological knowledge applicable to an engineer. Ropohl (1997:67) derives his framework for engineering knowledge from what he refers to as “a systems theory of technics¹⁵”. The categories of knowledge he identifies are:

- *Technological laws* relate to theoretical knowledge engineers' need to solving design problems. Rather than natural laws, however, this knowledge “covers a kind of systematisation”, referred to by Ropohl (1997:68) as technological laws. A technological law is an adaptation of one or more natural laws with regard to the real technological process and is often not simply applied in technology, but used in an intuitive combination with other natural laws to provide certain background knowledge for establishing a technological law. It is frequently based upon an empirical generalization and not derived from a scientific theory: “technology is not interested in scientific truth, but in practical success, and when a technological law succeeds in practice, its epistemological justification will be left at that” (Ropohl, 1997:68).
- *Functional rules* serve as mere recipes of what to do to obtain a certain result under specific circumstances without being understood on a theoretical level. They are commonly found in a user's manual in the form of diagrams, charts, instructions, etc. Functional rules are therefore not only applicable to engineering practice, but also to the everyday use of do-it-yourself technical systems (Ropohl, 1997:68-69).
- *Structural rules* are based on laws originating from science, for example Ohm's law, as well as on rules originating from traditional and current experiences. They are applied when a user has to service, maintain or repair a system. They include, for example, the rules needed to reinforce a frame construction or the rules needed for dimensioning a ball bearing. The importance of structural rules is clear

¹⁵ Ropohl (1997:65) uses the word “technics”, following the German tradition, to denote the field of engineering work and its products.

when an engineer, for example, has to create an object that does not yet exist. He then has to conceive details, which cannot be observed before the object has been created (Ropohl, 1997:69).

- *Technical know-how* concerns both “explicit knowledge” as well as “implicit knowledge”. Explicit knowledge can be expressed in terms of psychophysical and sensory-motor coordination skills, such as riding a bike. These skills can be acquired through known methods. Implicit knowledge on the other hand, implies cognitive resources, such as images, experiences and intuitions, of which the mind is not necessarily consciously aware. These resources cannot be addressed intentionally since they are located in the subconscious mind. The mind, however, is able to refer to hidden knowledge in order to solve a problem without realizing it explicitly. Implicit knowledge is increased by the positive or negative results of professional practice. Gaining implicit knowledge is a time-consuming process, which can normally not be controlled in a systematic manner (Ropohl, 1997:69-70).
- *Socio-technological understanding* refers to the long-neglected interrelationship between technical objects, the natural environment and social practice. Every invention is also an intervention in nature and society. The understanding of this interrelationship will acknowledge that every technical object has to be optimized while considering the ecological and psychosocial context within which the artefact is located (Ropohl, 1997:70).

There seems to be a fair amount of overlap between the categories of knowledge described by Ropohl and Vincenti. Only the category of socio-technological understanding seems to be missing from Vincenti’s categorisation (De Vries, 2003:3). The comparison of overlapping categories of knowledge will be presented in section 2.5.5.

2.5.3 De Vries’s framework

More recently, De Vries (2003) explored the types of technological knowledge by means of the LOCOS¹⁶ case study. While Vincenti’s (1990) analysis of historical cases deals with one particular field of engineering (aeronautic engineering) only, and focuses on “an object” (an aeroplane), De Vries (2003) explores a different field of engineering (the design of integrated circuits) and focuses on a structure in a material (De Vries, 2003:6). De Vries’s (2003) framework was meant as a more systematic alternative for Vincenti’s (1990) empirical framework, because for the latter there is no indication of completeness.

¹⁶ LOCOS is the acronym for LOCAL Oxidation of Silicon, a technique used for making transistors and integrated circuits (IC’s) on silicon substrates (De Vries, 2003:5).

De Vries (2003) bases his classification of technological knowledge upon the “main steps” derived from a study of the LOCOS technology:

- *Functional nature knowledge* is associated with the (intentionality-bearing) function that a material or artefact can fulfil, and is related to the “functional nature” properties of the material (De Vries, 2003:13). Compton (2004:7) notes that this category brings together Ropohl’s (1997) functional rules in terms of knowing what to do to ensure function and his structural rules, i.e. knowing how and why things would need to come together. It can also be compared to Vincenti’s (1990) fundamental design concepts and practical considerations (De Vries, 2003:16).
- *Physical nature knowledge* refers to knowledge about the physical nature of the material, in other words the properties of the material. It can be expressed in propositions such as ‘impurities do not easily invade into silicon nitride at high temperatures’ (De Vries, 2003:13-14). Compton (2004:7) holds that this category incorporates science understanding, but only as it is operationalised. It therefore links to Ropohl’s (1997) technological laws and could be described as prescriptive, explicit device knowledge. It could also be compared to Vincenti’s (1990) theoretical tools (as far as knowledge of scientific laws is involved), and descriptive quantitative data (De Vries, 2003:16).
- *Means-ends knowledge* entails judging whether the properties of a material are suitable for a specific application (De Vries, 2003:14). This knowledge of the relationship between functional and physical nature knowledge is, according to Compton (2004:8), clearly linked to Vincenti’s (1990) evaluative nature knowledge as it provides knowledge to judge whether the material/device is fit for its intended function. It is also knowledge that can be explicitly stated, and De Vries (2003:16) relates it to Vincenti’s (1990) criteria, specifications and prescriptive quantitative data categories.
- *Action knowledge* is about what actions will lead to the desired result (De Vries, 2003:14). Compton (2004:8) notes that it can be described as tacit procedural knowledge which is evaluative in nature and equates it with Ropohl’s (1997) category of technical know-how. De Vries (2003:16) compares this category of knowledge to the theoretical tools (as far as reasoning and the use of mathematics is concerned), and design instrumentalities described by Vincenti (1990).

The above-mentioned categories of technological knowledge can be related to Vincenti’s (1990) categories, and are not meant to complement or to contradict them, but to offer an alternative. The advantage of this alternative is that it can form a bridge to the philosophical terminology that is often used (De Vries, 2003:17).

2.5.4 Bayazit's framework

Classifications for technological knowledge have also been proposed from the side of the design practitioners (Broens & De Vries, 2003:460). Bayazit (1993:123), writing about designers' knowledge, classifies it into two main groups: procedural and declarative knowledge.

- *Procedural knowledge* is concerned with descriptions and explanations of the process. It can be composed of reasoning to:
 - derive information about a design problem under analysis;
 - derive knowledge about the existing or available knowledge; and
 - generate hypotheses based on design domain knowledge and information, which can be assumptions, statements and facts (Bayazit, 1993:123).
- *Declarative knowledge* is composed of a group of different kinds of knowledge:
 - *Positive knowledge* enables people to derive a large number of descriptive statements from a single explanatory statement and constitutes an attempt to explain the accumulation of facts about the world (Bayazit, 1993:124).
 - *Concrete scientific knowledge* is substantive knowledge concerned with the description and explanation of the physical nature of products (Bayazit, 1993:125).
 - *Knowledge of design discourse* is defined by Bayazit (1993:125) as “a formation constituted by all that is said, written or thought in a determinate field ... A discourse is a formation that consists of all that is expressed, represented or meant around some objects”. Knowledge of design discourse comprises design practices, design studies, design theories, discursive rules and formations (Bayazit, 1993:125).

In addition to procedural and declarative knowledge, Bayazit (1993:123+126) identifies another two forms of knowledge, since procedural and declarative knowledge (only) “do not comprise the whole space of design knowledge ...” (Bayazit, 1993:123). Bayazit (1993:126) also identifies design normative knowledge and collaborative design knowledge.

- *Design normative knowledge* refers to preferences, values, tastes and attitudes of designers and consists of value-laden statements of philosophers, politicians, etc. on what ought to be. Some describe it as “what has been consensually agreed upon, the norms for a given time”; to others it means “what ought to be – what a good world is”. Normative knowledge varies from society to society (Bayazit, 1993:126).

- *Collaborative design knowledge* and individual design work are two different methodological approaches to design. The difference originates from the group structure and the distributed responsibilities of the work and work-flow. Bayazit (1993:123) suggests that we have to consider the participants (such as architects and engineers) of the design team as expert designers with different roles. Although individual design works can be considered more powerful than group design work from a creativity point of view, groups play a crucial role in the organisation theory because they influence and are influenced by organization structure, and because they affect their members' behaviour and compliance. At present collaborative design work is recognized as more powerful than the individual design work. There are several characteristics that make collaborative work, as opposed to individual work, more powerful. These characteristics include co-ordination between people, a cooperated goal shared by the participants, goal-directed behaviour, a shared responsibility, an organic learning process between the participants in the group, belonging to a social group, etc. (Bayazit, 1993:126-127).

The foregoing frameworks of technological knowledge are the work of authors from different fields. Although at first glance it may seem that these authors have taken different approaches, it is possible to identify relationships between the categories they classify (Broens & De Vries, 2003:460).

2.6 Summary

A review of the literature indicates that the term *knowledge* is not easily or well defined. In the field of epistemology most debates circle around the short description of knowledge as “justified true belief”. Most philosophers, however, seem to agree that this description is not accurate and some have tried to “repair” the definition by adding more conditions. This account of knowledge is also not suited to defining technological knowledge, since it does not do justice to all types of technological knowledge. Vincenti (1990:198) suggests that for epistemological discussion, the classification of engineering knowledge according to its nature, may be more fundamental than according to its purpose for production or design. The nature of engineering knowledge is described in terms of descriptive, prescriptive and tacit knowledge.

Although the South African curriculum recognises the importance of indigenous knowledge to the extent that it is specifically listed as an assessment standard in learning outcome three in the RNCS for technology, it is not the focus of this study. This study

does however, acknowledge that all knowledge is learnt and constructed in a socio-cultural context and that the culture of a learner's immediate milieu plays an important role in learning.

The link between science and technology is so strong that it is often mistakenly assumed that *technology is applied science*. Scholars of technology reject this view and insist that technology is a cognitive system consisting of a separate body of technological knowledge. Layton (1971:578; 1974:40-41), referring to the "symmetric" relationship between science and technology, notes that technology and science might influence each other on all levels. The epistemological distinction between scientific knowledge and engineering knowledge seems to be one of priority and degree rather than method (Vincenti, 1990:226-227).

Contemporary theories of learning have important implications for how we see knowledge and how it is learnt. Two current views of learning are addressed in this study. They are the symbol-processing (or computational) and situated approaches. Although the two approaches are contrasted as different ends of a spectrum, Bredo (1994:32-34) recommends a balance between the two, rather than the dominance of one or the other, or their total divorce.

Authors from different theoretical backgrounds have taken a very negative position toward the possibility of transfer of knowledge. Alexander and Murphy (1999:571) propose that a domain-specific perspective be adopted in regard to the problem of transfer. Dispositions toward transfer require a rich and cohesive body of domain knowledge, a well-honed strategic repertoire, as well as a personal investment in or identification with, an academic domain.

In order to form an idea of the content of technological knowledge, four frequently cited frameworks for technological knowledge are explored in this study. The authors of these frameworks provide different views on technological knowledge from different disciplines in the field:

- Vincenti (1990:208) lists six categories of engineering design knowledge which he derived from an analysis of aeronautical history cases. They are fundamental design concepts, criteria and specifications, theoretical tools, quantitative data, practical considerations and design instrumentalities.
- Ropohl (1997:67-71), in a philosophical effort to classify technological knowledge, identifies five categories of technological knowledge applicable to an engineer.

They are technological laws, functional rules, structural rules, technical know-how, and socio-technological understanding.

- De Vries's (2003:13-14) framework is derived from technological practice and development (the development of the LOCOS technology). The categories based upon the "main steps" in that development are functional nature knowledge, physical nature knowledge, means-ends knowledge and action knowledge.
- Bayazit (1993:123), writing about designers' knowledge, classifies designers' knowledge into two main groups: procedural and declarative knowledge. In addition to these Bayazit (1993:126) also identifies design normative knowledge and collaborative design knowledge.

Although it may seem that these authors have taken different approaches, it is possible to identify relationships between the categories they classify (Broens & De Vries, 2003:460).

In addition to categories of knowledge, Vincenti (1990:229) also identifies seven knowledge-generating activities which contribute to the categories of knowledge, i.e. activities from which engineers derive their knowledge. They are transfer from science, invention, theoretical engineering research, experimental engineering research, design practice, production, and direct trial. In addition, Vincenti (1990:235) presents a summary, in tabular format (see table 4), that shows which knowledge-generating activities contribute to different categories of knowledge. The conceptual framework in the next chapter will be derived from table 4.

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