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The technological knowledge used by technology education students in capability tasks

by

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Abstract

The inception of technology education as a learning area in the South African national curriculum has posed challenges different from those in the other learning areas. Technology education is, compared to subjects such as mathematics and science, still a fairly new subject both nationally and internationally. As a result technology education does not have a large research base or established subject philosophy. This can lead to problems in understanding the nature of technology and other pedagogical problems, such as the fragmentation of curricula in which content is simply parcelled in 'departments'.

One way through which technology can be conceptualized and understood is through *technology as knowledge* (epistemology). In the absence of an established subject philosophy for technology education, one can draw on frameworks from other disciplines in the field, such as engineering and design practice, for insights into technological knowledge. Educators, however, still need to determine the usefulness of these frameworks to technology education.

The purpose of this study therefore, is to investigate the usefulness of an epistemological framework chiefly derived from engineering to be able to describe the nature of technological knowledge, in an attempt to contribute towards the understanding of this relatively new learning area. The conceptual framework for this study was derived mainly from Vincenti's (1990) categories of knowledge and knowledge-generating activities based on his research into historical aeronautic engineering cases.

A combination of quantitative and qualitative research was used to provide insight into the categories of knowledge and knowledge-generating activities used by students at the University of Pretoria during capability tasks. This included an analysis of the questionnaire (quantitative data), which was administered to and completed by the students, as well as a content analysis (qualitative data) of the students' project portfolios.

Findings from this study suggest that the conceptual framework chiefly derived from and used by professional engineers is useful in technology education. The findings also suggest that both the categories of technological knowledge and the knowledge-generating activities apply to all the content areas, i.e. structures, systems and control, and processing, in technology education.

The study recommends that researchers and educators deepen their understanding of the nature of technological knowledge by considering the categories of technological knowledge and the knowledge-generating activities presented in the conceptual framework. In order to “operationalise” the conceptual framework, educators must consciously attempt to include items of knowledge from each category of knowledge when conceptualising capability tasks for their learning programmes. The framework can then be used as a matrix to evaluate their learning programmes to ensure that all knowledge items (categories and activities) are addressed in each capability task in the technology learning programmes.

Keywords:
categories of technological knowledge
collaborative and cooperative learning
contemporary views of learning
knowledge
knowledge-generating activities
project- and problem-based learning
science and technology
technological knowledge
technology
technology education
transfer of knowledge

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Prelude to the enquiry — Chapter 1

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 education[1], 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 *tekhno*, 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 unit[2] 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 credit[3] subject presented in four periods of fifty minutes each over a period of three years[4], 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 time[5]. 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 phase[6] 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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Literature review Chapter 2

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 ground[8]". 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 propositional[9], descriptive knowledge[10] than on knowledge with a normative[11] 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 engineering[12] 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 declarative[13] 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 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 technics[15]". 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 LOCOS[16] 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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Research design and methodology Chapter 3

3.1 Overview of this chapter

This chapter presents the strategy of inquiry as well as the guiding philosophical assumption. The conceptual framework used in this study is presented along with a motivation for using it. In addition, it's limitations are discussed and insight is provided into the target population and the contextual background. Subsequently the instrument, reliability and validity, as well as the sampling, are explicated. The chapter ends with a description of the data collection and analysis.

3.2 Strategy of inquiry

This study engages a combination of quantitative and qualitative research. The rationale for using this design is that the quantitative and qualitative data are needed for different purposes in addressing the research questions. The quantitative data is required to answer the research questions both in terms of the frequencies of knowledge in which students engaged, and the correlation of the knowledge engagement by the students between the two content areas. The qualitative data, on the other hand, is required to inform *what* knowledge the students used and *how* they used it to complete the capability tasks. The added advantage of this design is that the qualitative data could also be used to validate the student responses to the questionnaire. Figure 1 illustrates the strategy of inquiry.

Figure 1: Strategy of inquiry (Creswell, 2003:213)

QUAN Data collection	→	QUAN Data analysis	→	qual Data collection	→	qual Data analysis	→	Interpretation of entire analysis

Figure 1 shows that the quantitative data (QUAN) took precedence, since it represents a major aspect of the data collection and because most of the research questions of this study could be answered during this phase of the study. The qualitative data (qual), on the other hand, answered certain research questions, but was also used to complement the quantitative data by providing examples from the students' project portfolios, i.e. context.

The quantitative data collection and analysis in the first sequence was followed by the second sequence, the qualitative data collection and analysis. These studies (QUAN and qual) will be presented separately in two phases: Chapter 4 explores the data and results of the quantitative phase while chapter 5 investigates the data and results of the qualitative phase of this study. The research questions are answered in the final chapter (6) through an interpretation of the entire analysis.

3.3 Philosophical assumption

The philosophical assumption that governs this study is that of pragmatism. According to Johnson and Onwuegbuzie (2004:18), the philosophical implications are *inter alia* that pragmatism:

- attempts to find a middle ground between philosophical dogmatism and scepticism, and to find a workable solution (sometimes including outright rejection) to many longstanding philosophical dualisms about which agreement has not been historically forthcoming;
- rejects traditional dualisms, e.g. rationalism versus empiricism, realism versus antirealism, facts versus values, subjectivism versus objectivism, and generally prefers more moderate and commonsense versions of philosophical dualism based on how well they work in solving problems;
- prefers action to philosophizing (pragmatism is, in a sense, an anti-philosophy);
- views knowledge as both constructed and based on the reality of the world we experience and in which we live;
- replaces the historically popular epistemic distinction between subject and external object with the naturalistic and process-orientated organism-environment transaction;
- endorses practical theory (theory that informs effective practice);
- acknowledges fallibility (current beliefs and research conclusions are rarely, if ever, viewed as perfect, certain, or absolute);
- endorses eclecticism and pluralism, e.g. different, even conflicting, theories and perspectives can be useful; observation, experience, and experiments are all useful ways to gain an understanding of people and the world; and
- offers the “pragmatic method” for solving traditional philosophical dualism and for making methodological choices.

These philosophical implications are in keeping with Creswell’s (2003:12) pragmatic knowledge claims, i.e. pragmatism opens the doors to multiple methods, different worldviews and different assumptions.

3.4 Conceptual framework

The conceptual framework of this study was derived chiefly from Vincenti's (1990:208) categories of technological knowledge. In keeping with Broens and De Vries' (2003:463-464) framework, Vincenti's (1990:208) categories of technological knowledge will be extended by adding Ropohl's (1997:70) category of socio-technological understanding and Bayazit's collaborative design knowledge (1993:123), which both seem to be missing from Vincenti's (1990:208) framework. This amended conceptual framework will give an indication of *what* knowledge the students engage during the two capability tasks. To explore *how* the students acquired such knowledge, Vincenti's (1990:229) knowledge-generating activities will be added to the framework, as shown in table 5.

Table 5: Conceptual framework* adapted from Broens and De Vries (2003:464)

Category of technological knowledge
Fundamental design concepts
Criteria and specifications
Theoretical tools
Quantitative data
Practical considerations
Design instrumentalities
Socio-technological understanding
Collaborative design knowledge
Knowledge-generating activities
Transfer from science
Invention
Theoretical engineering research
Experimental engineering research
Design practice
Production
Direct trial

* Also refer to table 4 (in chapter 2) that shows which knowledge-generating activities contribute to various categories of knowledge (as identified by Vincenti (1990:235)).

The framework shown in table 5 is complex and it should be noted that Vincenti (1990) did not intend his framework to be used for the purpose of this study. Some limitations of this framework therefore need to be addressed.

3.4.1 Motivation for using the conceptual framework

As noted earlier, Vincenti (1990) did not intend his framework to be used for the purpose of this study. The motivation for choosing Vincenti's (1990) framework is:

- it seems to be the most complete one (Broens & De Vries, 2003:461); and
- the students who participated in this study had to follow the design process prescribed by the DoE (2002), and all Vincenti's (1990) categories of knowledge refer to knowledge as related phases in the design process (Broens & De Vries, 2003:469). It therefore seemed appropriate to use Vincenti's (1990) framework as the conceptual framework for this study.

3.4.2 Limitations of the conceptual framework

Vincenti (1990:208,235) admits that neither the categories nor the activities are mutually exclusive and an item of knowledge can belong to more than one category. It is also possible that more than one activity, e.g. research and invention, can take place to generate an item of knowledge. In addition, Vincenti (1990:208) acknowledges that the categories of knowledge are not entirely exhaustive: "although the major categories are presumably complete, the subspecies within them most likely are not".

As a result, Broens and De Vries (2003:465) point out that Vincenti's (1990) framework does not follow the two basic rules of classification, viz. that classification should be mutually exclusive and complete. Both rules are, according to them (Broens & De Vries, 2003:465) more or less broken, but they regard the 'mutually exclusive' rule as the weakest link in Vincenti's (1990) classification scheme. This issue will be revisited in chapter 5 where some items of knowledge will be "duplicated" to serve as examples of different categories of knowledge.

3.4.3 The need to extend the meaning of theoretical engineering research as a knowledge-generating activity

Vincenti (1990:7, 207) declares that his historical cases focused on knowledge for *normal design*, acknowledging that his analyses are correspondingly limited. Normal design is "the design involved in normal technology" (Vincenti, 1990:7). An engineer engaging in normal design knows from the outset how the device in question works and what the customary features are. If a device were to be designed according to these known facts, there is a good likelihood that it would accomplish the desired task. If changes were made, they would be incremental instead of essential; normal design is evolutionary rather than revolutionary (Vincenti, 1990:7-8).

Linked to the previous point is what Vincenti (1990:206-207) calls *stored-up* knowledge. Vincenti (1990:206) postulates that the solution to all design problems depends on knowledge. This knowledge, however, need not be new, because once understanding and information are established, solutions can be devised without the generation of a great deal of additional knowledge. What is needed "is available in textbooks or manuals and can be looked up, taught to engineering students, or learned on the job" (Vincenti, 1990:206). The problems arising from historical cases, where attention is limited to normal design, are for the most part 'old hat' and are solved "mainly on the basis of stored-up engineering knowledge" (Vincenti, 1990:206).

Also, it is important to note that although Vincenti (1990:207) acknowledges the "widespread utility" of stored-up knowledge, the compelling question of "how the body of knowledge grows" over time was the main drive behind his endeavour. This drive was clearly reflected in the knowledge-generating activities in regard to which reference to stored-up knowledge was omitted.

The foregoing provides some challenges in terms of this study. As opposed to the output of established practising engineers, on whom Vincenti (1990) based his study, the participants of this study were third year design and technology education students. Most of these students had no previous engagement with the content of systems and control and structures. It is important to note that although technology is a compulsory learning area in South African schools from grade R to nine, these students were already in the Further Education and Training (FET) phase when technology was introduced in the General Education and Training (GET) phase and were therefore not exposed to it at school. This means that apart from a small number of students repeating the modules, the students had no or very little prior knowledge regarding the content of systems and control and structures. The following should therefore be considered:

- although in Vincenti's (1990) study, most day-to-day engineering design problems, in terms of normal design, were solved mainly on the basis of stored-up engineering knowledge, the stored-up knowledge pertaining to systems and control and structures required by the curriculum was still new to or undiscovered by the students. As novices, they still had to learn what is considered to be "old hat" by others in the field. It can, for example, be assumed that they did not know from the outset what the solution to their problem looked like or how it worked – this was established only after the investigation and design phases of the design process.

- the deficiency in the students' stored-up knowledge complicates the application of the knowledge-generating activities identified by Vincenti (1990), in their present form, for the analysis in this study. While these knowledge-generating activities were primarily contrived to describe and understand how this body of stored-up knowledge grows over time, the knowledge-generating activities of the participants in this study did not expand this existing body of knowledge, but was mostly limited to the acquisition of stored-up knowledge.

Considering that the purpose of this study is not to inquire how the body of engineering knowledge grows, but to examine the extent to which such an engineering framework can be used in technology education, the need to adapt and extend the meaning of Vincenti's (1990) concepts to accommodate the needs and scope of this study is apparent.
The concept that needs to be most pressingly adapted and extended is theoretical engineering research as a knowledge-generating activity. Vincenti (1990:230) takes "theoretical" to be synonymous with "mathematical". Theoretical research, for example, includes the working out of *new* mathematical tools to design a particular device.

This description of theoretical engineering research based on the explanation above, is not suitable for the purpose of this study, and therefore needs to be modified. For the purpose of this study, theoretical engineering research will be extended to include activities relating to the acquisition of stored-up knowledge, e.g. a literature study, and a search for information in textbooks and class notes.

3.5 Target population

The target comprised third year undergraduate students at the University of Pretoria, who selected technology as an elective subject as part of their four year Bachelor of Education (BEd) degree course. The reasons for selecting these teacher education students were discussed in chapter 1 (see section 1.6). It is, however, acknowledged that there are several advantages to using "experts" in the field, as opposed to novices. Glaser (1999:91) claims, *inter alia*, that experts' highly integrated structures of knowledge lie behind many salient features of their performance. Glaser (1999:91-92) postulates the following set of generalizations about the nature of expertise:

- *experts' proficiency is very specific* and the precision of experts' performance derives from the specialized knowledge that drives their reasoning (Glaser, 1999:91);
- *experts perceive large, meaningful patterns*, which guide experts' thinking in everyday working activities. Pattern recognition, for example, occurs so rapidly that

it appears to take on the character of intuition. In contrast, the patterns that novices recognize are smaller, less articulated, more literal and surface-oriented, and far less related to abstracted principles (Glaser, 1999:91);

- *experts' problem solving entails the selective search of memory or use of general problem-solving tactics*. Although novices display a good deal of search and processing of a general nature, experts' fast-access pattern recognition and representational capability facilitate approaches to problems that reduce the roles of these processes (Glaser, 1999:91);
- *experts' knowledge is highly procedural and goal-oriented*. Experts and novices may be equally competent at recalling small specific items of domain-related information, but high-knowledge individuals far more readily relate these items of information in cause-and-effect sequences that link the goals and sub-goals needed for problem solution (Glaser, 1999:92);
- *experts' knowledge enables them to use self-regulatory processes with great skill* and they monitor their own problem-solving activities proficiently. They have the ability to step back and observe their solution processes and the outcomes of their performances. Although these self-regulatory processes sometimes slow experts down as they initially encode a difficult problem, compared to novices whose reliance on surface features allows them speed initially, they (the experts) are faster problem solvers overall (Glaser, 1999:92); and
- *experts' proficiency can be routinized or adaptive*. Experts' attained proficiencies can be context-bound which result in their performances becoming routinized as well as efficient and accurate (Glaser, 1999:92).

Despite the above-mentioned advantages of using experts, the question of who qualifies as an "expert" in technology education, as discussed in chapter 1 (see section 1.6), remains problematic. The selected target therefore seems to be appropriate for this study, as the students were trained in technology education according to the most recent policy documents of the South African DoE and it is assumed that they are able to design and implement learning programmes successfully.

3.6 Contextual background

The operational approach to teaching technology in South Africa is project-based with an emphasis on learner-centredness. These projects consist of coherent units of work spread over an extended period of time, i.e. capability tasks. Within these longer project time frames, opportunities for shorter and more structured tasks, such as case studies and resource tasks, should be created (DoE, 2003:26).

For the purpose of this study, it was decided to make use of the capability task as a form of assessment. The rationale for this decision is that the procedures and elements of the design process that the students follow during a capability task, are similar to those described by Vincenti (1990), who structured his inquiry around the goal of design:

> *For engineers, in contrast to scientists, knowledge is not an end in itself or the central objective of their profession. Rather, it is … a means to a utilitarian end – actually, several ends* (Vincenti, 1990:6).

As part of the students' training, they have to conduct one capability task (project) per content area. These capability tasks are performed during non-contact time[17] (after hours, in their own time) in a constructivist manner, since each student's identified need and artefact, and therefore solution/s to the problem/s, is unique. Each student would therefore require different knowledge in different phases of the design process. This can, due to a time constraint, only be realised if the students work on their capability tasks in a constructivist manner during non-contact time. Contact time, i.e. class-time, is used only for lecturing, resource and research tasks and case studies.

This study focused on two capability tasks from two different content areas taken by the third year design and technology education students. The students were free to either work independently or to work in pairs for both the capability tasks. In the latter case they were allowed to choose their own partner, who usually turned out to be a friend[18]. The modules involved are JOT 353 and JOT 354.

3.6.1 Module JOT 353

JOT 353 is a seven-week (50 minutes x 4 periods per week) module in the third term that deals with the content area of systems and control in leaning outcome 2. In this module students had to design and make an educational toy. The outcomes of this capability task were aligned with the assessment standards stated for grade 9 in the RNCS for technology. The learner needs to:

i. *demonstrate knowledge and understanding of interacting mechanical systems and sub-systems by practical analysis and represents them using systems diagrams:*

[17] 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 had been part of their formal first and second year training.

[18] It is acknowledged that this method of composing groups is not ideal in terms of collaborative work, but since the students were not experts in design or technology, and they had more or less similar knowledge in terms of technology, it was decided to allow them to select their own team members to enhance their general motivation.

- *gear systems;*
- *belt drive or pulley systems with more than one stage;*
- *mechanical control mechanisms (e.g. ratchet and pawl, cleats);*
- *pneumatic or hydraulic systems that use restrictors;*
- *one-way valves; and*
- *systems where mechanical, electrical, or pneumatic or hydraulic systems are combined.*

ii. *demonstrate knowledge and understanding of how simple electronic circuits and devices are used to make an output respond to an input signal (e.g. resistors, light-emitting diodes, transistors, push or magnetic switches, thermistors, light-dependent resistors)* (DoE, 2002:49).

The toy was required to comprise 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 present the educational toy, as well as a comprehensive project portfolio documenting the design process followed to design and make the educational toy. Although both the educational toy and project portfolio were used to assess the students' capability task, only the portfolios were used for the content analysis in this study because the study investigates technology as knowledge (epistemology), and does not venture into technology as object (ontology) (see section 1.3). Figures 2 - 4 are examples of students' educational toys.

Figure 2: Educational toy 1

Figure 3: Educational toy 2

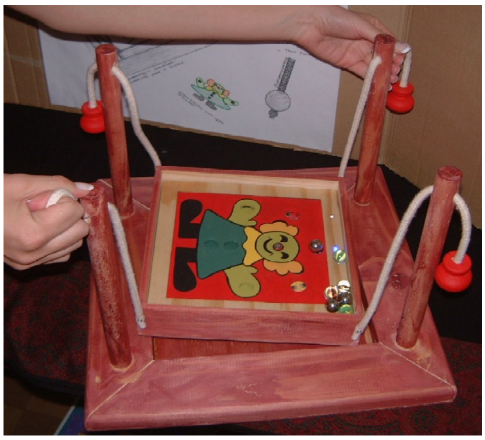

Figure 4: Educational toy 3

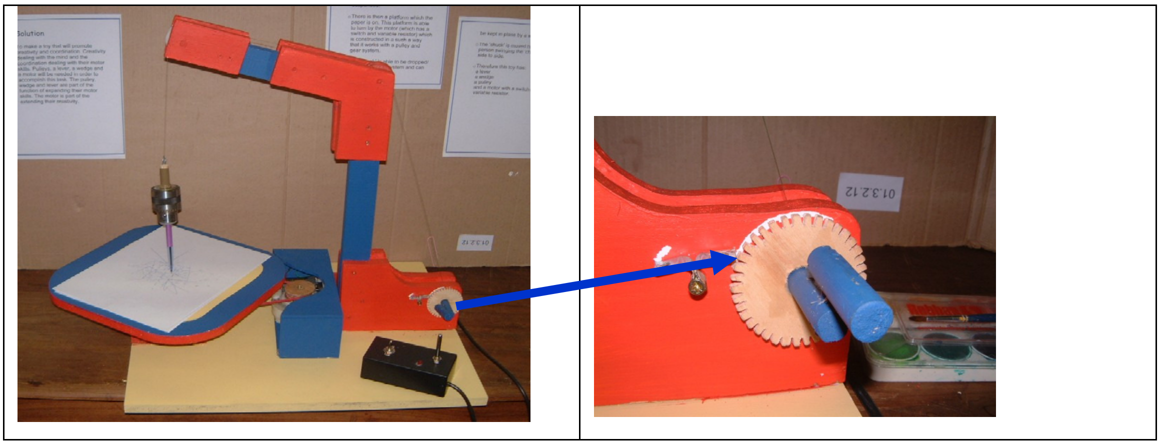

Figure 2 shows a toy that requires the player to match shapes and colours. A motor turns a spindle if the button is pressed. If the button is released the spindle will stop on one of four colours. The player then needs to insert the correct colour and block shape into the corresponding space on the toy. A light emitting diode (LED) will switch on, indicating that all three shapes have been correctly placed. The educational purpose of this toy is that it will allow the learners to practice colour and shape recognition.

In the toy depicted in figure 3, the player uses four cords and “pulleys” to manipulate a free-hanging platform (inclined plane) in order to manoeuvre three metal balls into three holes. An LED will indicate when the player has successfully manipulated the balls into the holes. The educational value of this game is that it improves hand /eye coordination.

Figure 4 depicts a drawing toy. A motor turns a platform on which a sheet of paper is placed. The player can swing the pen attached to a pendulum, which results in a drawing. The enlarged view of one section of the toy shows how a wooden ratchet and pawl are used to set the height of the pen. Provision was made for motor speed control and the purpose of this toy is to allow an element of fun in a drawing activity.

3.6.2 Module JOT 354

JOT 354 was another seven-week (50 minutes x 4 periods per week) module offered during the fourth term. This module dealt with the content area of structures in learning outcome 2 and here the capability task required the students to design and make a structural artefact based on and selected from their individual learning programmes drawn up in JMC 300, methodology of technology. As part of their JMC 300 module, all students had to draw up a complete learning programme for a phase[19] of their choice. These learning programmes had to comply with all the requirements stated in the policy documents, such as:

- three capability tasks (contextualised projects) need to be conceptualised and stated for each grade in the phase of their choice. These projects must address the assessment standards stated by the DoE for that grade;
- all three content areas in learning outcome 2 (structures, systems and control, and processing) need to be addressed for each grade each year; and
- all three aspects in learning outcome 3 (indigenous technology and culture, impacts of technology, and biases created by technology) need to be addressed for each grade each year.

In the module JOT 354, students were free to choose any project from any grade specified in their learning programme, as conceptualised in JMC 300, which related to the content area of structures. They then had to design and make the artefact as a capability task. They were therefore both the "teacher" as well as the "student" during this last module of their design and technology training. The students had to include a copy of their learning programmes (designed for JMC 300) that clearly indicated the grade and context of the capability task. This was needed in order to establish whether the project would indeed achieve the assessment standards for the selected grade. At the end of the module both the structural artefact as well the project portfolio were assessed for a mark. As pointed out in the previous section, only the portfolios were used for the content analysis in this study.

Figures 5 - 8 are examples of the students' structural artefacts.

[19] The RNCS are 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).

Figure 5: Structure 1

Figure 6: Structure 2

Figure 7: Structure 3

Figure 8: Structure 4

Figure 5 is a photograph of a compact disc container (CD box), which was conceptualised to address the assessment standards of structures for grade 6, i.e. the learner needs to:

> *demonstrate knowledge and understanding of materials suitable for supporting loads (e.g. stiffness, strength), how structures can be made stable, and how they can be reinforced (e.g. using appropriate cross-sections, cross-braces, triangular webs, folding)* (DoE, 2003:27).

The CD box was made from cold pressed paper (a form of cardboard) and strengthened by means of triangular corrugations. It was designed to store 12 compact discs in the context of storage (containerisation).

Figure 6 depicts a birdcage, which was conceptualised to address the assessment standards of structures for grade 7, i.e. the learner needs to:

demonstrate knowledge and understanding of structures in terms of:

- *specific properties and use of materials (e.g. water resistance, thermal insulation, fire resistance);*
- *stability (e.g. base size, centre of gravity);*
- *strengthening (e.g. corrugation, laminating, reinforcing); and*
- *joining techniques* (DoE, 2003:46).

The birdcage was made mostly from dowel sticks and pieces of recycled wood. The focus of this capability task was on joining techniques and the specific properties and use of wood, in particular, how to make it water resistant.

Figure 7 depicts a Christmas package, which was conceptualised to address the assessment standards of structures for grade 4, i.e. the learner needs to:

> *demonstrate knowledge and understanding of how to strengthen the structure of products by folding, tubing, and using triangular webs or strong joints* (DoE, 2003:26).

This structure was made by means of folding, tubing, and strong joints in the context of packaging (containerisation), since the purpose of this Christmas package was to contain something such as sweets or a small toy. It is possible to insert something (and take it out again), by means of a triangle that is able to "swing" open.

Figure 8 is a photograph of a table made mostly from plaster of Paris, which was conceptualised to address the assessment standards of structures for grade 7, i.e. the learner needs to:

demonstrates knowledge and understanding of structures in terms of:

- *specific properties and use of materials (e.g. water resistance, thermal insulation, fire resistance);*
- *stability (e.g. base size, centre of gravity);*
- *strengthening (e.g. corrugation, laminating, reinforcing); and*
- *joining techniques* (DoE, 2003:46).

Since this table was made from plaster of Paris and was designed for use in a garden as a focal point for pot plants, special attention was paid to water resistance (i.e. specific properties and use of materials). Reinforcing was also important, since the table had to carry the weight of the pot plants and plaster of Paris by itself, would not have been strong enough to carry the load.

3.7 Sampling

3.7.1 Quantitative phase

The sample was a non-random, or non-probability convenient sample (Cohen, Manion, & Morrison, 2001:92-103; Creswell, 2005:146-149; Neuendorf, 2002:87-88). The sample was non-random because the whole target was selected due to the small number of students available in the target population. The availability and willingness of the third year students at the University of Pretoria to participate, contributed towards the convenience of the study.

The sample consisted of two groups of students: the first group of 22 students was part of the JOT 353 (systems and control) module and the second group of 21 students was part of the JOT 354 (structures) module. Both groups were heterogeneous in terms of language, gender and culture, and ranged in age from 20-23.

Most of the students were present in both modules. Students who were repeating either or both of the modules accounted for the slight difference in student numbers between the two modules. The same students did not, however, necessarily repeat both modules. Five (out of twenty two) students repeated the JOT 353 module and six (out of twenty one) students repeated the JOT 354 module. Only two of these students repeated both modules and were therefore present in both modules. This means that three students from JOT 353 did not do JOT 354 while four "new" repeater students joined the JOT 354 module. This could have resulted in *experimental mortality*, a common threat to internal validity, pointed out by Neuman (2006:260-264), implying that it is unknown whether the results might have been different if the students had remained the same. The fact that the sample was not identical in both the modules is therefore a limitation of this study.

3.7.2 Qualitative phase

The sample was a non-probability, purposive or judgemental sample. It was appropriate to use purposive sampling since distinctive cases that were especially informative could be selected (Neuman, 2006:222). In this study, five of the best[20] project portfolios were used for analysis, since it was assumed that these portfolios would provide the most

[20] The best portfolios were those portfolios that scored the highest marks when they were assessed at the end of each module.

comprehensive documentation and as a result, richness in data. Three portfolios from the educational toy capability task and two portfolios from the structures capability task were used. The criterion used to determine the sample size was based on the principle of redundancy of information, which suggests that sampling should be terminated when no new information is forthcoming from new units (Lincoln & Guba, 1985:202), i.e. *data saturation* (Ary, Jacobs, & Razavieh, 2002:430).

3.8 Instruments, reliability[21] and validity[22]

3.8.1 Quantitative phase

A questionnaire (Appendix A) was used to collect data for the quantitative phase of this study and questions were derived from the categories of knowledge and knowledge-generating activities listed in the conceptual framework. The questionnaire consisted of two sections, one dealt with the categories of technological knowledge while the other covered the knowledge-generating activities. Both rating scale and open-ended questions were included in the questionnaire.

Rating scale questions were included in both sections of the questionnaire and students had to indicate the extent to which they made use of the various categories of knowledge and knowledge-generating activities, by selecting from the following options:

- Not at all
- To a limited extent
- To a fairly large extent
- Extensively

Open-ended questions were included in the knowledge-generating activities section of the questionnaire and required students to elaborate on their rating scale choices by giving examples of the knowledge they used. The reason for including open-ended questions only in the knowledge-generating activities section is that it was assumed that examples of the categories of knowledge could be identified more easily in the portfolio than examples of knowledge-generating activities.

[21] The reliability of a measuring instrument is the degree of consistency with which it measures whatever it is measuring (Ary et al., 2002:249). Reliability is essentially a synonym for consistency and replicability over time, over instruments and over groups of respondents (Cohen et al., 2001:117).
[22] Historically, validity was defined as the extent to which an instrument measured what it claimed to measure. The focus of recent views of validity is not on the instrument itself but on the interpretation and meaning of the scores derived from the instrument (Ary et al., 2002:242).

During the quantitative phase of the study, the following standards of rigour were addressed:

- Reliability
- Internal validity
- External validity
- Objectivity

3.8.1.1 Reliability (consistency)

In order to enhance the reliability, the questionnaire was piloted at the end of the second term. The module (JOT 310) involved, focused on electrical systems and was the first part of the systems and control module (JOT 353). It was found that the questionnaire was too complex, since some of the students did not understand the questions/terminology. The questionnaire was then simplified by stating the questions more simply and by providing short descriptions from Vincenti's (1990) book to explain the concepts.

The revised questionnaire was then re-tested on five students who were initially involved in the pilot in an informal interview-like situation. These students found the revised questionnaire easier to complete. By asking probing questions not included in the questionnaire, I tested their understanding of the questions and concepts. From their answers it seemed that they understood the questions and terminology. This understanding enhanced the reliability of the results.

3.8.1.2 Internal validity (truth value)

Truthfulness was established by means of content validity and was achieved by deriving the questions for the questionnaire directly from all the categories of knowledge and knowledge-generating activities listed in the conceptual framework. A technology education specialist[23] verified that the questionnaire items were representative of all the categories of knowledge and knowledge-generating activities.

Validity was further enhanced by the qualitative phase of this study where examples from the students' project portfolios substantiated their responses to the questionnaire in terms of the categories of knowledge and knowledge-generating activities used during the capability tasks.

[23] Technology education specialist refers to the other lecturer who was co-responsible for the development of the design and technology education curriculum at the University of Pretoria as described in section 1.6.

3.8.1.3 External validity (generalizability)

Vincenti (1990:7, 207) derived his framework from knowledge for normal, everyday design and it can be related to phases in the design process prescribed by the DoE (2002) (as discussed in section 3.4.1). Since the questionnaire was derived from Vincenti's (1990) framework, the data it generates can be generalized to other teacher education institutions, as well as to schools, which also follow the design process prescribed by the DoE (2002).

3.8.1.4 Objectivity (neutrality)

Neutrality is the extent to which the research is free of bias in the procedures and the interpretation of results (Ary et al., 2002:456). This was achieved by making use of rating scale questions and by merely counting the responses to determine the frequencies of engagements. The analysis of the open-ended questions was peer reviewed by a second technology education lecturer at the University of Pretoria to enhance objectivity.

3.8.2 Qualitative phase

During the qualitative phase of this study a content analysis was performed on the students' project portfolios for both the educational toy and the structural artefact. The project portfolios contained comprehensive documentation of the design process that the students followed in order to design and make their artefacts. All the students had to follow the design process prescribed by the policy document (DoE, 2002) and document their progress, ideas, findings, etc. accordingly. The content analysis entailed a search for evidence of the knowledge-generating activities contributing to each of the categories of technological knowledge as presented in the conceptual framework. The examples from the portfolios served not only as evidence to validate the student responses to the quantitative phase of this study, but they also informed (gave context to) the quantitative data by elaborating on *what* knowledge the students used and *how* they used it to complete the capability tasks.

During the qualitative phase of the study, the following standards of rigour were addressed:

- Dependability
- Credibility
- Transferability
- Confirmability

3.8.2.1 Dependability (reliability)

The dependability of the qualitative study was enhanced by means of inter-rater reliability which was achieved by asking a second technology education lecturer at the University of Pretoria to independently classify a sample of ten examples which had been randomly selected from a list of student portfolio examples used in this study. The second lecturer classified the examples into the categories of knowledge and knowledge-generating activities, using the same conceptual framework that guided this study. The consistency of the agreement between the two raters was determined by using the following formula (Jackson, 2006:61):

$$\text{Inter-rater reliability} = \frac{\text{Number of agreements}}{\text{Number of possible agreements}} \text{ X } 100$$

$$= \frac{8}{10} \text{ X } 100$$

$$= 80\%$$

A review of the second lecturer's classification revealed that the small disagreement noted above (20%) could be attributed to the fact that in Vincenti's (1990) framework, the categories of knowledge and knowledge-generating activities are not mutually exclusive. Two examples (items of knowledge), which could have belonged to more than one category/activity, were classified in the "other" category/activity.

3.8.2.2 Credibility (internal validity)

The credibility of the qualitative phase was enhanced through structural corroboration[24], which was achieved by using different methods (methods triangulation). Although the qualitative data, in this study, is used to extend/inform the quantitative data, the design has the added advantage that one set of data, i.e. qualitative, can be used to confirm the other set of data, i.e. quantitative. Ary et al. (2002:452) note that when these different procedures or different data sources are in agreement, there is corroboration. For example, an abundance of examples in the students' project portfolios of a specific item of knowledge can be used to confirm a high frequency response by the students to that item of knowledge in the questionnaire.

[24] Structural corroboration is a means through which multiple types of data are related to each other to support or contradict the interpretation and evaluation of a state of affairs (Eisner, 1998:110).

3.8.2.3 Transferability (external validity)

The transferability of a set of findings to another context depends on the similarity or "goodness of fit" between the context of the study and other contexts (Ary et al., 2002:454). This was addressed by using the design process as prescribed by the policy document of technology for schools (DoE, 2003) during the capability tasks, i.e. using the same assessment standards. In addition, all the capability task projects were contrived using the assessment standards in learning outcome 2 of the policy document. The findings of this study could therefore be transferred and applied to other teacher education institutions, as well as to schools.

3.8.2.4 Confirmability (objectivity)

Ary et al. (2002:456) point out that since it may be impossible (for qualitative researchers) to achieve the levels of objectivity that quantitative studies strive for, qualitative researchers are concerned with whether the data they collect and the conclusions they draw can be confirmed by others investigating the same situation. Thus in qualitative studies, the focus shifts from the neutrality of the researcher to the confirmability of the data and interpretations (Ary et al., 2002:456). In this study the confirmability was enhanced by the examples provided by Vincenti (1990) for each of the categories of knowledge and knowledge-generating activities. Vincenti's examples (1990) served as a useful indication of the items of knowledge for which to search in the students' portfolios, which limited the possibility of bias in the interpretation of the results.

3.9 Procedures of data collection and analysis

3.9.1 Quantitative phase

All the JOT 353 and JOT 354 students had to complete a questionnaire at the end of the module. Once the questionnaires had been collected student responses to each category of technological knowledge and knowledge-generating activity of the rating scaled questions, were counted to determine the frequency of categories and activities used by the students when they designed and made an artefact. The results were electronically captured and stored in *Microsoft Excel™.*

The results were represented in the form of clustered column graphs to show the number of student responses for each scale in percentages. In addition, a comparison was conducted to determine the extent to which the categories technological knowledge and knowledge-generating activities between the two content areas were related. The Pearson product moment correlation coefficient (*r*) was used to determine:

- the relationship, if any, between the categories of technological knowledge used in two different content areas in technology education; and
- the relationship, if any, between the knowledge-generating activities drawn upon in two different content areas in technology education.

Microsoft Excel™ was used to calculate the Pearson product moment correlation coefficient, since it is faster and easier than doing it manually with the help of a calculator. It also reduces the risk of making mistakes.

The answers to the open-ended questions were scrutinized to search for evidence to substantiate students' answers to the rating scale questions. Examples of students' answers were presented after a presentation and discussion of the frequency of each knowledge-generating activity.

3.9.2 Qualitative phase

A content analysis of the students' project portfolios for both the educational toy and the structural artefacts was performed to search for evidence of the knowledge-generating activities contributing to each of the categories of technological knowledge presented in the conceptual framework by using the categories of knowledge and knowledge-generating activities listed in the conceptual framework. The examples from these portfolios served not only as evidence to validate student responses to the quantitative phase (questionnaire), but they also informed (gave context to) the quantitative data.

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Data and results of the quantitative phase Chapter 4

4.1 Overview of the chapter

This chapter presents the data and results of the quantitative phase of this study, which entailed the use of a questionnaire (Appendix A). The questions in the questionnaire were derived directly from the categories of knowledge and knowledge-generating activities listed in the conceptual framework discussed in section 3.4.

The results of the student responses to questions pertaining to the categories of technological knowledge are presented first, by means of both a table and a graph. A more detailed description and comparison between the two content areas of each category of technological knowledge are then provided.

This will be followed by a representation in tabular and graph form of the results of the student responses to the questions pertaining to the knowledge-generating activities. A more detailed description and comparison between the two content areas of each knowledge-generating activity will then be provided. This section will also offer examples of student responses to the open-ended questions related to the knowledge-generating activities.

4.2 Categories of technological knowledge

The first section of the questionnaire consisted of rating scale questions that required students to indicate the extent to which they made use of the categories of technological knowledge to design and make an artefact. It should be noted that although acceptable research methods and procedures were followed to enhance the reliability and validity of the questionnaire, the students' ability to make such a sophisticated estimation of their knowledge remain problematic and is therefore acknowledged as a limitation of this phase of this study.

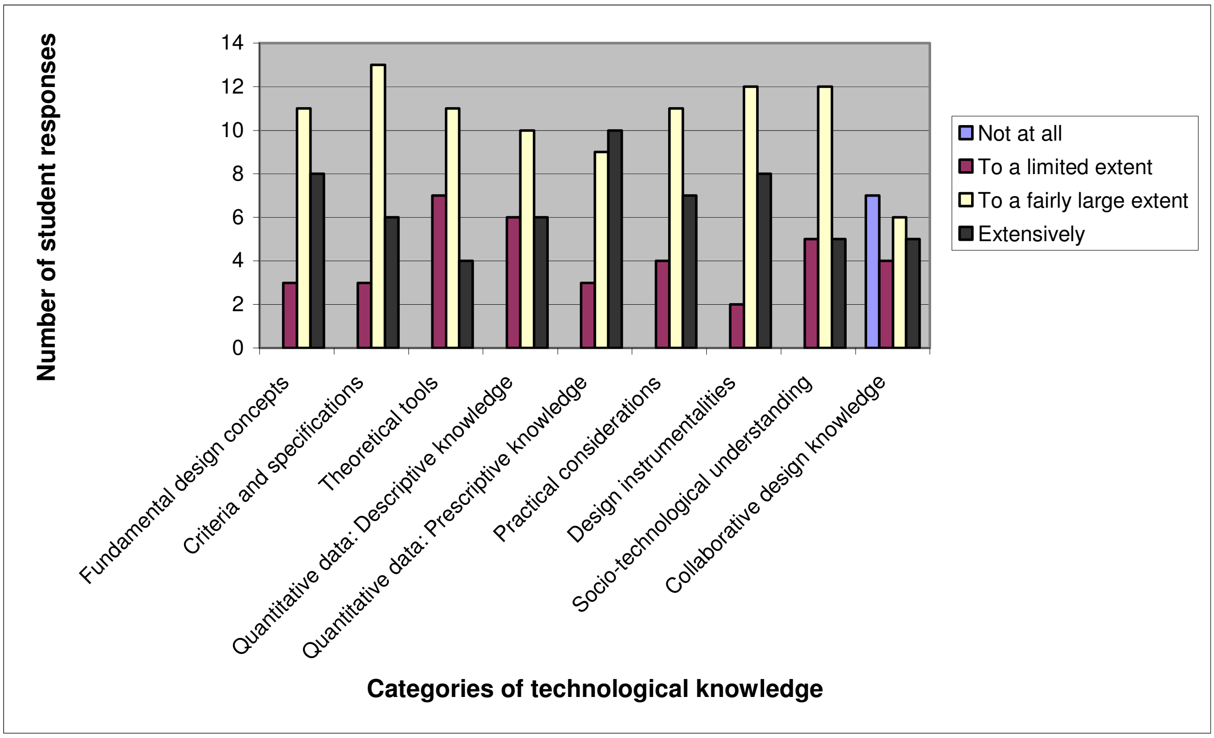
The questionnaire was administered at the end of each module, thus also at the end of the section of work on each content area. For the first content area, systems and control, the students had to design and make an educational toy. For the second content area (structures), the students had to design and make a structural artefact as described in the previous chapter. The results of the students' responses to the rating scale questions, indicating the extent to which each category of technological knowledge was used to design and make an educational toy are shown in table 6 and graph 1.

Table 6: Number of student responses to each category of technological knowledge relevant to the educational toy

Category of technological knowledge	Not at all	To a limited extent	To a fairly large extent	Extensively
Fundamental design concepts	0	3	11	8
Criteria and specifications	0	3	13	6
Theoretical tools	0	7	11	4
Quantitative data: descriptive knowledge (how things are)	0	6	10	6
Quantitative data: prescriptive knowledge (how things should be)	0	3	9	10
Practical considerations	0	4	11	7
Design instrumentalities	0	2	12	8
Socio-technological understanding	0	5	12	5
Collaborative design knowledge	7	4	6	5

N = 22

Graph 1: Number of student responses to the categories of technological knowledge applicable to the educational toy



N = 22

Table 6 and graph 1 show that the students indicated that they engaged predominantly "to a fairly large extent" in seven of the nine (78%) of the categories of technological knowledge while designing and making the educational toy. This high level of engagement indicated by the students suggests that the categories of technological knowledge, identified chiefly by Vincenti (1990:208), were relevant to this capability task.

In the category of quantitative data, pertaining to prescriptive knowledge, the "extensively" scale was selected by 10 of the 22 students (45%), while the "not at all" scale was selected by 7 of the 22 students (32%) for the category of collaborative design knowledge. It is believed that the students' very low level of engagement in the category of collaborative design knowledge might, at least partly, be attributed to their limited experience and knowledge in general and in regard to technological design specifically. Another possible reason is that because the capability tasks were performed during non-contact time (after hours), students did not always have direct contact with each other, since not all of them lived in campus residences.

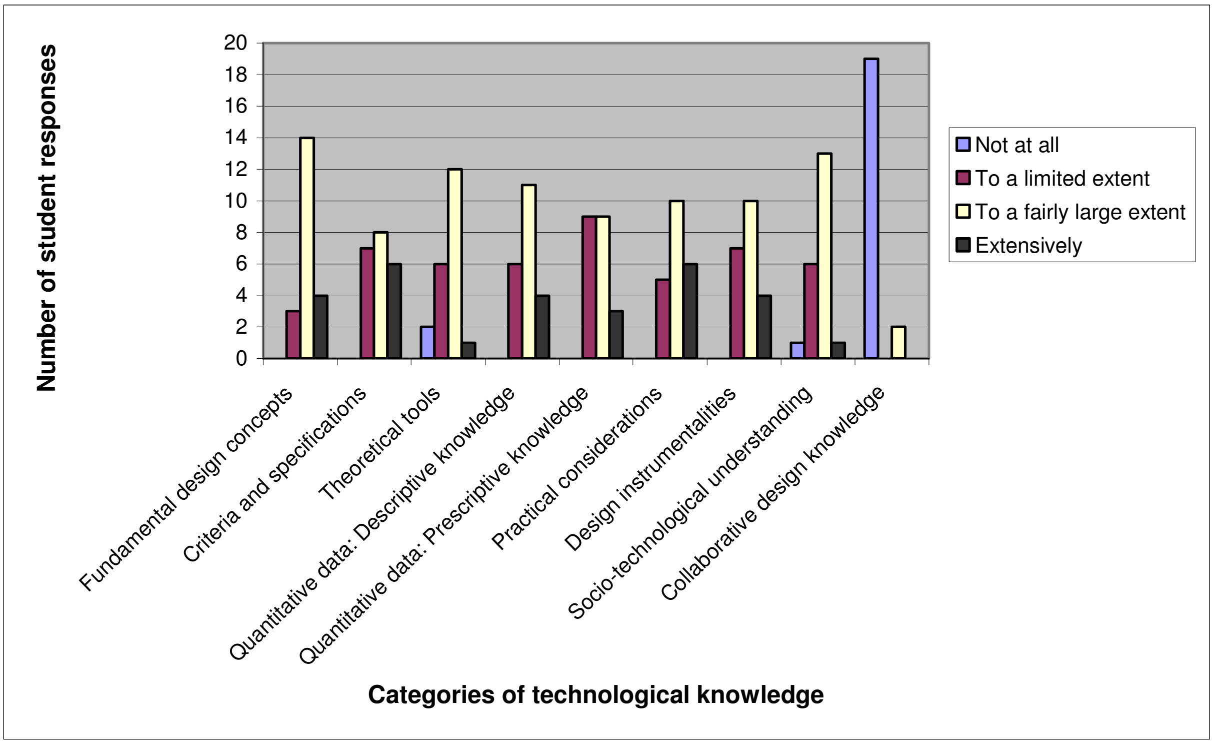
The results of the students' responses to the rating scale questions indicating the extent to which each category of technological knowledge was used to design and make a structural artefact, are shown in table 7 and graph 2.

Table 7: Number of student responses to each category of technological knowledge relevant to the structure artefact

Category of technological knowledge	Not at all	To a limited extent	To a fairly large extent	Extensively
Fundamental design concepts	0	3	14	4
Criteria and specifications	0	7	8	6
Theoretical tools	2	6	12	1
Quantitative data: descriptive knowledge (how things are)	0	6	11	4
Quantitative data: prescriptive knowledge (how things should be)	0	9	9	3
Practical considerations	0	5	10	6
Design instrumentalities	0	7	10	4
Socio-technological understanding	1	6	13	1
Collaborative design knowledge	19	0	2	0

N = 21

Graph 2: Number of student responses to the categories of technological knowledge applicable to the structure artefact



N = 21

Table 7 and graph 2 show that the students indicated that they again engaged predominantly "to a fairly large extent" in seven of the nine (78%) categories of technological knowledge during the designing and making of the structural artefact. This high level of engagement indicated by the students, suggests that Vincenti's (1990:208) categories of technological knowledge were also relevant to this capability task.

As with the educational toy, the "not at all" scale was selected by most students (19 out of 21) for the category of collaborative design knowledge. It is suspected that the increase in the number of students who selected this scale (compared to the educational toy scale) could be attributed to the fact that students started to work more in isolation from their team members due to the general increase in workload that they experienced closer to the end of the year. Projects, tasks and tests in their other subjects demanded more of their time. Refer to section 4.2.8 for additional reasons and explanations as to why such a low level of student responses was recorded for the category of collaborative design knowledge.

The category of quantitative data, pertaining to prescriptive knowledge, received an equal number of student responses for the "to a limited extent" and the "to a fairly large extent" scales. This contrasts to an extent with what was found in regard to the educational toy for which this category was used extensively. It seemed that the students steered clear of prescriptive quantitative data in the structure capability task, possibly due to the nature of the structure capability task, which this time did not involve components required to operate within certain parameters.

From the foregoing it seems that the categories of technological knowledge derived from professional engineering are useful to technology education, as evident in the high extent of student engagement in most of the categories of technological knowledge in both content areas.

A more detailed description of the student responses to each category of technological knowledge, as well as a comparison between the two different capability tasks regarding the way the students engaged in the categories of technological knowledge follows.

4.2.1 Fundamental design concepts

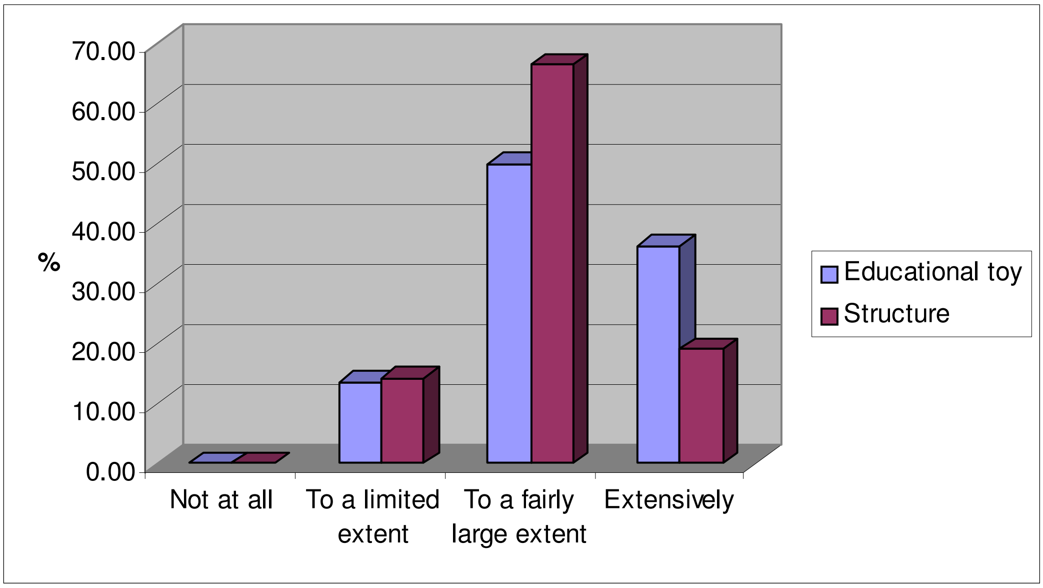
Fundamental design concepts are part of a technologist's knowledge and have to be learned deliberately to form part of a technologist's essential knowledge. This category of knowledge includes the:

- operating principle of an artefact (how does it work); and
- general shape and arrangement of the artefact, that are commonly agreed to best embody the operational principle (normal configuration) (Vincenti, 1990:208-211).

Refer to the detailed description of the category of fundamental design concepts in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of fundamental design concepts. Graph 3 is a clustered column graph representing the number of student responses in percentages for each scale, and compares the two content areas for the knowledge category of fundamental design concepts.

Graph 3: Fundamental design concepts – comparison between the two content areas



The scale that was selected by most students was the "to a fairly large extent" for the structure (66,67%) and the educational toy (50%). The second highly selected scale was "extensively", with 36,36% and 19,05% of student responses regarding the educational toy and structure respectively. The "to a limited extent" scale was indicated by 14,29% (structure) and 13,64% (educational toy) of students. No students selected the "not at all scale".

The difference observed between the two content areas on the "extensively" scale, could be attributed to structures having less fundamental design concepts than the educational toy.

Another possible reason for the difference might be ascribed to the difference in the level of difficulty of the two capability tasks. The capability task for the educational toy was conceived and provided by the lecturer and selected to be cognitively demanding. It required a system (toy) comprising electrical and mechanical components to be designed and made. Students had to engage in both the operating principle and normal configuration of these components to be able to produce a toy that functioned as it was intended to.

The capability task for the structure, on the other hand, was conceptualised and selected by the students from the learning programmes they had designed for JMC 300 (methodology of technology). On assessing the artefacts and project portfolios, it became clear that the students had chosen simple projects for the structure capability task, that were easy to design and make (i.e. cognitively less demanding than the capability task for the educational toy). The fact that the students selected simpler projects for their structure capability task might account for the difference between the two content areas on the "extensively" scale, since they chose not to engage to a larger extent in the category of knowledge described as fundamental design concepts.

4.2.2 Criteria and specifications

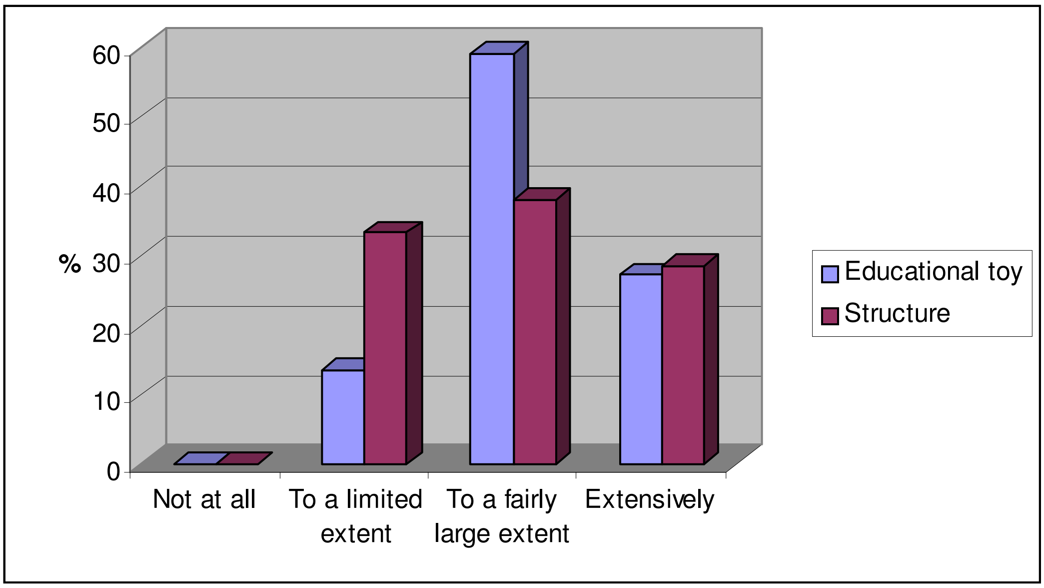
To design a device, a designer must have specific requirements, e.g. a customer's needs and wants, in terms of the device. These qualitative (non technical requirements/needs) goals/data set by the customer must be translated into quantitative goals/data (concrete technical terms) (Vincenti, 1990:211-213). Refer to the detailed description of the category of criteria and specifications in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they:

- made use of criteria and specifications such as the customer's needs and wants; and
- translated these qualitative criteria and specifications into technical terms.

Graph 4 shows the number of student responses in percentages for each scale, and makes a comparison of the two content areas for the knowledge category of criteria and specifications.

Graph 4: Criteria and specifications – comparison between the two content areas



Most of the students selected the "to a fairly large extent" scale: the educational toy received 59,09% of the responses and the structural artefact 38,1% of the responses for this scale. The scale that received the second highest response for the educational toy is "extensively" (27,27%) followed by "to a limited extent" (13,64%). The responses to the scale regarding the structural artefact were slightly different: the students' answers indicate that "to a limited extent" received the second highest number of responses (33,33%) while "extensively" received the third most responses (28,57%). Neither of the two content areas received any responses on the "not at all" scale.

The difference observed between the two content areas on the "to a fairly large extent" scale shows that more students indicated that they engaged in the category of criteria and specifications during the educational toy capability task. A possible reason could be the difference in the nature of the content areas. The educational toy comprised more components, both electrical and mechanical, where some type of numerical values or limits had to be assigned as operating criteria. Most of the structural artefacts, on the other hand, were simple frame or shell structures where criteria and specifications were limited mainly to dimensions (length, breadth, thickness and height). The lists of specifications and criteria for the educational toy were therefore longer, which might explain the higher number of student responses to the "to a fairly large extent" scale regarding the educational toy.

4.2.3 Theoretical tools

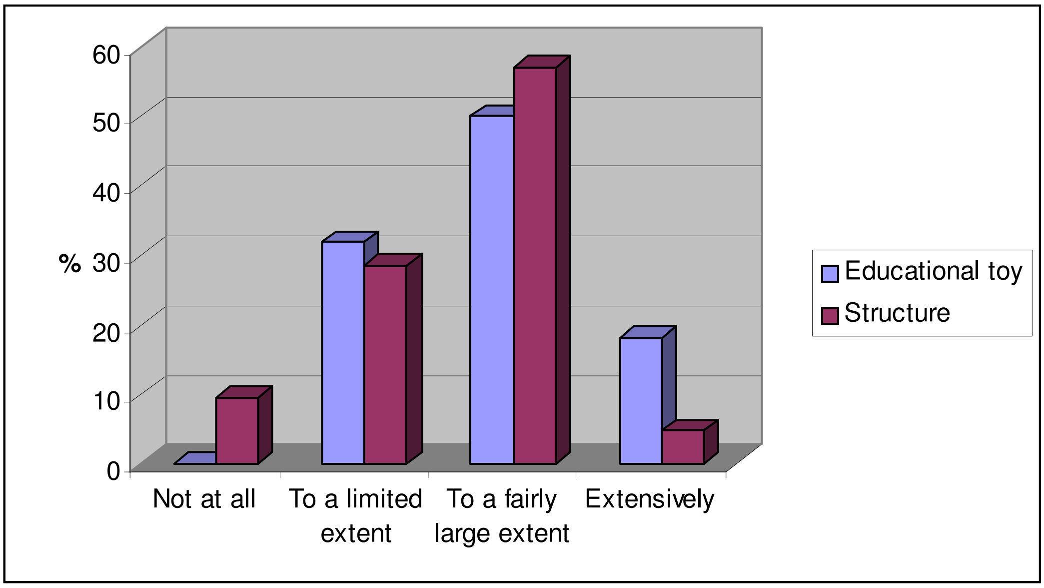
Technologists make use of a wide range of theoretical tools to accomplish their design task. These include:

- mathematical methods and theories for making design calculations. These mathematical methods and theories range from elementary formulas for simple calculations to complex calculative schemes; and
- intellectual concepts for thinking about design. Such concepts provide the language for articulating the thoughts in people's minds (Vincenti, 1990:213-216).

Refer to the detailed description of the category of theoretical tools in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of theoretical tools. Graph 5 shows the results and comparison between the two content areas for the category of theoretical tools.

Graph 5: Theoretical tools – comparison between the two content areas



The majority of students selected the "to a fairly large extent" scale for both the educational toy (50%) and the structural artefact (57,14%). The "to a limited extent" scale received the second highest number of student responses with the toy receiving 31,82% and the structural artefact receiving 28,57%. In the third place, the toy received 18,18%

responses under the "extensively" scale while the structure received 9,52% on the "not at all" scale. No-one selected the "not at all" scale for the toy and the structure received the least number of responses (4,76%) for the "extensively" scale.

The larger number of student responses to the "extensively" scale for the educational toy, compared to the responses for the structural artefact, is possibly due to the fact that the students had to use formulas for simple calculations to design and make the educational toy. These formulas were needed for calculations in the designing of both the electronic circuit (e.g. circuit theory) as well as for the mechanical components (e.g. to calculate mechanical advantage). As for the structure, most students refrained from using formulas and calculations, since this is not a requirement in the technology policy document (DoE, 2003): It was explained in chapter 1 and chapter 3 that the students selected their capability tasks from their learning programmes in JMC 300, which were based on the assessment standards of the policy document (see section 1.6.2 and section 3.6.2).

The students however, indicated that they engaged "to a fairly large extent" in the designing and making of the structural artefact. It is believed that they engaged in intellectual concepts for thinking about design. They had to design and make their artefacts whilst consciously considering the interrelationship between design aspects such as functionality, ergonomics, aesthetics and value – language for articulating the thoughts in their minds. The same applies to the design and making of the educational toy.

No-one selected the "not at all" scale for the educational toy, indicating that all the students indeed engaged in this category of knowledge during this capability task. A limited number of students (2 out of 21) did, however, indicate that they did "not at all" make use of the category of theoretical tools during the structures capability task. It can therefore be assumed that these two students did not use any mathematical methods and theories or intellectual concepts during the design and making of the structures. This might be a result of the simple (easy) structure they chose to design and make as a capability task.

4.2.4 Quantitative data

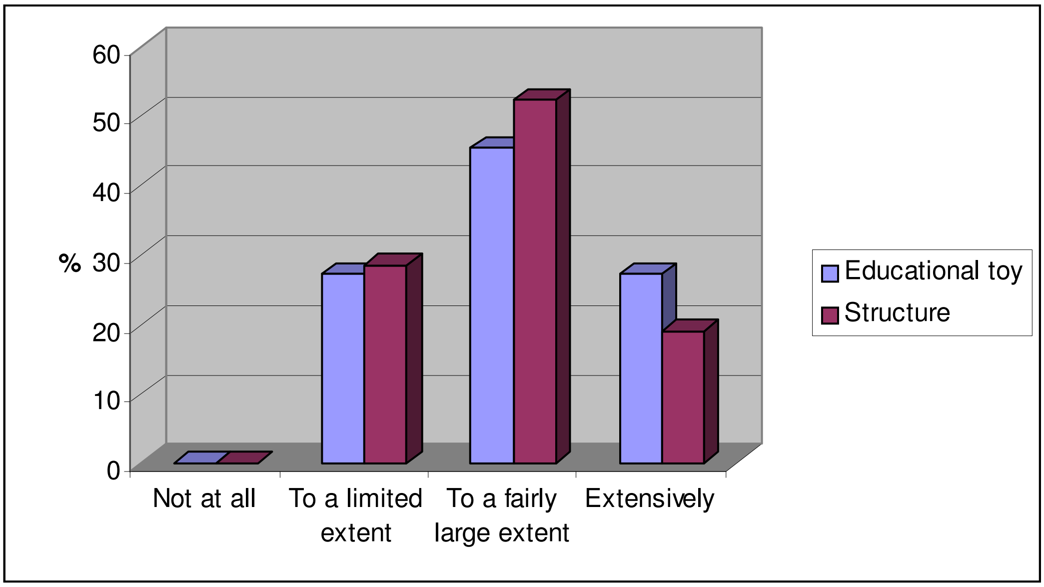
Mathematical tools will be of little value without data for the physical properties or other quantities required in the formulas. Vincenti (1990:216-217) distinguishes between two types of quantitative data, namely descriptive and prescriptive knowledge.

4.2.4.1 Quantitative data: descriptive knowledge

Descriptive data includes data such as physical constants, properties of substances, strength of materials, etc. (i.e. how things are) (Vincenti, 1990:216). Refer to the detailed description of the category of quantitative data (descriptive knowledge) in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of descriptive knowledge. Graph 6 shows the number of student responses in percentages for each scale, and a comparison of the two content areas for the knowledge category of quantitative data in terms of descriptive knowledge.

Graph 6: Quantitative data: descriptive knowledge – comparison between the two content areas



The scale that was selected by most of the students was the "to a fairly large extent" scale for both structures (52,38%) and the educational toy (45,45%). The "to a limited extent" received the second highest number of student responses for the structural artefact (28,57%). The educational toy received an equal number of responses (27,27%) to the "to a limited extent" and "extensively" scales. No students selected the "not at all scale".

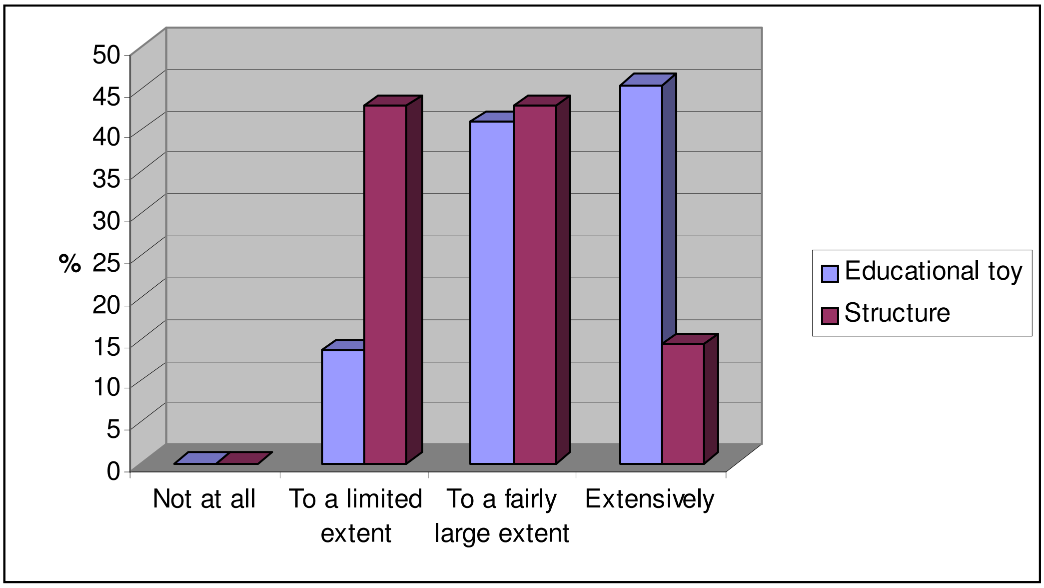
The differences observed between the two content areas on the "to a fairly large extent" and "extensively" scales are too small to make any suggestion as to why they differ. Only two students more selected the "extensively" scale for the educational toy than for structure. One student more selected the "to a limited extent" scale for the structure than for the educational toy.

4.2.4.2 Quantitative data: prescriptive knowledge

Prescriptive knowledge is knowledge of how things should be to in order to obtain the desired result (e.g. data or process specifications that manufacturers issue for guidance to assist designers and other workers) (Vincenti, 1990:217). Refer to the detailed description of the category of quantitative data (prescriptive knowledge) in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of prescriptive knowledge. Graph 7 shows the number of student responses in percentages for each scale and makes a comparison of the two content areas for the knowledge category of quantitative data in terms of prescriptive knowledge.

Graph 7: Quantitative data: prescriptive knowledge – comparison between the two content areas



The "extensively" scale was selected in regard to the educational toy by most students (45,45%). The "to a fairly large extent" and "to a limited extent" scales received the second highest number of student responses, to an equal extent with reference to the structural artefact (42,86%). Then followed the "extensively" scale for the structural artefact (14,29%) and the "to a limited extent" scale for the educational toy (13,64%). No student selected the "not at all scale".

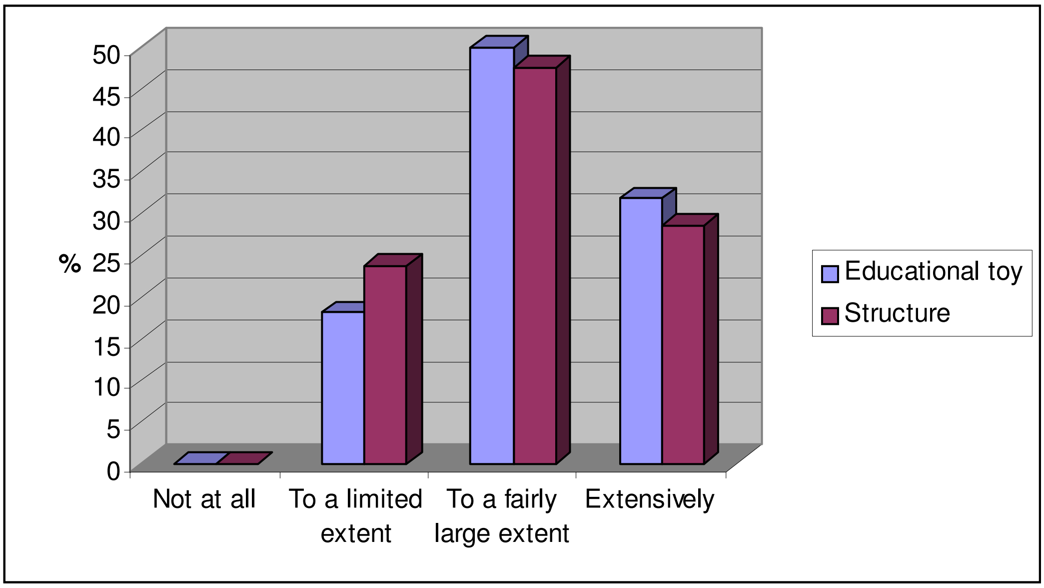
The difference observed between the two content areas on the "extensively" scale shows that the students indicated that they engaged to a higher extent with the category of quantitative data (prescriptive knowledge) during the educational toy capability task, possibly due to the nature of the educational toy capability task. The components (such as an LED or electric motor) used in this project very often specify technical parameters (see the examples in section 5.2.1.2 and section 5.2.2.1) within which the component needs to operate and, according to Vincenti (1990:217), technical specifications are prescriptive by virtue of the fact that they prescribe how a device should be to fulfil its intended purpose. The structure capability task, on the other hand, did not require components to operate within pre-specified parameters. Also, the students chose simpler projects, as discussed earlier in this chapter, which were easier to design and make, and therefore limited their engagement in terms of quantitative prescriptive data.

4.2.5 Practical considerations

Some knowledge can be learned mostly in practice (e.g. learning from accidents, experience in practice and tricks of the trade), rather through training or textbooks (Vincenti, 1990:217-219). Refer to the detailed description of the category of practical considerations in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of knowledge derived from experience. Graph 8 shows the percentage of student responses for each scale and a comparison of the two content areas for the knowledge category of practical considerations.

Graph 8: Practical considerations – comparison between the two content areas



The scale selected by most students was "to a fairly large extent" for both the educational toy (50%) and the structural artefact (47,62%). This was followed by the "extensively" scale which indicates 31,82% for the educational toy and 28,57% for the structural artefact. The "to a limited extent" scale indicates 23,81% for the structural artefact and 18,18% for the educational toy. No student selected the "not at all scale".

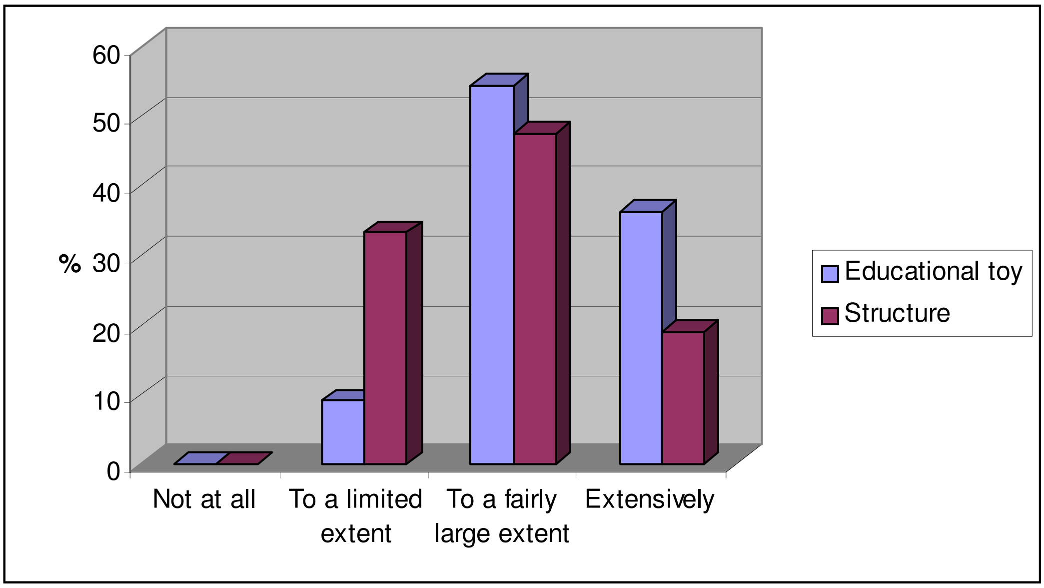
The differences observed in graph 8 between the two content areas are too small to make any suggestion as to why the ratings differ. In each case the differences between the two content areas are the result of only one student more selecting that scale in the particular content area.

4.2.6 Design instrumentalities

In order to carry out a given task, you need to "know how" to carry out the task, e.g. follow the design process. The instrumentalities of the process include the procedures, ways of thinking and judgement skills through which it is conducted (Vincenti, 1990:219-222). Refer to the detailed description of the category of design instrumentalities in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of know-how or procedural knowledge. Graph 9 shows the results and comparison between the two content areas for the category of design instrumentalities.

Graph 9: Design instrumentalities – comparison between the two content areas



Most students selected the "to a fairly large extent" scale. The educational toy received 54,55% of the responses and the structural artefact 47,62%. The "extensively" scale received the second highest number of student responses for the educational toy (36,36%), followed by the "to a limited" scale for the structural artefact (33,33%). No student selected the "not at all scale".

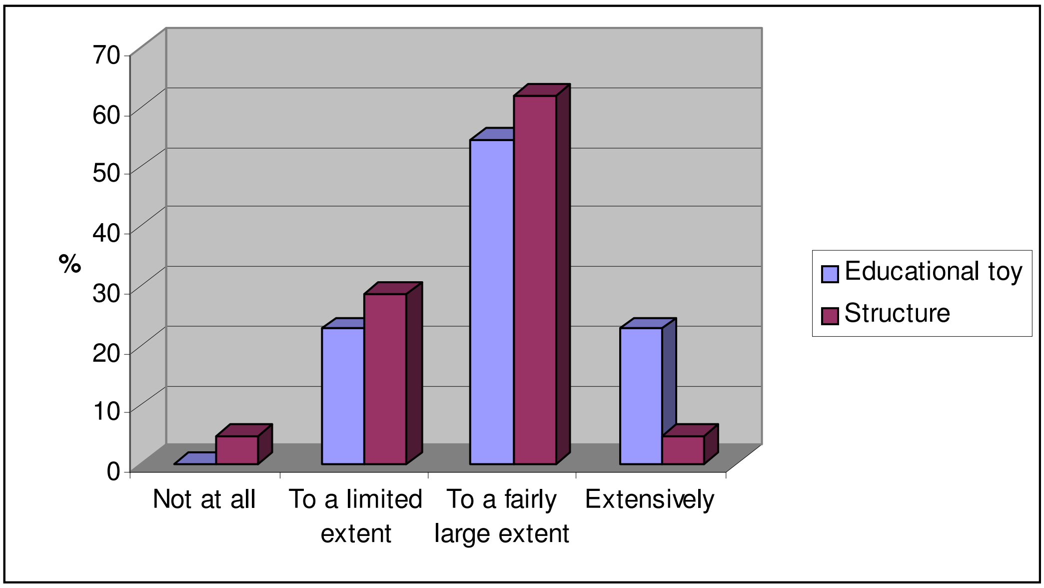
The difference between the two content areas on the "extensively" scale shows that more students indicated that they engaged in the category of design instrumentalities during the designing and making of the educational toy. This pattern is repeated on the "to a fairly large extent" scale, which suggests that the students indeed engaged to a larger extent in this category during the educational toy task than the structure task, possibly due to the fact that the educational toy was a cognitively more demanding capability task, indicating that the students had to engage to a higher extent in *procedures*, *ways of thinking* and *judgmental skills* during the design and making of the toy.

4.2.7 Socio-technological understanding

For this questionnaire item students had to indicate the extent to which they considered the inter-relationship between their technical artefacts, the natural environment and social practice, as identified by Ropohl (1997:70), during the design and making of their artefacts. Refer to the detailed description of the category of socio-technological understanding in section 2.5.2.

Graph 10 shows the results and comparison between the two content areas for the category of design instrumentalities.

Graph 10: Socio-technological understanding – comparison between the two content areas



The scale selected by most of the students was the "to a fairly large extent" scale for both the educational toy (54,55%) and the structural artefact (61,9%), followed by the "to a limited extent" scale for the educational toy (22,73%) and the structural artefact (28,57%). The educational toy also received 22,73% responses for the "extensively" scale. The structure received 4,76% responses for both the "extensively" and the "not at all scale". No student selected the "not at all" scale for the educational toy.

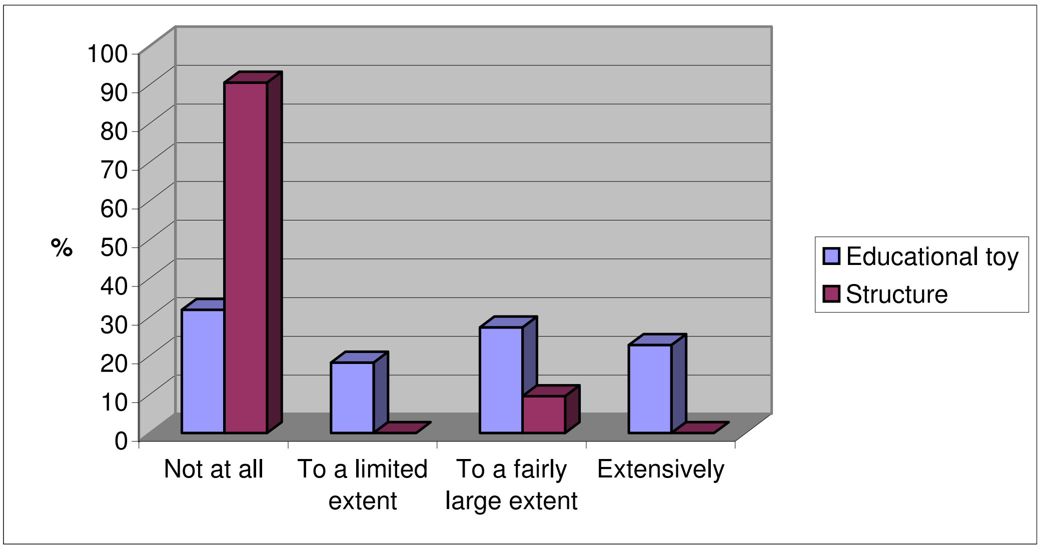
A difference between the two content areas in the extent to which the students engaged in the category of socio-technological understanding, is most notable on the "extensively" scale. The educational toy received the most responses on this scale, indicating that the students were more aware of the inter-relationship between their toy, the natural environment and social context. A possible reason why the students engaged more extensively in this category of knowledge regarding the educational toy than in regard to the structure capability task, could be due to the difference in expectations stated in the briefs which set the stage for the capability tasks. The brief for the educational toy stated that the toy had to have educational value, which meant that each student had to identify a child's specific educational need, e.g. regarding cognition, hand-and-eye-coordination or fine motor skills. The students therefore needed to consider this inter-relationship (socio-technological understanding) carefully, even during the investigation phase of the design process. The briefs that the students conceptualised for the structure capability task, on the other hand, were less demanding and rather straight-forward, as discussed earlier in this chapter.

4.2.8 Collaborative design knowledge

The difference between collaborative and individual design work originates from the group structure and the distributed responsibilities of the work and work-flow. A design team consists of expert designers such as architects and engineers, each fulfilling a different role (Bayazit, 1993:123). Refer to the detailed description of the category of collaborative design knowledge in section 2.5.4.

For this questionnaire item students had to indicate the extent to which they engaged in knowledge pertaining to the category of collaborative design knowledge. Graph 11 shows the results and comparison between the two content areas for the category of collaborative design knowledge.

Graph 11: Collaborative design knowledge – comparison between the two content areas



For this category of knowledge the students' responses to both the educational toy and the structures capability tasks peaked at the "not at all" scale, and the responses regarding the educational toy indicate 31,82%, while responses regarding the structural artefact indicate 90,42%. A possible reason for this low level of student engagement in this category of knowledge is that the capability tasks were performed during non-contact time, which meant that the students did not always have direct contact with each other after hours, since not all of them lived in campus residences.

Another possible reason is that the students were not experts, but novice teacher education students, all with more or less the same prior knowledge in terms of technology. Although those who chose to work in groups had different roles and responsibilities in the groups, their lack of expert knowledge most probably limited their opportunity to engage with knowledge in this category of knowledge, since they did not have meaningful (expert) knowledge to share. This contradicts the perspective described by Matthews (1995:101), namely that collaborative learning is a pedagogy that has at its centre the assumption that people make meaning together and that the process enriches and enlarges them.

In addition to the reasons stated above, it is also possible that students started to work in a more isolated fashion (away from their team members) due to a general increase in workload that they experienced closer to the end of the year: projects, tasks and tests in their other subjects demanded more of the their time.

4.2.9 Relationship between the extent to which students made use of the categories of technological knowledge in the two content areas

The Pearson product moment correlation coefficient (*r*) was used to establish whether a relationship exists in the extent to which students made use of the categories of technological knowledge between the two content areas. Table 8 shows the Pearson *r* for each category of technological knowledge.

Table 8: The relationship between the two content areas of student engagement in the categories of technological knowledge

Category of technological knowledge	***r***
Fundamental design concepts	+ .88
Criteria and specifications	+ .76
Theoretical tools	+ .90
Quantitative data: descriptive knowledge (how things are)	+ .96
Quantitative data: prescriptive knowledge (how things should be)	+ .35
Practical considerations	+ .98
Design instrumentalities	+ .72
Socio-technological understanding	+ .90
Collaborative design knowledge	+ .83

For a study involving 22 students, (df[25] = 20), a coefficient of .54 is needed to be significant[26] at the .01 level (Ary et al., 2002:361,548). Eight of the nine relationships shown in table 8 were statistically significant at the .01 level, since their *r* values are higher then .54. Since there is only a 1 in 100 possibility of chance, these relationships are unlikely to be a function of chance.

One relationship, for the category of quantitative data pertaining to prescriptive knowledge, however, is significant only at the .10 level, with an *r* value of .35. This lower level of significance means that the relationship has a higher probability of being a function of chance (1 in 10) than the other eight relationships shown in table 8.

Jackson's (2006:124) estimates were used to interpret the abovementioned (table 8) Pearson product-moment correlation coefficient. Table 9 lists the estimates.

Table 9: Estimates for weak, moderate and strong correlation coefficients (Jackson, 2006:124)

Correlation coefficient	**Strength of relationship**
± .70 – 1.00	Strong
± .30 - .69	Moderate
± .00 - .29	None (.00) to weak

[25] df = N – 1
[26] Significant means "less likely to be a function of chance than some predetermined probability" (Ary, et al.2002:179).

From table 9 it can be seen that eight of the nine categories of knowledge listed in table 8 show a strong positive relationship between the two content areas. Only the category of quantitative data that relates to prescriptive knowledge shows a moderate positive relationship between the two content areas. This suggests that the students engaged in the knowledge from the categories of technological knowledge to nearly the same extent in both content areas, which implies that the knowledge contained in one content area, i.e. systems and control, does not significantly favour the categories of knowledge above the knowledge contained in the other content area, i.e. structures.

4.3 Knowledge-generating activities

This section of the questionnaire consisted of rating scale as well as open-ended questions. The rating scale questions required students to indicate the extent to which they made use of the knowledge-generating activities to design and make an artefact. In answering the open-ended questions, students had to give examples of the kind of knowledge they used.

The results of the students' responses to the rating scale questions indicating the extent to which they drew knowledge from the knowledge-generating activities to design and make an educational toy, are shown in table 10 and graph 12.

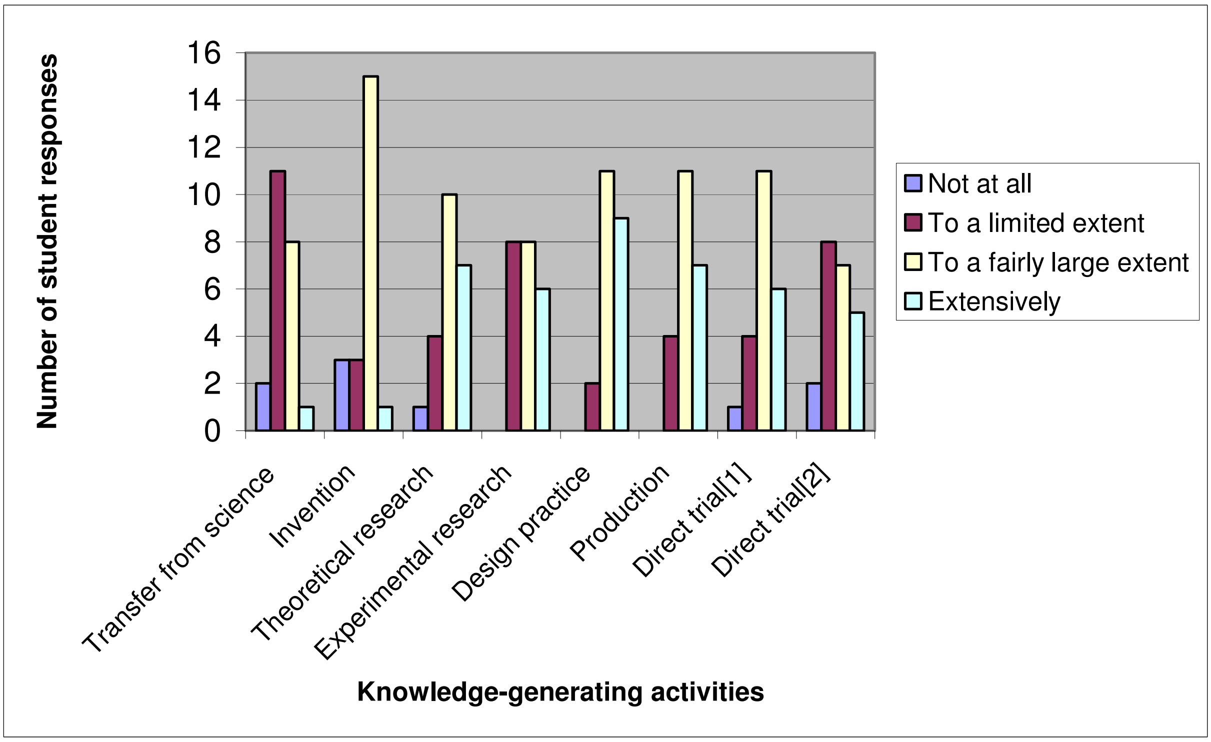
Table 10: Number of student responses to each knowledge-generating activity relevant to the educational toy

Knowledge-generating activities	Not at all	To a limited extent	To a fairly large extent	Extensively
Transfer from science	2	11	8	1
Invention	3	3	15	1
Theoretical research	1	4	10	7
Experimental research	0	8	8	6
Design practice	0	2	11	9
Production	0	4	11	7
Direct trial[27]	1	4	11	6
Direct trial[28]	2	8	7	5

N = 22

[27] To what extent did you evaluate (test) your artefact in order to determine whether it does what it was designed to do?
[28] To what extent did you use the knowledge acquired about the artefact's shortcomings during the direct trial to improve the design or at least make suggestions to improve the design?

Graph 12: Number of student responses to the knowledge-generating activities relevant to the educational toy



N = 22

Table 10 and graph 12 show that the students indicated that they drew predominantly "to a fairly large extent" from six of the eight (75%) knowledge-generating activities during the educational toy capability task. The high level of student responses to this scale suggests that Vincenti's (1990:229) knowledge-generating activities were relevant to this capability task.

Two knowledge-generating activities peaked at the "to a limited extent" scale, i.e. transfer from science (selected by 11 out of 22 students) and direct trial [2] (selected by 8 out of 22 students). A possible reason for the students' reluctance to transfer more knowledge from science, might be the problem related to transfer as discussed in chapter 2. In section 2.4.2 it was noted that various authors from different theoretical backgrounds have found that learners find it difficult (or impossible) to transfer knowledge successfully from one context (e.g. the science classroom) to another (e.g. the technology classroom) (De Corte, 1999:556; Hatano & Greeno, 1999:645; Stark, Mandl, Gruber, & Renkl, 1999:591).

The second part of direct trial, which peaked at the "to a limited extent" scale, explored the extent to which the students used the knowledge acquired about the artefact's shortcomings during the direct trial to improve the design, or at least make suggestions to improve the design. Although most of the students did make suggestions for improvements after they had tested the artefact during the evaluation phase of the design process (as stipulated in the RNCS for technology), few went so far as to actually improve the artefact. The students claimed that they ran out of time at the end of the module, although laziness might be the real reason they did not make improvements.

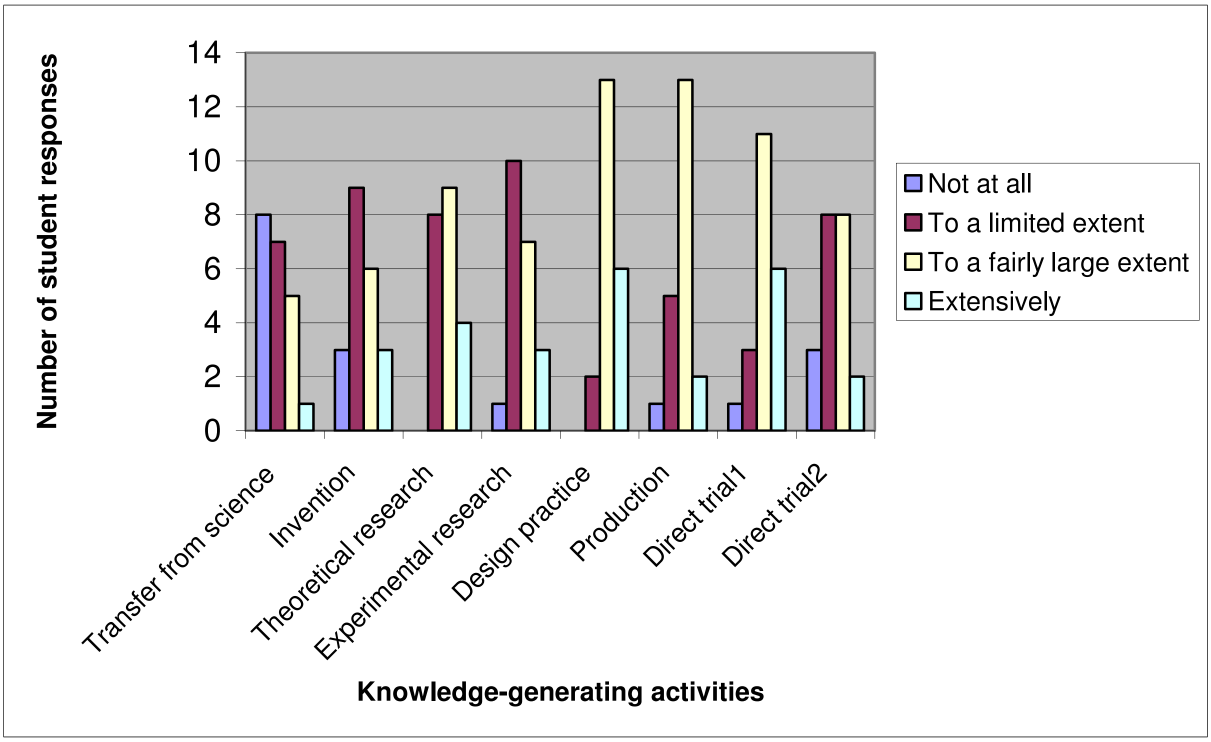
The results of student responses to the rating scale questions that indicate the extent to which they drew knowledge from the knowledge-generating activities to design and make a structure artefact, are shown in table 11 and graph 13.

Table 11: Number of student responses to each knowledge-generating activity relevant to the structure artefact

Knowledge-generating activities	Not at all	To a limited extent	To a fairly large extent	Extensively
Transfer from science	8	7	5	1
Invention	3	9	6	3
Theoretical research	0	8	9	4
Experimental research	1	10	7	3
Design practice	0	2	13	6
Production	1	5	13	2
Direct trial[1]	1	3	11	6
Direct trial[2]	3	8	8	2

N = 21

Graph 13: Number of student responses to the knowledge-generating activities relevant to the structure artefact



N = 21

Table 11 and graph 13 show that the students indicated that they drew predominantly "to a fairly large extent" from five of the eight (63%) knowledge-generating activities during the structure capability task. The fairly high level of student responses to this scale suggests that Vincenti's (1990:229) knowledge-generating activities were also relevant to this capability task.

One knowledge-generating activity, namely transfer from science, peaked (selected by 8 out of 21 students) at the "not at all" scale. In addition to the suggestion earlier, discussed in the section on the educational toy, as to why students did not transfer more knowledge from science, it is surmised that it may be as a result of the fact that not all the students who selected technology as an elective also selected science as an elective. Only about half the students in the technology class also specialise in science at university level. All the students should, however, have a basic background in science, since it is a compulsory learning area up to grade 9. It is therefore disappointing that transfer from science, even on an elementary level, did not occur to a greater extent, because scientific knowledge is an important contributor to engineering knowledge (Layton, 1971:578; Vincenti, 1990:225-229).

From the foregoing it seems that the knowledge-generating activities derived from professional engineering are useful to technology education, as can be seen from the high extent to which the students drew from most of the knowledge-generating activities in both content areas.

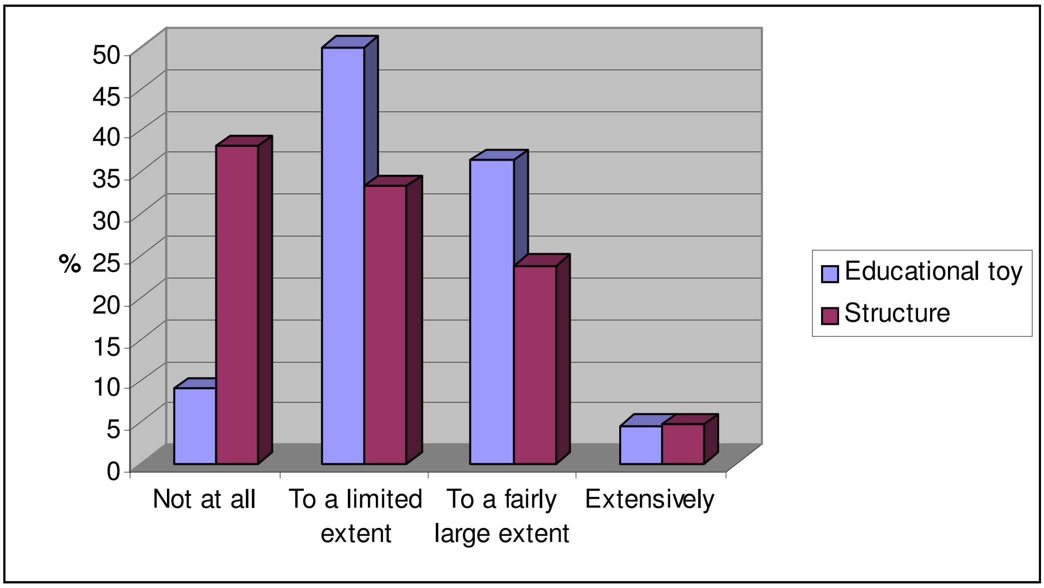
A more detailed description of student responses to each of the knowledge-generating activities, as well as a comparison between the two different capability tasks pertaining to the way in which the students drew from the knowledge-generating activities will now be provided. This section also includes examples of student responses to open-ended questions. The open-ended question, following the rating scale question, required students to cite examples of the knowledge they drew from each knowledge-generating activity. The examples provided by the students were, however, generally of poor quality, since they lacked detail and depth, possibly because responding to open-ended questions is time consuming, which seems to be a general disadvantage of open-ended questions (Ary et al., 2002:390; Cohen, Manion, & Morrison, 2001:256). The richness of these open-ended responses was enhanced through the content analysis in chapter 5.

4.3.1 Transfer from science

A transfer of knowledge from theoretical science often entails reformulation or adaptation to make the knowledge useful to engineers (Vincenti, 1990:229-230). Refer to the detailed description of this knowledge-generating activity in section 2.5.1. Also see section 2.3 for an explanation of the difference and mutual influence between technological and scientific knowledge.

For this questionnaire item students had to indicate the extent to which they made use of knowledge transferred from science. Graph 14 indicates the results and comparison in percentages, between the two content areas that relate to transfer from science.

Graph 14: Transfer from science – comparison between the two content areas



The majority of students indicated that they transferred knowledge from science "to a limited" (50%) and "to a fairly large extent" (36,36%) for the design and making of the educational toy. The extensive use of knowledge from science was rated lowest for the educational toy at 4,55%.

Most students (38%) indicated in regard to the structures capability task that that they did "not at all" transfer knowledge from science. The "to a limited extent" scale was selected by 33,33% and the "to a fairly large extent" scale by 23,33% of the students in terms of the structural artefact. The extensive use of scientific knowledge was rated lowest for the structural artefact at 4,76%.

The differences observed between the two content areas on the "not at all", "to a limited extent" and the "to a fairly large extent" scales, clearly indicate that the students transferred knowledge from science to a larger extent during the design and making of the educational toy than during the structures capability task, most likely because some of the knowledge, e.g. circuit theory, required to design and make the educational toy, is located in science. The students therefore needed to transfer this knowledge from science to be able to complete the capability task. The structure, on the other hand, was selected by the students to be cognitively less demanding (as discussed earlier in this chapter). The design solution of the structure was therefore more obvious, which meant that knowledge from science was not needed to the same extent as in regard to the design and making of the educational toy. The implication is that educators must ensure that the capability tasks they conceptualise for structures must also be cognitively demanding. They must also formulate the brief in such a way that the design solutions require knowledge to be transferred from science.

The open-ended question following the rating scale question required students to give examples of the knowledge they transferred from science. Examples of students' answers relating to the educational toy:

The distance that the car should have travelled $\rightarrow v = \frac{s}{t}$ *(s23356911).*

and

Gravitational acceleration (s23208636).

Examples of students' answers relating to the structure are:

Termiese insulering (s20169206).
Translated as:
Thermal-insulating (s20169206).

and

Invloed van kragte op voorwerpe (s23080532).
Translated as:
Influence of forces on objects (s23080532).

All the examples provided for structures were vague, since they did not specify detail (as is evident in the examples above). As no detail was given in terms of the thermal insulation to which this student referred or the kind of forces acting on the objects, it is difficult to comment on the open-ended answers.

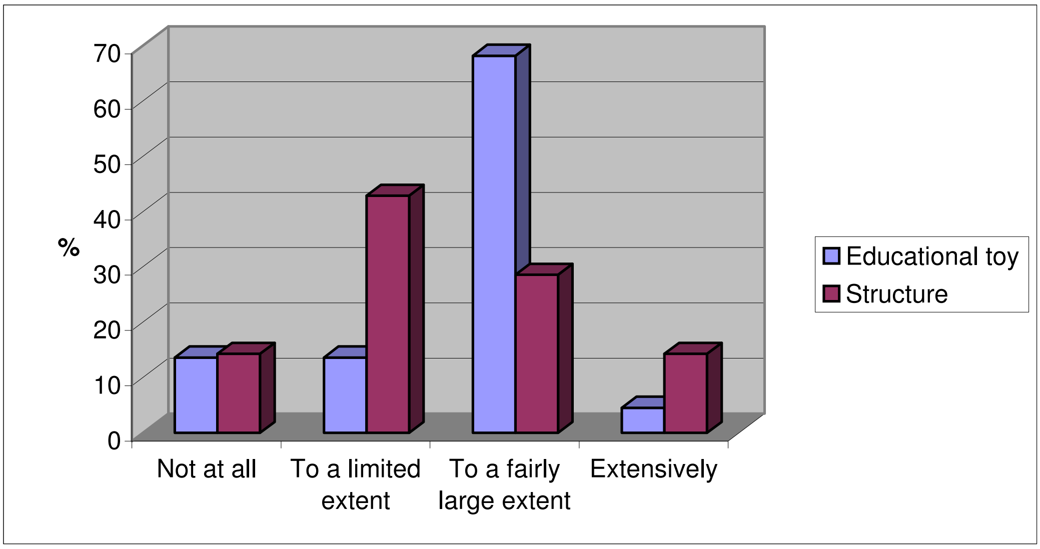
4.3.2 Invention

Invention is a source of the operational principles and normal configurations that underlie normal design (Vincenti, 1990:230). Refer to the description of this knowledge-generating activity in section 2.5.1.

Although Vincenti's (1990:206-207,225) knowledge-generating activities focuses on the growth of the existing body of knowledge (see section 3.4.3), for the purpose of this study, invention will not be used in an absolute way, but rather in a relative way (invention as an action by that specific designer) for the same reasons explained in section 3.4.3. The fact that the students 'invent' something that already exists, therefore, still can count as invention as long as they were not aware of its previous existence.

For this questionnaire item students had to indicate the extent to which they discovered and made use of "new" knowledge as a result of their invention or "unique" artefact. Graph 15 indicates in percentages the results and comparison between the two content areas for knowledge acquired through invention.

Graph 15: Invention – comparison between the two content areas



Both systems and control (13,64%) and structures (14,29%) were rated low on the "not at all" scale, indicating that most students are of the opinion that they discovered and used new knowledge as a result of their invention. The highest number of student responses was counted in regard to the educational toy for the "to a fairly large extent" scale (68,18%), followed by structures capability task "to a limited extent" scale (42,86%).

The educational toy indicated 13,64% responses on the "to a limited extent" scale and 4,55% responses on the "extensively" scale. The structural artefact received 28,57% responses to the "to a fairly large extent" scale and 14,29% responses to the "extensively" scale.

The differences observed between the two content areas on the "to a limited extent", and the "to a fairly large extent" scales indicate that the students believed that they drew more knowledge from invention during the educational toy capability task. The "to a fairly large extent" scale was selected by 15 of the 22 students in this capability task compared to the 6 out of 21 students in regard to the structures capability task.

A possible explanation for this difference might be that the students had no/little prior knowledge of electronics. What seems to be old hat for experienced designers might have appeared to the students to be an "invention". On the other hand, the structure probably seemed more 'familiar' to the students since they are to a large extent, exposed to structures in everyday life.

The open-ended question required students to give examples of the knowledge they contrived or came upon coincidentally due to their inventions. Examples of students' answers relating to the educational toy:

> *The extent to which the size of the gear can make it (the platform) turn faster/slower (s23208636).*
>
> and
>
> *Die groot impak van wrywing – verwering (s23080532).*
> Translated as:
> *The great impact of friction – weathering (s23080532).*

Examples of students' answers relating to the structure are:

> *Clear bostik vreet plastiek (s23140772).*
> Translates as:
> *Clear bostik dissolves plastic (s23140772).*
>
> and
>
> *Die skarniere het 'n gaping veroorsaak in die hout (s23208172).*
> Translated as:
> *The hinges made a gap in the wood (s23208172).*

The students' answers to the open-ended questions were very general and appear to be common sense answers. It seems from the examples that the knowledge was not the result of a unique invention, but rather a “discovery” due to a lack of investigation before possible design solutions were considered. For example, the properties of materials, e.g. “clear bostik dissolves plastic“, should have been considered as part of “investigate” in the design process and should have been done even before a variety of possible solutions to the need, which should have resulted in the artefact, were considered. The knowledge of the properties of materials could therefore not be a result of the invention, since it should have been acquired in the early stages of the design process before the artefact, or any other possible artefact, was made.

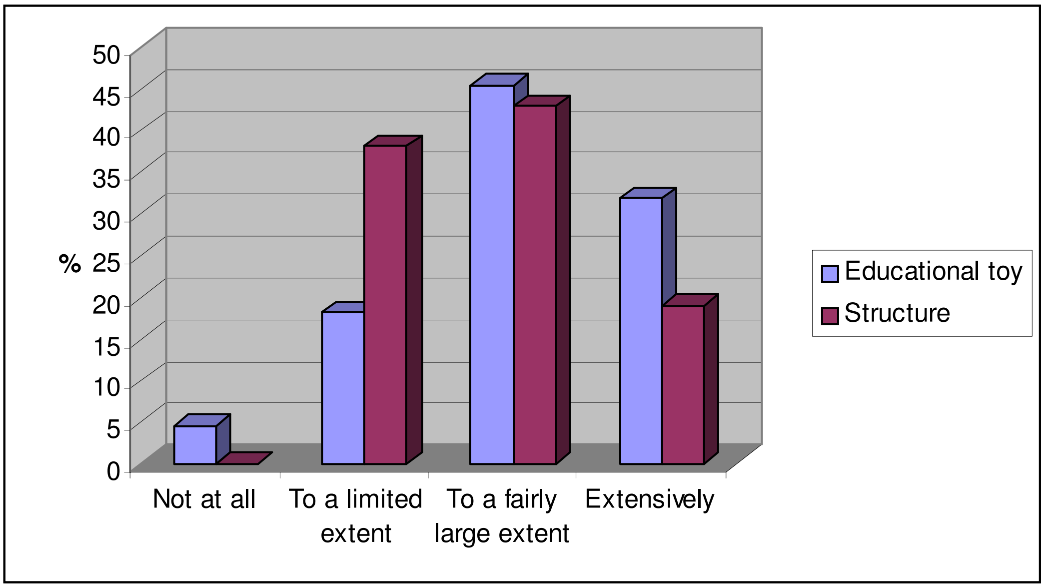
Since it is unfortunately not clear from the students’ relatively short answers to determine whether they discovered and made use of “new” knowledge as a result of their invention or “unique” artefact, the portfolio analysis in the next chapter will revisit this issue.

4.3.3 Theoretical engineering research

Vincenti (1990:230) takes “theoretical” as synonymous with “mathematical”. Theoretical research, for example, includes the working out of *new* mathematical tools to design a particular device. For reasons described in section 3.4.3, this description of theoretical engineering research is not suitable for the purpose of this study and therefore needs to be modified. For the purpose of this study, therefore, theoretical engineering research will be extended to include activities relating to the acquisition of stored-up knowledge, e.g. a search for information in textbooks and class notes.

For this questionnaire item students had to indicate the extent to which they made use of theoretical research to acquire the necessary knowledge that enabled them to design and make their artefacts. Graph 16 indicates the results and comparison in percentages between the two content areas for the knowledge acquired through theoretical research.

Graph 16: Theoretical engineering research – comparison between the two content areas



The majority of students indicated that they did make use of theoretical research and they selected the "to a fairly large extent" scale. In regard to the educational toy there were 45,45% responses and for the structural artefact 42,86%. This was not unexpected, since the first stage of the design process namely "investigate", requires the students to do extensive theoretical research. Both the educational toy (4,55%) as well as structural artefact (0%) indicated the lowest response on the "not at all" scale. It is unclear why one student selected the "not at all" scale for the educational toy, as most students indicated that they did indeed draw knowledge from theoretical research.

The educational toy received 31,82% responses on the "extensively" scale and 18,18% responses on the "to a limited extent" scale. The structural artefact received 38,10% responses on the "to a limited extent" scale and 19,05% responses on the "extensively" scale.

The differences observed between the two content areas on the "to a limited extent", and the "extensively" scales shows that the students drew more knowledge from theoretical research during the educational toy capability task. A possible reason is that because electronics (educational toy) is a new field to most of the students, it demanded more research (e.g. the literature study), compared to the simpler structures the students designed and made during the structure capability task.

Two open-ended questions were asked to probe this questionnaire item. The first question asked the students to identify the main sources they consulted during their theoretical research. Table 12 shows the results for the first question regarding the educational toy.

Table 12: Sources consulted by the students during the theoretical research for the educational toy

Sources consulted	Frequency
Internet	19 students
Books	12 students
Looking at toys in shops	6 students

Most of the students in the class indicated that they made use of the Internet for the theoretical research on the design and the making of the educational toy. The twelve students gave no indication as to the kind of books they used. Six students indicated that they visited toy stores to see the toys available and to see how they work. Similar results were provided for the structural artefact. Table 13 shows the results of the first question for the structural artefact.

Table 13: Sources consulted by the students during the theoretical research for the structural artefact

Sources consulted	Frequency
Internet	21 students
Books	10 students
Consulting professionals	2 students

All the students in the class indicated that they made use of the Internet for the theoretical research on the design and making of the structural artefact. Ten students indicated that they used books. The identities of the “professional” people consulted are not clear from the answers provided by the students.

The second open-ended question required the students to give examples of the knowledge they acquired through theoretical research. Examples of students’ answers relating to the educational toy:

Hoe die 'six simple machines' beweging tot gevolg het (s23080532).

Translated as:

How the six simple machines bring about movement (s23080532).

and

Wat 'n opvoedkundige speelding is (s23155630).

Translated as:

What an educational toy is (s23155630).

Examples of students' answers relating to the structure are:

Las- en voegtegnieke van hout, byvoorbeeld 'joining' waar die dele net by mekaar inskuif (s23080532).

Translated as:

Wood-joining and dove-tailing techniques for example 'joining' where the parts can slide into each other (s23080532).

and

Eienskappe van materiale (s22207300).

Translated as:

Properties of materials (s22207300).

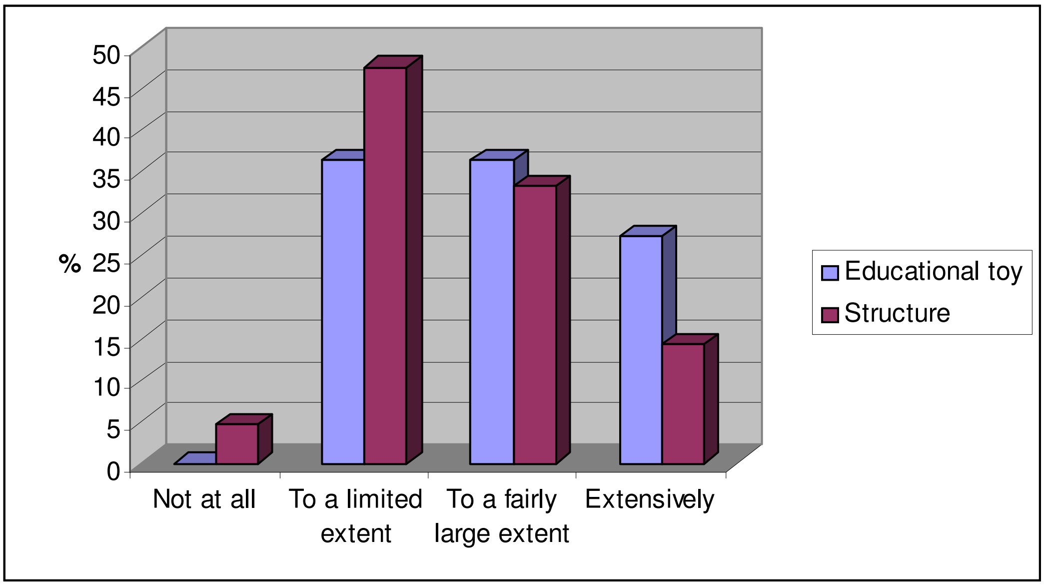
The students' answers above were again very general and lacked detail. It was for example, not clear what properties of which materials were researched.

4.3.4 Experimental engineering research

This activity, which is a major source of quantitative data, requires special test facilities, experimental techniques and measuring devices (Vincenti, 1990:231-232). Refer to the description of this knowledge-generating activity in section 2.5.1.

For this questionnaire item, students had to indicate the extent to which they drew knowledge from experimental research in designing and making the artefacts. Graph 17 indicates in percentages, the results and comparison between the two content areas for the knowledge acquired through experimental research.

Graph 17: Experimental research – comparison between the two content areas



All the students, with the exception of one (4,76%) who selected the "not at all" scale, indicated that they made use of experimental research in the content area of structures. Most students selected the "to a limited extent" scale for the educational toy (36,36%) as well as the structural artefact (47,62%) followed by the "to a fairly large extent" scale: 36,36% and 33,33% respectively. The educational toy received 27,27% responses on the "extensively" scale while the structural artefact received 14,29%.

The fact that most students indicated that they made use of experimental research might be due to the prescribed stages of the design process. "Investigate" requires the students to perform practical testing procedures to determine or compare the suitability or fitness of purpose of relevant properties of materials, etc.

The differences observed between the two content areas on the "to a limited extent", and the "extensively" scales shows that the students indicated that they drew more knowledge from experimental research during the educational toy capability task. The complexity of the various components, both electronic and mechanical, could have compelled the students to do more experimental research during the design and making of the educational toy.

Two open-ended questions were asked to probe this questionnaire item. In answer to the first question which asked students to indicate how they performed experimental research, all students indicated that they conducted testing procedures using practical experimental techniques, in accordance with the investigating phase of the design process during the educational toy capability task. These techniques include testing the conductivity of various metals and experimenting with gear ratios and motor speed. The short answers were not clear on exactly how this was done.

All the students also indicated that they conducted experimental research through testing and practical experimental techniques during the structures capability task. These techniques include physical stretching, bending and twisting to determine the strength of the materials, as well as wetting them to test water-resistance. The students also stated that they experimented with and tested the properties of various materials such as plastic, perspex, polyester foam, wood, cardboard and metals. The short answers were again not clear on exactly how this was done.

The second open-ended question asked students for examples of the type of knowledge they acquired through experimental research. Examples of students' answers relating to the educational toy:

> *Dat 'n metal balletjie elektrisiteit die beste gelei, maar dat die balletjie die stroombaan behoorlik moet voltooi om effektief te werk (s23080532).*
> Translated as:
> *That a metal ball conducts electricity best, but the ball must complete the circuit properly to work effectively (s23080532).*
>
> and
>
> *Gear-speed; pendulum-movement (s23208636).*

Examples of students' answers relating to the structure are:

> *Perspex kan maklik smelt (s23037190).*
> Translated as:
> *Perspex can easily melt (s23037190).*
>
> and
>
> *Riffelkarton is sterk, maar skeur vinnig as dit gebuig word (s22207300).*
> Translated as:
> *Corrugated cardboard is strong, but tears easily when it is bent (s22207300).*

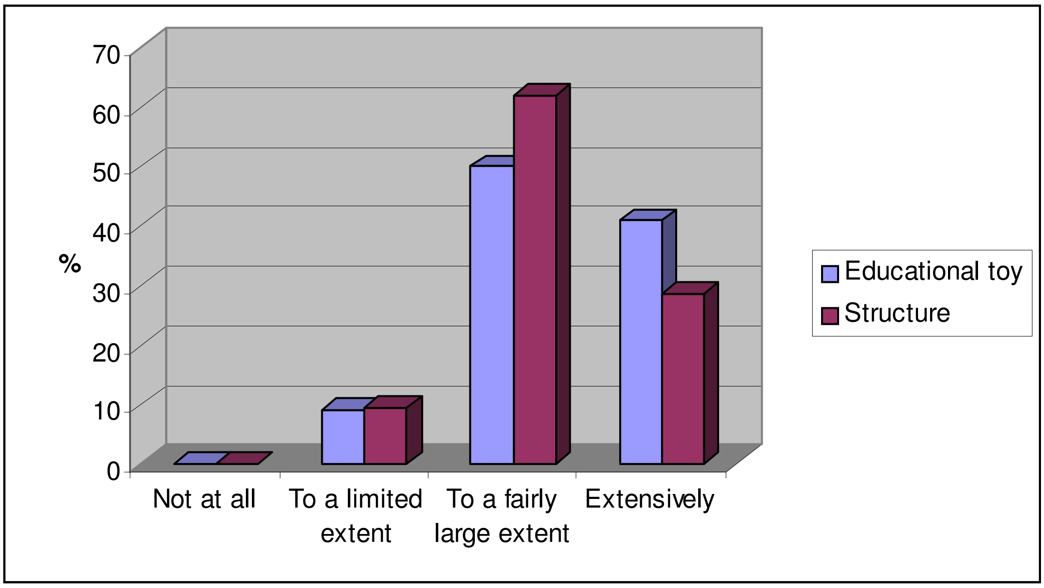
From the forgoing examples it is clear that the experimental research was performed in a very crude/basic manner since the students did not have access to special test facilities and sophisticated measuring devices. It seems that they conducted most of the practical experimental techniques themselves and that measurements were based on visual observations.

4.3.5 Design practice

Day-to-day design practice not only makes use of engineering knowledge, it also contributes to it (Vincenti, 1990:232-233). Refer to the description of this knowledge-generating activity in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they made use of knowledge derived from design practice. Graph 18 indicates in percentages the results and comparison between the two content areas for the knowledge acquired by design practice.

Graph 18: Design practice – comparison between the two content areas



All the students indicated that they made use of knowledge from design practice. No-one selected the "not at all" option and the "to a limited extent" scale was also rated low: the educational toy received 9,09% responses and the structural artefact received 9,52% responses on the "to a limited extent" scale. Knowledge from design practice peaked at "to a fairly large extent" with 50% student responses for the educational toy and 61,90% responses for the structural artefact. This was followed by "extensively" in both the content areas: 40,91% responses to the education toy and 28,57% responses to the structural artefact.

The reason for the high design practice results is that the students had to follow the design process prescribed by the RNCS policy document. The assessment rubric used to assess students' portfolios was designed according to the prescribed phases of the design process, forcing the students to follow the design process in great detail. Students were also taught about the design aspects, i.e. functionality, aesthetics, ergonomics and value. They had to use these design principles during the design process to help them to make certain choices. Both the design process, as well as the design principles, were derived from design practice and students had to use them as "tools" in the design and making of their artefacts.

The differences observed between the two content areas on the "to a fairly large extent" and the "extensively" scales are negligible. Only three students more selected the "extensively" scale for the educational toy than for the structure. Two students more selected the "to a limited extent" scale for the structure than for the educational toy.

The open-ended question asked students to give examples of knowledge items they used from design practice. Examples of students' answers relating to the educational toy:

> *Kennis van visuele estetika & simmetrie (s23230879).*
> Translated as:
> *Knowledge of visual aesthetics & symmetry (s23230879).*
>
> and
>
> *The colour wheel (s23219272).*

Examples of students' answers relating to the structure:

> *Vorm, grootte en kleur van artefak (s23230879).*
> Translated as:
> *Shape, size and colour of the artefact (s23230879).*

and

Materiale wat gebruik kan word (s23215552).

Translated as:

Materials that can be used (s23215552).

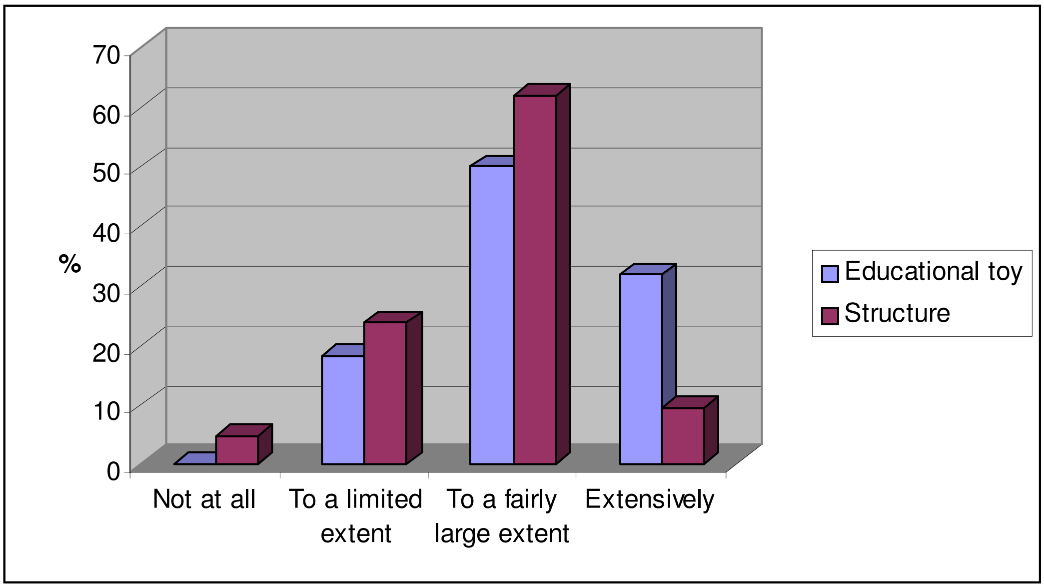
The students' answers focused mostly on the design aspects they were taught at university in previous years. A number of answers relating to colour theory were found. The short answers again lacked detail, making it difficult to comment on them.

4.3.6 Production

The making (production) of an artefact could result in practical considerations that were not comprehended during design. Production can, for example, reveal that a material is too thin and too large, which can lead to cracking or that a machine is too large, which limits the operating space on the floor (Vincenti, 1990:233). Refer to the description of this knowledge-generating activity in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they derived knowledge from production. Graph 19 indicates in percentages the results and comparison between the two content areas for the knowledge acquired through production.

Graph 19: Production – comparison between the two content areas



Both the educational toy (50%) as well as the structural artefact (61,9%) were rated highest at the "to a fairly high extent" and lowest at the "not at all" scales with 0% and 4,76% responses respectively. The educational toy received 31,82% responses on the "extensively" scale and 18,18% responses on the "to a limited extent" scale. The structural artefact, on the other hand, received 23,81% responses on the "to a limited extent" scale and 9,52% responses on the "extensively" scale.

The difference observed between the two content areas on the "extensively" scale shows that the students indicated that they derived more knowledge from production during the educational toy capability task. This could be attributed to the 'newness' to the students of electrical systems and control compared to structures. It is possible that the making of the toy revealed more information which was not comprehended during design to the students, mainly because of their unfamiliarity with systems and control and their resultant inability to foresee all aspects of the design.

The open-ended question asked students to give examples of the knowledge they derived from production during the making of the artefacts. Examples of students' answers relating to the educational toy:

> *Materiaal was te sag om metaallaste te gebruik (s20169206).*
> Translated as:
> *Material was too soft to use metal joints (s20169206).*
>
> and
>
> *Die hout was te dun en ek moes die hele struktuur versterk (s23152096).*
> Translated as:
> *The wood was too thin and I had to reinforce the whole structure (s23152096).*

Examples of students' answers relating to the structure:

> *Die knippie was te klein om die boks toe te hou (s23208172).*
> Translated as:
> *The latch was too small to keep the box closed (s23208172).*

and

Om die dikte van die material in berekening te bring by berekeninge (s23230879).

Translated as:

To take the thickness of the material into considerarion during the calculations (s23230879).

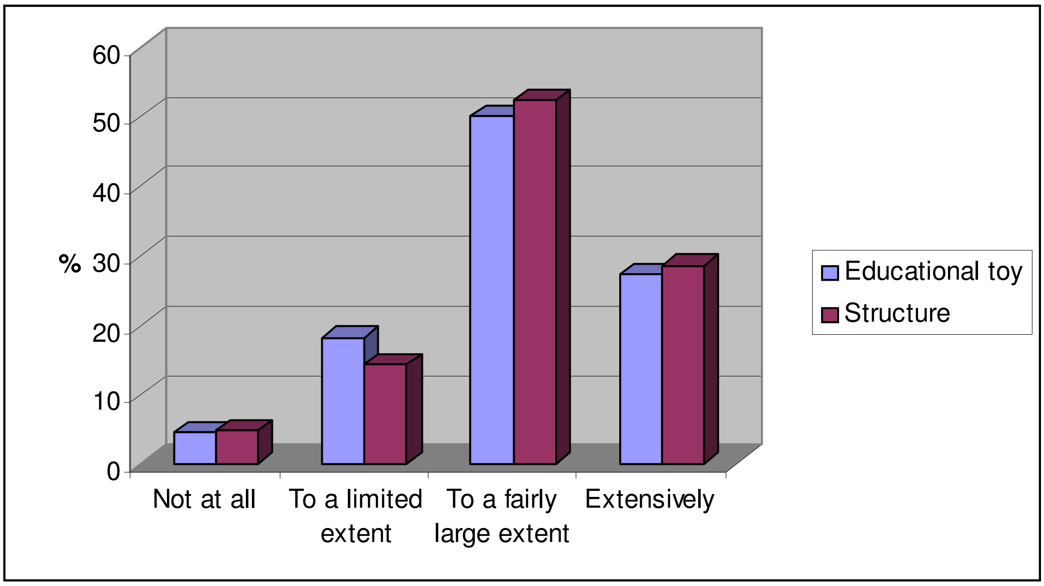
The students' answers seem to describe the typical problems that inexperienced people (students) encounter when making artefacts, due to a lack of relevant tacit knowledge. Many of their problems were not comprehended by the students during the designing phase, but were discovered and solved during the making phase of the design process.

4.3.7 Direct trial

In order to test the devices they design, engineers conduct a *proof test* to determine whether the devices (artefacts) perform as intended. Likewise, consumers who buy the devices put them to use in everyday life. Both kinds of direct trial provide design knowledge (Vincenti, 1990:233-234). Refer to the description of this knowledge-generating activity in section 2.5.1.

For this questionnaire item students had to indicate the extent to which they evaluated (tested) the artefact in order to determine whether it does what it was designed to do. Graph 20 indicates in percentages the results and comparison between the two content areas for the knowledge acquired through direct trial.

Graph 20: Direct trial[1] – comparison between the two content areas



Both the educational toy and the structural artefact were rated highest on the "to a fairly high extent" scale with 50% and 52,38% responses respectively. This was followed by the "extensively" scale on which the educational toy received 27,27% responses and the structural artefact 28,57%. The "not at all" scales were rated lowest for both the educational toy (4,55%) and the structural artefact (4,76%). No major differences were observed between the two content areas in the extent to which the students evaluated (tested) the artefacts in order to determine whether they do what they were designed to do.

The open-ended question asked the students to state what they discovered during the direct trial. Examples of students' answers relating to the educational toy:

> *Die skuinsvlak het effens hakkerig beweeg, nie so egalig nie (s23080532).*
> Translated as:
> *The inclined plane moved gawkily, not very smoothly (s23080532).*
>
> and
>
> *The batteries ran flat very quickly (s23215292).*

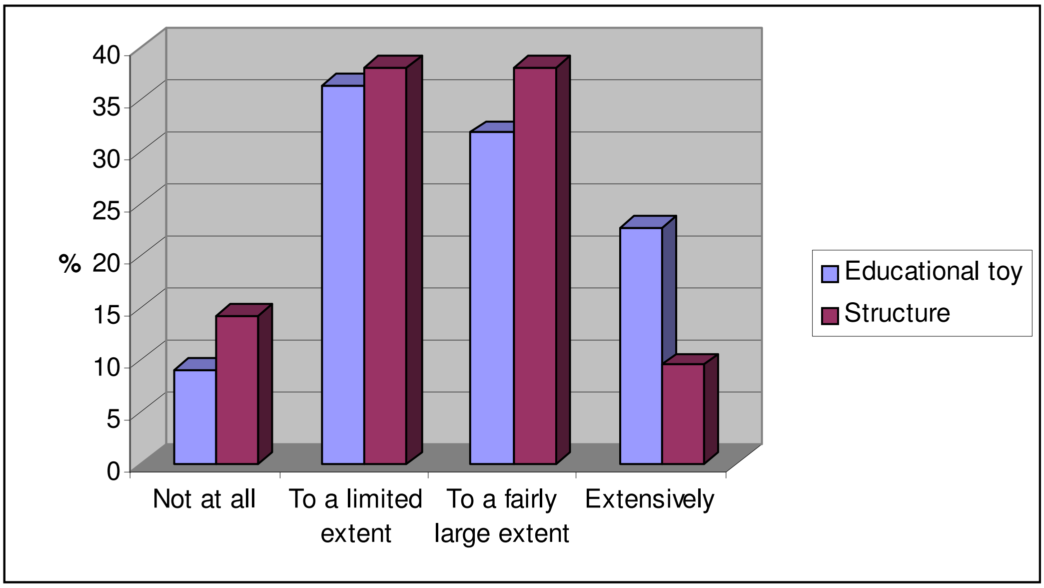
Examples of students' answers relating to the structure:

> *As die wind nie sterk genoeg is nie, wil die vlieër glad nie vlieg nie (s23215552).*
> Translated as:
> *The kite does not fly if the wind is not strong enough (s23215552).*
>
> and
>
> *Dele (van die struktuur) sukkel om uitmekaar te haal (s23080532).*
> Translated as:
> *It is difficult to separate parts (of the structure) (s23080532).*

Testing of the artefact was performed during the 'evaluating' phase of the design process. The students' answers seem to report on some of the problems they identified during the testing of the artefacts.

For the second part of this questionnaire item students had to indicate the extent to which they used the knowledge acquired about the artefact's shortcomings during the direct trial to improve the design or at least make suggestions to improve the design.

Graph 21: Direct trial² – comparison between the two content areas



The "to a limited extent" scale was rated highest for both the educational toy (36,36%) and the structural artefact (38,10%). This was followed by the "to a fairly large extent" scale where the educational toy received 31,82% responses and the structural artefact 38,1% responses. The educational toy also received 22,73% responses on the “extensively” scale and 9,09% responses on the “not at all” scale. The structural artefact, on the other hand, received 14,29% responses on the “not at all” scale and 9,52% responses on the “extensively” scale.

The difference observed between the two content areas on the “extensively” scale shows that the students indicated that they used the knowledge acquired about the shortcomings of the artefact during the direct trial to improve the design (or at least make suggestions to improve the design) to a higher extent during the educational toy capability task. A possible reason might be because structures are included in the final module in the third year. During this time of the year the students’ workload increases as a result of due dates for assignments in other subjects (especially year modules), which are scheduled towards the end of the year. The students therefore claimed that they did not have time to make the necessary improvements to their artefacts. It is also suspected that they were tired (towards the end of the year), and laziness might also be a contributing factor.

4.3.8 Relationship in the knowledge-generating activities between the two content areas

The Pearson product moment correlation coefficient (*r*) was again used to establish whether a relationship exist in the extent to which students have made use of the knowledge-generating activities between the two content areas. Table 14 shows the Pearson’s *r* for each knowledge-generating activity.

Table 14: The relationship between the two content areas

Knowledge-generating activities	*r*
Transfer from science	+ .42
Invention	+ .24
Theoretical research	+ .72
Experimental research	+ .84
Design practice	+ .93
Production	+ .81
Direct trial[1]	+ .99
Direct trial[2]	+ .81

For a study involving 22 students, (df[29] = 20), a coefficient of .54 is needed to be significant at the .01 level (Ary et al., 2002:361,548). Six of the eight relationships shown in table 14 were statistically significant at the .01 level since their *r* values are higher than .54 and these relationships are less likely to be a function of chance, since there is only a 1 in 100 possibility of chance.

One relationship (for the knowledge-generating activity pertaining to transfer from science) is significant at the .05 level with an *r* value of .42. This relationship is therefore also statistically significant with only a 5 in 100 possibility of chance.

One relationship for the knowledge-generating activity pertaining to invention is not significant at the .10 level with its *r* value of .24 and this relationship has a higher probability to be a function of chance than the other seven relationships shown in table 14.

Five of the seven knowledge-generating activities (direct trial counts as one activity only) show a strong positive relationship between the two content areas (according to table 9). This means that the students have drawn knowledge from these knowledge-generating activities to nearly the same extent in both the content areas. Transfer from science shows a moderate positive relationship ($r = + .42$) and invention shows a weak positive relationship ($r = + .24$) between the two content areas.

4.4 Conclusion

The data and results obtained from the questionnaire in the quantitative phase of this study shows that the “to a fairly large extent” scale was selected by the highest number of students in seven of the nine categories of technological knowledge in the design and making of the educational toy. The other two categories were quantitative data (prescriptive knowledge) and collaborative design knowledge, regarding which most students selected the “extensively” and the “not at all” scales respectively.

These trends were also observed in the designing and making of the structural artefact. The highest number of students selected the “to a fairly large extent” scale in eight of the nine categories of technological knowledge. The category of collaborative design knowledge received, similarly to the educational toy capability task, the highest number of student responses on the “not at all” scale.

[29] df = N – 1

The highest number of students selected the "to a fairly large extent" scale in the knowledge-generating activities section for six of the seven knowledge-generating activities in the design and making of the educational toy. Transfer from science received the highest number of responses on the "to a limited extent" scale.

For the structural artefact, the highest number of students selected the "to a fairly large extent" scale in four of the seven knowledge-generating activities. Invention and experimental research received the highest number of responses on the "to a limited extent" scale, while transfer from science received the most responses to the "not at all" scale.

The high level of student engagement in most of the categories of technological knowledge and knowledge-generating activities in both content areas, seem to indicate that the conceptual framework chiefly derived from and used by professional engineers, is useful to technology education. One important aspect in the 'usefulness' of the framework is that it is apparently able to distinguish between two capability tasks, showing how they differ in knowledge used and drawn from. This is significant if one wants to use the framework to determine if one course is better in displaying the full spectrum of technological knowledge than another.

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Data and results of the qualitative phase Chapter 5

5.1 Overview of the chapter

This chapter presents the data and results of a content analysis performed on the students' project portfolios for both the educational toy and the structural artefact using the conceptual framework presented in table 5 of this study. The portfolios were used to search for evidence of knowledge-generating activities which contributed to each of the categories of technological knowledge shown in table 4. It should be noted that the qualitative data was used for an entirely different purpose than the quantitative data: The quantitative data investigated the frequencies of knowledge in which students engaged, and the correlation of the knowledge engagement by the students between the two content areas. The qualitative data, on the other hand, informed *what* knowledge the students used and *how* they used it to complete the capability tasks.

The data and results in this chapter will be presented by listing the categories of technological knowledge as headings. After introducing the category of technological knowledge, the knowledge-generating activities that contributed directly to the category of technological knowledge will be listed. This will be followed by a discussion of each of the knowledge-generating activities as they relate to the specific category of technological knowledge. Each discussion will be presented in the following format:

- an introduction to the knowledge-generating activity;
- an introduction to the evidence of the knowledge-generating activity found in the students' portfolios relating to the category of technological knowledge;
- the evidence (quotation, sketch, etc.) from the students' portfolios; and
- a discussion of the evidence from the students' portfolios.

As the chapter progresses, the format will change slightly because most of the knowledge-generating activities contribute to more than two categories of technological knowledge. Consequently, instead of repeating the same explanation of the knowledge-generating activity, it will be explained only in the introduction when the knowledge-generating activity is first encountered. Thereafter the discussion will start with the introduction to the evidence found in the students' portfolios.

5.2 Categories of technological knowledge

Although each category of technological knowledge will be dealt with separately it should be reiterated that neither the categories nor the activities are mutually exclusive. As pointed out by Vincenti (1990:235), an item of knowledge can belong to more than one category and activity. This will be evident during the following discussion in which cross-references will be made between the various categories and activities.

5.2.1 Fundamental design concepts

This category of technological knowledge includes both the knowledge of the operating principles of artefacts as well as the knowledge of the general shape and arrangement of the artefacts that are commonly agreed to best embody the operating principle, i.e. the normal configuration (Vincenti, 1990:208-209). Refer to the detailed description of the category of fundamental design concepts in section 2.5.1.

Examples of the following knowledge-generating activities, which contribute to fundamental design concepts, were found in the students' project portfolios:

- theoretical engineering research;
- experimental engineering research; and
- direct trial.

The abovementioned knowledge-generating activities are closely aligned with Vincenti's (1990:235) proposed framework regarding fundamental design concepts. The invention activity of which no evidence could be found in the students' portfolios, is omitted here, although it appears in Vincenti's (1990:235) framework. This does not, however, imply that the students did not engage in the act of invention since they indicated in the quantitative phase of this study that they acquired knowledge through invention from "a limited extent" (structures) to "a fairly large extent" (educational toy). Although Vincenti (1990:230) notes that contriving such fundamental concepts – or coming onto them by serendipity – are by definition an act of invention, it is unlikely that the students tested whether these perceived inventions were indeed original. Also, the students did not explicitly indicate in the portfolios what knowledge was acquired through invention. In addition, the elusive nature of knowledge produced through this activity makes it problematic to identify such knowledge in the portfolios. Although some invention on a limited scale is acknowledged, the results in the quantitative phase relating to invention, i.e. the students' belief that they invented new concepts, could be attributed to their lack of experience, knowledge and exposure.

The discussion will now focus on evidence found in the students' project portfolios of the knowledge-generating activities that contribute to fundamental design concepts.

5.2.1.1 Theoretical engineering research

Vincenti (1990:230) notes that a large number of modern-day engineers, mostly in academic institutions, research laboratories, etc. work to produce knowledge through theoretical research. Vincenti (1990:230) defines "theoretical" in this context as synonymous with "mathematical", referring to concepts such as the working out of "new mathematical tools" and "sophisticated theoretical analysis". For reasons explained in section 3.4.3, the meaning of theoretical research will be expanded to include research activities involved in the acquisition of what Vincenti (1990:206) refers to as "stored-up knowledge". Such activities will, for example, include a literature study, interviews, class discussions and class notes.

Fundamental design concepts that come from theoretical research were found in a student's (s23080532) educational toy project portfolio (see figure 3 in section 3.6.1 for a photograph of the educational toy). The student demonstrated an understanding of the operating principle of a pulley by acknowledging that a single pulley can change only the direction of movement of a load and that if mechanical advantage is needed, two or more pulleys are required.

> *Indien die tou getrek word, kom die las in beweging. Die las kan op of af beweeg word. 'n Katrol laat die … rigting van beweging verander… Meganiese voordeel kom in wanneer meer as een katrol gebruik word…Deur meer katrolle te gebruik word die afstand vergroot wat die tou getrek moet word. Twee katrolle sal die inspanning halveer, maar die tou sal twee keer verder getrek moet word (s23080532:9).*
>
> Translated as:
>
> *If the string is pulled, the load will come into motion. The load can be moved up or down. A pulley allows … a change in the direction of movement … Mechanical advantage is achieved when more than one pulley is used … By using more pulleys, the distance the cord must be pulled is increased. Two pulleys will halve the force required, but the cord will have to be pulled twice the distance* (s23080532:9).

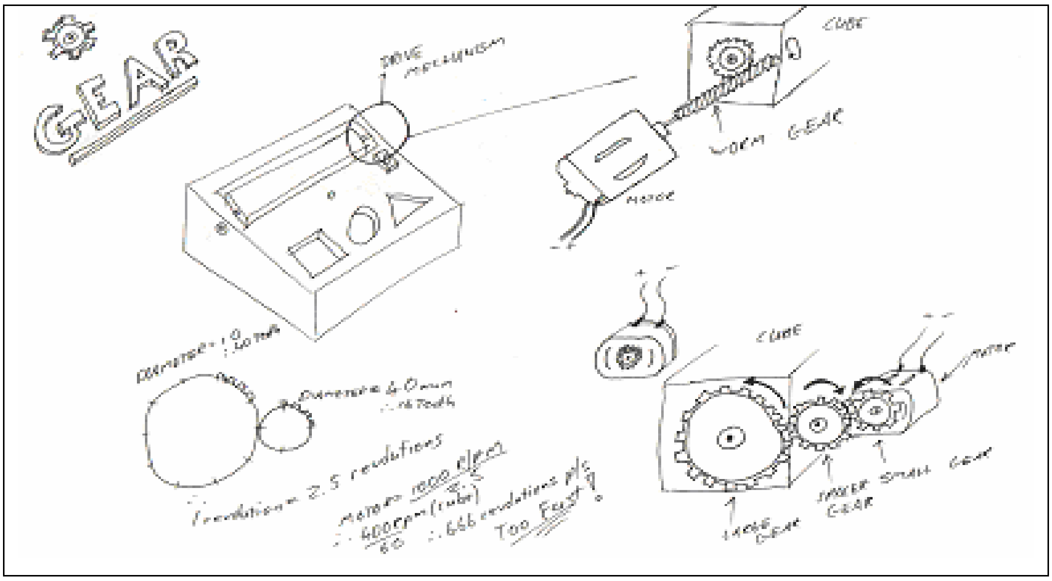
The citation above provides an explanation of how two or more pulleys are able to provide mechanical advantage: the force required to lift a load can be decreased by increasing the number of pulleys – therefore increasing the distance the rope must be pulled → **W**ork = **F**orce x **D**istance. The formula (theoretical tool) was, however, not included in the students' explanation, but it is clear that the student has a clear understanding of how a single pulley and a pulley system work, i.e. fundamental design concepts. The source the student consulted was referenced in the text and listed in the bibliography, indicating that the knowledge was obtained by means of theoretical research.

5.2.1.2 Experimental engineering research

Vincenti (1990:231) identifies experimental research as the major source of quantitative data. As pointed out in the detailed description in section 2.5.1, such research requires special test facilities, experimental techniques and measuring devices. Since technology education students at the University of Pretoria do not have access to such special testing facilities and instruments as engineers have, it can be assumed that experimental research takes a more basic form. The knowledge acquired, for example, through simple observation techniques might not provide the same kind of quantitative data as a sophisticated measuring device would, but could still provide valuable design data and ways of thinking that can influence the normal configuration of the device.

Such fundamental design concepts derived from basic experimental research in conjunction with theoretical research were found in the students' (s23230879 & s23046377) project portfolio for the educational toy (see figure 2 in section 3.6.1 for a photograph of this educational toy). These students needed a mechanical system that could transfer the rotation of the motor's output to the spindle. In addition they needed to reduce the high rotation speed of the motor to a more suitable speed at the spindle. They first experimented with a gear system, demonstrating their theoretical researched knowledge regarding the shared operating principle and normal configuration of gear systems: If a small driver gear is connected to a larger driven gear, the rotation speed of the driven gear will be smaller than that of the driver gear – thus reducing the rotation speed. This is illustrated by means of the annotated sketches depicted in figure 9.

Figure 9: Annotated sketch showing a possible solution using a gear system



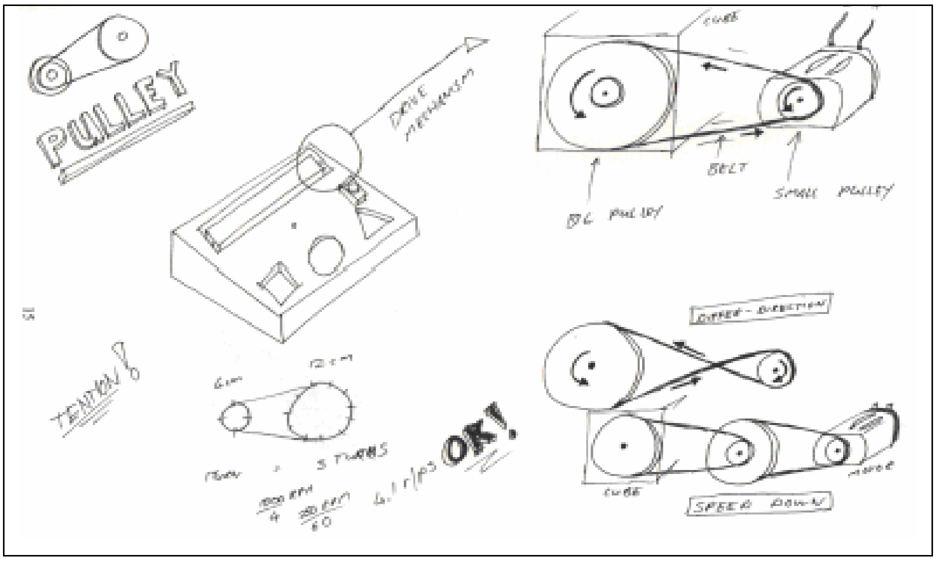
From figure 9 it is clear that the students decided, based on a theoretical calculation (theoretical tool), that the output rotation speed of 6,66 revolutions per second (rps) was too high. This calculated output speed (quantitative data) did not however take the effect of motor torque, the weight of the spindle, which is a solid block of wood, and friction into consideration. They could therefore not predict exactly whether the speed was really too high without visually observing the performance of the gear system through experimental research. The experiment revealed that the speed was indeed too high, which resulted in problems as cited in their project portfolio:

> *… maar ons het gevind dat die spoed van die motortjie te hoog is en dat hy die rat strip of uit sy monteringsrakkie spring as gevolg van sy hoë spoed (s23230879 & s23046377:5).*
>
> Translated as:
>
> *… but we found that the speed of the motor is too high and that it strips the gear or that it jumps out of its mounting bracket as a result of the high speed (s23230879 & s23046377:5).*

They discovered through theoretical and experimental research that the gear system did not work: The output speed was too high and resulted in various problems with the gear system, as well as its mounting. These problems called for a rethink in terms of components and the normal configuration of the design, since they “did not have access to other gears or another motor” (s23230879 & s23046377:5). It should be noted that all the students in this course are full time students with little or no additional income and the cost to design and make an artefact was limited, as they had to provide their own funds.

Although the financial constraint had an impact on the components and other resources at their disposal, it provided more richness in data for this study, since they (the students) had to be innovative to find alternative solutions to solve their design problems. In an attempt to solve their speed problem they (s23230879 & s23046377:5) replaced the gear system with a pulley system, which they had at their disposal, as illustrated in figure 10.

Figure 10: Annotated sketch showing a possible solution using a pulley system



The pulley system shown in figure 10, produced an output speed of 4,1 rps and resulted in a lower rotation speed than that of the gear system design. Through theoretical and experimental research they decided that this rotation speed (of 4,1 rps) was acceptable. In addition, the experimental research revealed that they had greater control of the position in which the spindle stops, which is vital for playing this game.

> *… dit is moontlik deur die skakelaar te gebruik om die spindle te laat stop waar jy wil hê dit moet stop (s23230879 & s23046377:6).*
>
> Translated as:
>
> *… it is possible by using the switch, to stop the spindle where you want it to stop (s23230879 & s23046377:6).*

The students did not explain why the same control could not be achieved by means of the gear system, but it could be because it was more difficult to control the spindle position due to the higher speed that resulted from the gear system.

The foregoing demonstrates the students' knowledge of a shared operating principle and normal configuration in both designs depicted in figure 9 and figure 10. The students knew how to arrange the gear and the pulley system to best embody the operating principle.

They knew for example, that in order to achieve speed reduction, the small driver gear/pulley needed to be connected to a larger driven gear/pulley. It is clear from both the cited text as well as the annotated sketches that the students came upon these fundamental design concepts through a combination of experimental and theoretical research. This combined approach is "often most fruitful" (Vincenti, 1990:232).

5.2.1.3 Direct trial

Proof tests determine whether a design performs as intended and can include tests conducted by the engineer, as well as everyday use by customers, since some information is revealed only over time, operation and everyday use. Both kinds of direct trial provide essential design knowledge (Vincenti, 1990:233-234). Refer to the detailed description of direct trial in section 2.5.1.

The students were required to test their artefacts against criteria derived from the design specifications that include, *inter alia*, functionality, ergonomics, aesthetics and value as part of the "evaluate" phase of the design process. They then had to make suggestions for improvements based on the results. Evidence of fundamental design concepts that come from direct trial was found in the students' (s23044170 & s23208636) project portfolio for the educational toy (see figure 4 in section 3.6.1 for photographs of this educational toy). They (s23044170 & s23208636) discovered through direct trial that it would be easier to draw something constructive by making some modifications to the drawing toy:

> *We feel that next time the pen should be fixed and the base moving freely. This would be easier for the child to draw something constructive and … making it easier for the child …(s23044170 & s23208636:12).*

In its present form the drawing toy allows the pen, attached to a pendulum, to swing/rotate freely while the base rotates by means of a motor. Although the speed of the motor can be adjusted by means of a variable resistor and the height of the pen can be adjusted by means of a ratchet and pawl, the drawings produced by this toy are limited to a meaningless scribble. This might be "fun" for a limited time, but it has little educational value, which was a prerequisite for the toy. The proposed modifications would require more hand-eye coordination, which could result in more meaningful drawings and the psychomotor exercise demand will have educational value. These modifications will contribute to the normal configuration of the artefact and are hence considered to be part of the fundamental design concept.

5.2.2 Criteria and specifications

To design a device, the designer must know the specific requirements of the hardware. This entails that the general, qualitative goals of the device need to be translated into specific, quantitative goals couched in concrete technical terms. To accomplish this, knowledge of technical criteria appropriate to the device and its use is needed (Vincenti, 1990:211). Refer to the detailed description of the category of criteria and specifications in section 2.5.1.

The following knowledge-generating activities that contribute to criteria and specifications were found in the students' project portfolios:

- theoretical engineering research;
- experimental engineering research;
- design practice; and
- direct trial.

The abovementioned knowledge-generating activities are akin to Vincenti's (1990:235) proposed framework regarding the category of criteria and specifications. Evidence of the knowledge-generating activities that contributes directly to this category, which was found in the students' project portfolios, is now under discussion.

5.2.2.1 Theoretical engineering research

As part of the design phase of the design process, students have to conceptualise and specify the design specifications and constraints of an identified problem. This is followed by the generation of a range of possible solutions that have links to the design brief and the specifications and constraints. The final solution is then chosen for development from this range of possible solutions.

An example of criteria and specifications originating from theoretical research, was found in a student's project portfolio for the educational toy. This student (s23080532) stated general qualitative criteria as specifications and constraints regarding the toy. The design specifications took design aspects into consideration as they relate to the needs and wants of the target for which the artefact is intended, i.e. children:

> *Die speelding moet met batterye werk (s23080532:16).*
>
> *Die speelding moet veilig wees … die liggies moet nie te warm word … wat gevaarlik vir die leerder is nie (s23080532:15).*
>
> Translated as:
>
> *The toy must operate with batteries (s23080532:16).*

The toy must be safe … the lights should not get too warm … which can be dangerous to the learner (s23080532:15).

The first criterion cited above entails ensuring the portability of the toy and relates to the second criterion, which demands safety. A battery will be much safer than the high voltage of the general household electricity supply and will allow the user to play with the toy anywhere.

Based on the foregoing general qualitative specifications, the student then made technical choices to comply with the specifications:

Die kragtoevoer is 9 V – 'n spanning wat geen gevaar vir die leerders inhou nie (s23080532:17).

'n LED is gebruiksvriendelik … dit word nie te warm nie (s23080532:15).

Translated as:

The power supply is 9V – a voltage which is not dangerous to learners (s23080532:17).

An LED is user-friendly … it does not get too warm (s23080532:15).

It was decided that a 9-volt battery would suffice in terms of voltage safety and that a light emitting diode (LED), due to its low heat emission, was appropriate, as it posed no danger to the learner. These choices, however, called for theoretical research, as an LED will be damaged if it is connected directly across the 9-volt supply. Through theoretical research it was established that some of the normal operating parameters[30] of a LED are:

V_L *= spanning oor LED = 2V*

I = stroom deur LED = 20 mA (s23080532:12).

Translated as:

V_L *= voltage across LED = 2V*

I = current through the LED = 20 mA (s23080532:12).

To obtain these values, using a 9-volt battery as supply, a resistor must be connected in series with the LED. The circuit diagram, in the student's (s23080532) project portfolio and shown in figure 11, illustrates this connection[31].

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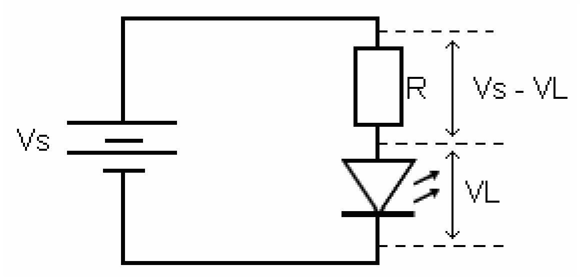
[30] Cross-reference: also refer to theoretical engineering research contributing to the category of quantitative data. The operating limits of the LED are an example of prescriptive data.

[31] This connection is another example of the fundamental design concepts in terms of normal configuration. This student knew that an LED was needed to be connected in series with a resistor in order to protect it from too high voltage.

Figure 11: Light emitting diode (LED) circuit diagram (s23080532:12)



The value of the resistor R in figure 11 was then calculated using the following formula[32] (s23080532:12):

$$R = \frac{V_S - V_L}{I}$$

V_S = Supply voltage
V_L = Voltage across the LED
I = Current in circuit

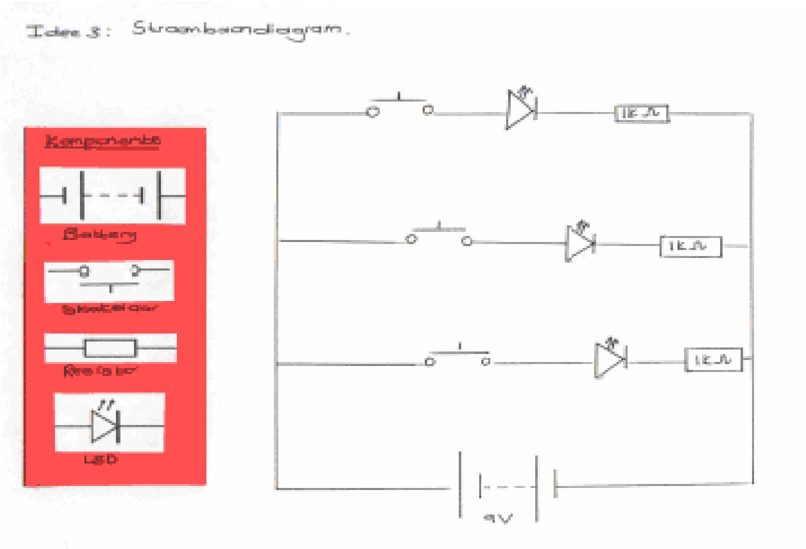
The theoretical value of the resistor was calculated to be 350 Ω, but the resistor with the closest value to this, which the student had available, was a 1 000 Ω (1 kΩ) resistor which was then used (s23080532:12). Although this resistor was higher in value, it worked, as the student noted:

> *…dit gaan die LED ongelukkig flouer laat brand (s23080532:12).*
>
> Translated as:
>
> *…this will unfortunately result in the LED burning less brightly (s23080532:12).*

Since the voltage drop across the 1 kΩ resistor will be higher compared to a 350 Ω resistor, the voltage across the LED will be lower than the stated norm of 2-volt. According to Ohm's law[33], the higher value resistor (1 kΩ) will result in a lower flow of current in the circuit which will result in the LED glowing less brightly than if a 350 Ω resistor were used. Figure 12 depicts the circuit diagram showing the values of the resistors and supply voltage as design criteria.

[32] Cross-reference: refer also to the category of theoretical tools. Theoretical tools include simple formulas for direct calculation.
[33] Refer to section 5.2.3.1 for a description of Ohm's law.

Figure 12: Circuit diagram depicting the value of the resistors in series with the LED (s23080532:12)



From the foregoing it is clear that the student (s23080532) weighed criteria and specifications that took the needs of the learner/child into consideration. Theoretical researched knowledge was demonstrated when the student translated the general qualitative goals into concrete quantitative technical terms. This was done on component level during which numerical values were assigned to those components, i.e. the norms and standards of the LED, the value of the resistor and the battery voltage.

5.2.2.2 Experimental engineering research

As pointed out earlier, an item of knowledge can belong to more than one category and activity of knowledge. The experimentally researched knowledge presented in the category of fundamental design concepts section (refer to the annotated sketches depicted in figure 9 and 10 and the relevant text), also applies to the category of criteria and specifications.

The students (s23230879 & s23046377:11-12) decided that since their toy was to be used by children between two and six years of age, the safety aspects regarding the toy were a major concern. One safety aspect considered was the rotation speed of the spindle:

> *Die veiligheidaspek van die speelding … Die spindle kan 'n probleem wees vir sy hoë spoed … (s23230879 & s23046377:11-12).*
>
> Translated as:
>
> *The safety aspect of the toy … The spindle can be a problem in terms of its high speed … (s23230879 & s23046377:11-12).*

Although the students acknowledged that a high rotation speed could be dangerous, they did not assign any value or limit to the rotation speed at this stage. It was only through experimental research they could observe whether the spindle rotated too fast, since their theoretical calculations did not account for the motor torque, friction and mass of the wooden spindle. Only after the experimental research was done, did they decide that a rotation speed of 4,1 rps[34] (performance specification) was acceptable in terms of safety and operation.

5.2.2.3 Design practice

Vincenti (1990:232-233) notes that day-to-day design practice not only uses engineering knowledge, it also contributes to it. It is important to be acquainted with what designers do to be able to identify knowledge arising from design practice. Cross (2002:127) identifies four major aspects of what designers do. They:

- produce novel and unexpected solutions;
- tolerate uncertainty, as they work with incomplete information;
- apply imagination and constructive forethought to practical problems; and
- use drawings and other modelling media as means of problem solving.

Although the technology education students at the University of Pretoria are not professional designers, they do engage in design activities as described above. It is, however, accepted that they cannot contribute to engineering knowledge as professional designers would, and it is also accepted that the criteria they specify for their design solutions will be less complex and complete. The search for evidence was therefore limited to finding knowledge arising from the abovementioned design activities, which resulted in criteria and specifications for the students' own artefacts.

As part of the design phase of the design process, students had to make use of sketches and drawings as a way to explore the problem in an attempt to find solutions. This is, according to Cross (2002:127), one of the major aspects of what designers do and the search for evidence of "design practice" which contributed to the category of criteria and specifications therefore centred around the drawings. An example of such a drawing was found in a student's (s23230879:16) portfolio of the structural artefact (see figure 5 in section 3.6.2 for a photograph of this structure). This student (s23230879:16) needed to design and make a compact disc (CD) box, using only cardboard (cold pressed paper)

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[34] Cross-reference: also refer to experimental research contributing to the category of quantitative data. The performance specification is an example of prescriptive data.

and glue. It was required that the CD box be able to store 12 compact discs. The student made use of sketches to calculate the dimensions of the box, panels and triangular corrugations. Figure 13 depicts these sketches and the design calculations.

Figure 13: Sketches with design calculations

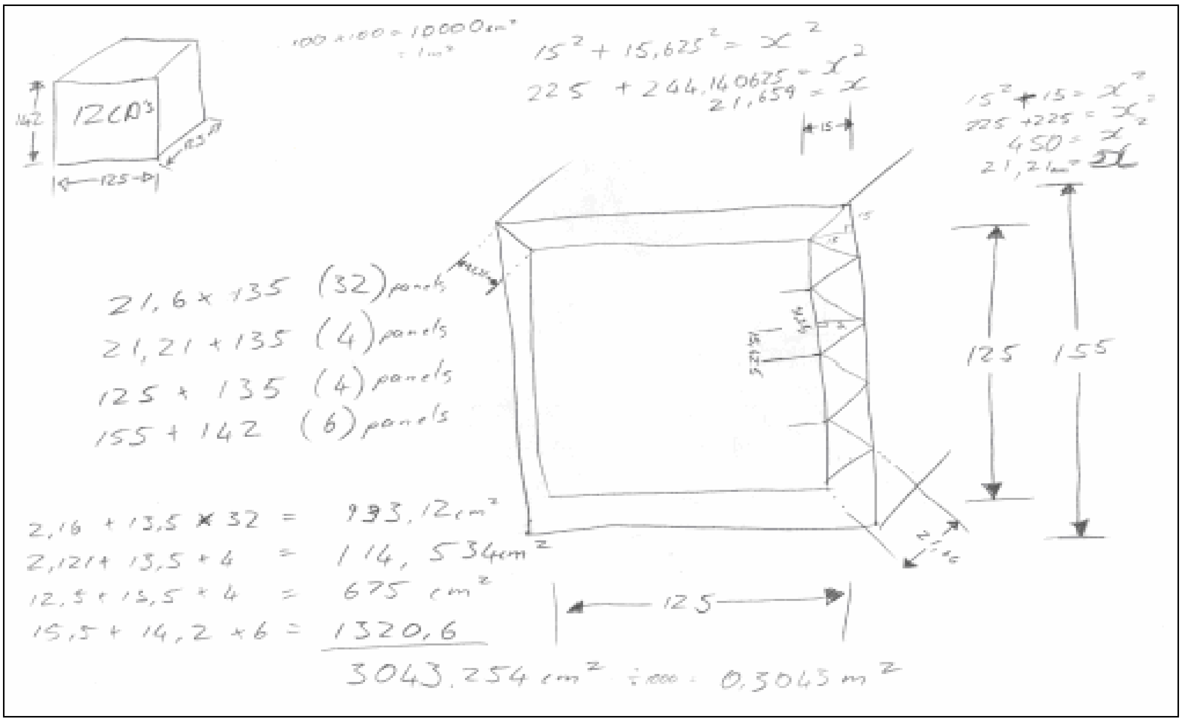


Figure 13 shows that the student (s23230879:16) used the dimensions of a single CD container (142 X 125 X 100) as point of departure to determine the dimensions of the inner box. As this was a box-within-a-box design, the sketches helped the student to visualise and calculate the dimensions of the outer box as well as the dimensions of the triangular corrugations, which were included for additional strength. These dimensions, arising from one of the major design activities (what designers do, i.e. design practice), using drawings as a means of problem solving, became the design specifications and criteria used to make the CD box.

5.2.2.4 Direct trial

Findings from direct trial serve to satisfy both designer and customer that the device will do what it is meant to do, or if it falls short, to suggest how it might be redesigned or corrected (Vincenti, 1990:233). As part of the evaluation phase of the design process, the students needed to test their artefacts to find out if their designs performed as intended. They were also expected to suggest sensible improvements (DoE, 2002:43).

Evidence of a suggestion for improvement, as a result of direct trial, was found in a student's (s23230879:28) portfolio of the structural artefact (refer to the previous discussion of the CD box). The student discovered during the evaluation of the CD box that the CDs did not fit into the box properly. The reason was that the student had not accounted for the thickness of the construction material (cardboard/cold pressed paper) during the design calculations:

> *In most of the design calculations the thickness of the material was not taken into account (s23230879:28).*

The dimensions resulting from these miscalculations caused the CDs to fit too tightly into the CD box. This made inserting and removing them difficult and caused damage to the CD box. Although the design calculations were not reviewed, the student suggested that the "calculations need to be improved and corrected" (s23230879:28). Such "improved and corrected" calculations would then serve as revised dimensions in the category of criteria and specifications. It is important to note that the RNCS for technology requires the students/learners only to suggest "sensible improvements" (DoE, 2003:43), and not to implement these improvements to correct their artefacts, during the evaluation phase of the design process. The students at the University of Pretoria are, however, penalised for not implementing proposed improvements. Even though they knew they would be penalised during the assessment at the end of the module, few students implemented the improvements they had suggested, most claimed that they ran out of time at the end of the module.

5.2.3 Theoretical tools

Theoretical tools include *mathematical methods and theories* as well as *intellectual concepts* for thinking about design. These concepts and methods cover a spectrum ranging from items generally regarded as part of science to items of a peculiarly engineering character (Vincenti, 1990:213). Refer to the detailed description of the category of theoretical tools in section 2.5.1.

The following knowledge-generating activities that contribute to theoretical tools were found in the students' project portfolios:

- transfer from science;
- theoretical engineering research;
- design practice; and
- direct trial.

The abovementioned knowledge-generating activities are, for the most part, in line with Vincenti's (1990:235) proposed framework regarding the category of theoretical tools. The experimental engineering research activity, of which no evidence could be found in the portfolios, is however, absent compared to Vincenti's (1990:235) framework. This finding was expected, since the RNCS does not require learners to be able to derive theoretical tools through experimental research. In addition, the students did not have access to special test facilities and measuring devices necessary to develop, for example, mathematical methods and theories.

On the other hand, evidence of design practice directly contributing to theoretical tools was found in the students' portfolios. This contribution was omitted from Vincenti's (1990:235) framework as he argues that design practice has an indirect influence on theoretical tools, and he lists only the immediate contributions (Vincenti, 1990:234). This aspect will be discussed in section 3.2.3.3.

Evidence of knowledge-generating activities found in the students' project portfolios and that contributes directly to theoretical tools, will now be discussed.

5.2.3.1 Transfer from science

Scientific knowledge in this study is taken as knowledge generated by scientists, who use it primarily to generate more scientific knowledge for the purpose of understanding. As pointed out in section 2.3, scientific knowledge also contributes to engineering knowledge. The transfer of such knowledge often entails reformulation or adaptation to make the knowledge useful for engineers (Vincenti, 1990:229).

The example of the formula from the student's project portfolio for the educational toy (s23080532:12), presented as theoretical researched knowledge in the category of criteria and specifications in section 5.2.2.1, is also an example of knowledge transferred from science. The adapted formula[35] (*mathematical methods and theories* - simple formula) used by this student is based on *Ohm's law*, the result of research by George Simon Ohm, a German physicist. The law states that in a direct current circuit, the current passing through a conductor is proportional to the potential difference, i.e. voltage drop or voltage, across the conductor, and inversely proportional to the resistance through which the current flows (Grob, 1986:26-30). The formula is written as:

35

$$R = \frac{V_S - V_L}{I}$$

V_S = Supply voltage

V_L = Voltage across the LED

I = Current in circuit

$I = \frac{V}{R}$ Where: I is the current in amperes
V is the potential difference in volts
R is resistance in ohms

This example, apart from being a simple formula adapted/reformulated to allow the design calculation, also provided the language (*intellectual concepts*) which allowed the thinking described in section 5.2.2.1. Such language includes basic ideas from science, such as electric current (Vincenti, 1990:216), resistance and voltage used by this student and focused upon in section 5.2.2.1. The student used the concepts (in section 5.2.2.1) for qualitative conceptualising and reasoning before and during engagement in the design calculation.

5.2.3.2 Theoretical engineering research

Ohm's basic formula described in section 5.2.3.1 (transfer from science), could not be applied as is, but was adapted and manipulated to calculate the value of the resistor in the light emitting diode circuit (refer to figure 11 in section 5.2.2.1). An understanding of basic electric circuit theory is required to be able to adapt the formula (shown in section 5.2.2.1) from Ohm's law. The student (s23080532:12) demonstrated the understanding that in order to calculate the value of the resistor needed to protect the light emitting diode in the circuit (figure 11), the voltage required in terms of Ohm's law is the voltage difference between the supply voltage (V_S) and the normal operating voltage across the light emitting diode (V_L). A common mistake amongst students not familiar with the basics of circuit theory is to make use of only the supply voltage (V_S) in Ohm's law. This student has thus demonstrated an understanding of basic circuit theory, which is assumed to be the result of knowledge acquired through theoretical research.

5.2.3.3 Design practice

Vincenti (1990:234) points out that his framework indicates the knowledge-generating activities only as they contribute immediately to the categories of knowledge, and that it omits indirect contributions. For this reason Vincenti (1990:234-235) does not indicate the "indirect influence" of design practice on theoretical tools in his framework.

Theoretical tools, however, include the *intellectual concepts* which provide the language "for thinking about design" (Vincenti, 1990:215). It can also be assumed that some of these intellectual concepts come from design practice, and therefore the immediate contribution of design practice to theoretical tools cannot be ignored or omitted from the framework.

As part of the students' training to help them conceptualise their ideas, they are expected to be explicitly conscious of the interrelationship between design aspects such as functionality, aesthetics, ergonomics and value. These design aspects (concepts found in design practice – see Press & Cooper (2003:11-64)), are usually considered whilst taking into account the manufacturing methods and materials involved in making the artefact.
The students use these concepts (design aspects) as a 'tool' to help them understand the problem and to guide them throughout the design process towards an appropriate solution. For example, during the investigation phase (DoE, 2002:35) of the design process they need to do an analysis of existing products that could solve the problem. During the analysis, the students must discuss the product in terms of the design aspects, indicate how each aspect influences the other and explain how it relates to the problem. This helps them understand the problem. To help them design an appropriate solution, the students need, during the design phase (DoE, 2002:39) of the design process, to generate a range of possible solutions (sketches) that are significantly different from each other. Each of their annotated sketches must show how the design aspects have been considered and how they link to the design brief and problem.

An example of how knowledge from design practice contributes to theoretical tools was found in a student's (s25258193:14-15) portfolio of the structural artefact (see figure 8 in section 3.6.2 for a photograph of this structure). This student (s25258193:2) needed to design and make a garden table to withstand all weather conditions in South Africa. The table had to be strong and stable enough to support and hold pot plants placed on its surface. It was decided to make the table mainly from plaster of Paris to align it with the assessment standards stated for grade 7, which focus on the specific properties and use of materials in structures, e.g. water resistance (DoE, 2002:46).

The following quotation demonstrates the student's (s25258193:14&15) knowledge of some of the design aspects:

> *… to use tiles for the texture and décor … they are smooth and have fine finishing touches. The plaster will be treated with "Hard as nails" varnish, and this adds value (by making it waterproof) … the shiny rough surface on the legs and with little crack-like antique lines on the surface (s25258193:14).*

The quotation above was provided under the heading of aesthetics. The student demonstrated a conscious understanding of the influence of the choice of materials on the appearance (and feel) of the table, especially how the choice of material can contribute to visual appeal. In addition, reference was also made to the design aspect of value. The student knew that the choice of material would not only influence the aesthetics, but also the value – the varnish would produce the 'crack-like antique' finish, but would also make it waterproof. These requirements were recognised from the outset, whilst considering functionality as design aspect:

> *The primary function [of the garden table] is to have a variety of pot plants on display in the garden.*
>
> *The secondary function of the garden table is to be a focal point in the garden – aesthetical attraction (s25258193:14).*

The primary function of the garden table implies that some kind of waterproofing is needed, since the table will be made mainly of plaster of Paris and it will be used in the garden. The secondary function demands visual appeal from the table, since it will be a focal point in the garden and will be used to display pot plants.

By considering the abovementioned quotations relevant to functionality and aesthetics, it seems that knowledge about the interrelationship between the design aspects helped the student to:

- understand the need/s and or problem/s by providing a 'language' (*intellectual concepts*) to articulate the need/problem(s); and
- conceptualise a solution/s in a structured way.

The quality of the students' solutions seems to be related to their ability to express themselves either verbally or non-verbally (e.g. through sketches). The design aspects add 'language' to their vocabulary, enabling them to give meaning to their thoughts effectively and therefore make a direct contribution to theoretical tools.

5.2.3.4 Direct trial

Proof tests can, according to Vincenti (1990:234), reveal that a theoretical tool used in design is inadequate. Such a discovery, resulting from a proof test, of an inadequacy in a design calculation (*mathematical method and theory*) was found in a student's (s23230879:28) portfolio of the CD box structural artefact (figure 5). During the evaluation phase of the design process, the student tested the CD box by checking whether the box could indeed store 12 compact discs (containers) as stipulated in the design specifications. It was found that the CD box did not *perform as intended* and the student suggested the following:

> *The second improvement, which would be made, concerns the calculations. In most of the design calculations the thickness of the material was not taken into account (s23230879:28).*

The design calculations mentioned in the quotation above refers to those shown in figure 13. The student discovered during the direct trial that the thickness of the construction material (cold press paper) had not been taken into account when the calculations were done. The student used the dimensions of a compact disc container as point of departure to determine the dimensions of the inner box, the outer box and the sizes of the triangular corrugations, but never considered the space taken up by the material itself. This inadequacy in the design calculation resulted in the CDs not fitting properly and was discovered during direct trial.

5.2.4 Quantitative data

Quantitative data, essential for design, is usually obtained empirically, but may also be calculated theoretically. It is typically represented in tables or graphs and divided into two kinds of knowledge, descriptive and prescriptive (Vincenti, 1990:216). Refer to the detailed description of the category of quantitative data in section 2.5.1.

The following knowledge-generating activities that contribute to quantitative data were found in the students' project portfolios:

- theoretical engineering research; and
- experimental engineering research.

Compared to Vincenti's (1990:235) framework, no evidence could be found in the portfolios of transfer from science, production and direct trial as knowledge-generating activities contributing to the category of quantitative data.

Although no evidence could be found in the portfolios of quantitative data transferred from science, it does not exclude the possibility that students could have transferred such data from science. It seems quite plausible that students could for example, have made use of a simple physical constant (descriptive knowledge) such as gravitational acceleration (cited as an example in the open-ended questions in section 4.3.1) in a theoretical tool, during their design calculations. Unfortunately no such example could be found in the students' portfolios.

Production of the artefact, in the context of this study, takes place during the making phase of the design process where students are expected to show dimensions and quantities in their formal drawings (DoE, 2002:41). These dimensions (quantities), however, are not the result of a 'practical consideration' due to production, but an extension of the design specifications and criteria taken from the design phase of the design process. An example of such a quantitative dimension is shown in figure 14.

Figure 14: Flat drawing showing quantitative dimensions

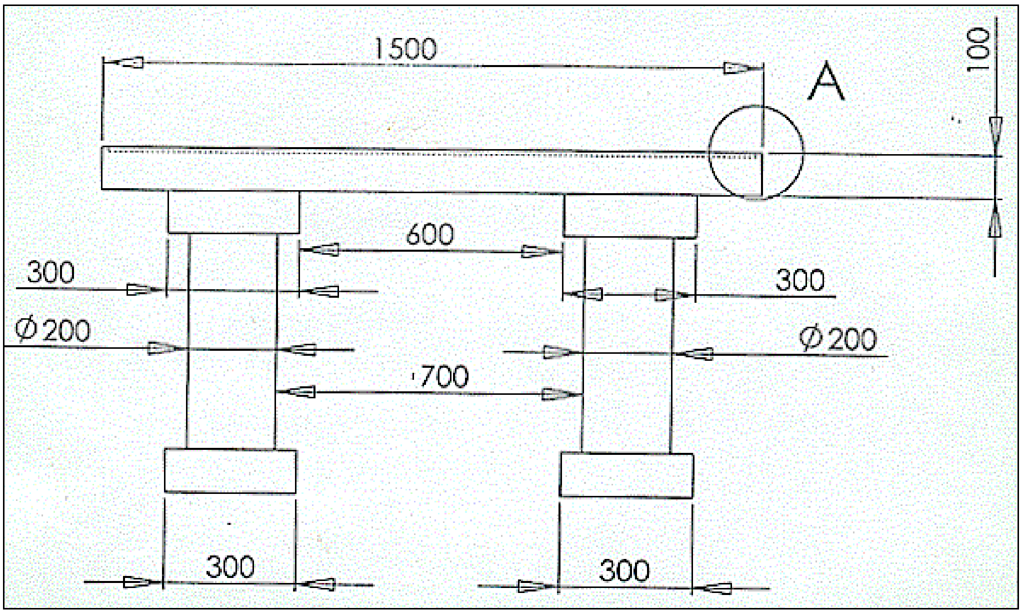


Figure 14 shows a flat drawing in which the dimensions of a table are indicated. As noted above, these quantitative dimensions are not the result of production, but a visual representation and quantification of the design specification and criteria. Given the limited time spent on making and the limited range of resources available to the students, the activity of production, in this context, is most likely not a major contributor to the category of quantitative data. This does, however, not exclude the possibility that the students contributed to quantitative data through the production activity. The limiting framework of the prescribed design process that the students used to structure their documentation, could also be a reason why no evidence of such contributions was found.

Direct trial, on the other hand, takes place during the evaluation phase of the design process. During this phase, the students' artefacts were tested against the need/problem and the design specifications and criteria. The results of the tests were then documented in the portfolio. Although part of this evaluation phase is to make sensible suggestions for improvements, no evidence of any data that contributed to the category of quantitative data was found in the students' portfolios. Even though an artefact such as the one depicted in figure 13, was found to be flawed in terms of the quantitative design specifications and criteria, which resulted in the box being too small, no quantitative data was suggested as a result of direct trial to correct the problem. All portfolios presented a mere qualitative 'report' on the tests that had been performed, the results of the tests and the suggestions for improvement. The lack of quantitative data from the evaluation phase of the design process could be due to the students' inherent resistance to working with this kind of data (Van Putten, 2008:32).

Evidence of the knowledge-generating activities that contribute to quantitative data as found in the students' project portfolios will form the focus in the next section.

5.2.4.1 Theoretical engineering research

A part of the example provided in section 5.2.2.1, indicating how theoretical engineering research contributes to the category of criteria and specifications also applies to the category of quantitative data. The student (s23080532:12) established the normal operating parameters (limits) of an LED through theoretical research:

> *V_L = spanning oor LED = 2V*
>
> I = stroom deur LED = 20 mA (s23080532:12).
>
> Translated as:
>
> *V_L = voltage across LED = 2V*
>
> *I = current through the LED = 20 mA* (s23080532:12).

These parameters (prescriptive quantitative data) were used, as discussed in section 5.2.2.1, to calculate the value of the resistor needed to be connected in series with the LED to protect it against the too high voltage source available to the student. The operating limits of the LED constitute prescriptive knowledge as they specify how things should be to attain the desired result.

5.2.4.2 Experimental engineering research

The example provided in section 5.2.2.2 of how experimental research contributes to the category of criteria and specifications, also applies to the category of quantitative data. Vincenti (1990:217) points out that technical specifications are prescriptive by virtue of how the device should fulfil its purpose. The example in section 5.2.2.2 (s23230879 & s23046377:11-12) describes how a spindle rotation speed of 4,1 rps was found, through experimental research, to be acceptable in terms of safety and operation. This rotation speed is a quantitative performance specification prescribing the acceptable spindle rotation speed.

5.2.5 Practical considerations

Practical considerations are learned mostly in the workplace, rather than in schools or from books, and designers tend to carry these considerations, sometimes more or less unconsciously, in their minds. The practice from which they are derived includes not only design, but production and operation too (Vincenti, 1990:217). Refer to the detailed description of the category of practical considerations in section 2.5.1.

The following knowledge-generating activities that contribute to practical considerations were found in the students' project portfolios:

- design practice;
- production; and
- direct trial.

The abovementioned knowledge-generating activities are akin to Vincenti's (1990:235) proposed framework regarding the category of practical considerations. Evidence of the knowledge-generating activities that directly contributes to this category, which was found in the students' project portfolios will now be discussed.

5.2.5.1 Design practice

Experience in design often produces knowledge that takes the form of design rules of thumb. These rules allow rapid design assessments and supply a rough check as a new design proceeds (Vincenti, 1990:218). An example of a practical consideration derived from design practice was found in a student's (s23080532:12) project portfolio for the educational toy. This example was the result of the theoretical research the student did in order to calculate the value of the resistor required to be connected in series with the LED as shown in figure 11. Refer to theoretical research as it relates to the category of criteria and specifications (section 5.2.2.1) for a detailed discussion of this example.

The student (s23080532:12) calculated that based on the operating parameters of the LED, a resistor of 350 Ω was needed to be connected in series with the LED. The student, however, did not have a 350 Ω resistor available, but noted that:

> *Indien die berekende resistor waarde nie beskikbaar is nie, kies dan die naaste resistor effens groter as die waarde wat bereken is, dit gaan die LED ongelukkig flouer laat brand (s23080532:12).*
>
> Translated as:
>
> *If a resistor of the calculated value is not available, choose the closest resistor slightly bigger than the value which was calculated, it will unfortunately result in the LED burning less brightly (s23080532:12).*

The citation above demonstrates that the student applied a design rule of thumb that, although it did not represent the first choice, it was safer to use a resistor of higher value than a resistor of lower value if the value that was theoretically calculated was not available. The only consequence is that the LED will not shine as brightly, as opposed to the danger of using a resistor of lower value, resulting in a higher current and possibly LED burnout.

5.2.5.2 Production

Production, as mentioned in section 5.2.4, takes place during the making phase of the design process. An example of knowledge from production contributing to the category of practical considerations was found in a student's (s25258193:33) portfolio of the structural artefact (see figure 8 in section 3.6.2 for a photograph of this structure). This student (s25258193) made a garden table consisting mainly of plaster of Paris in order to address the assessment standards stated for grade 7, which focus on the specific properties and use of materials in structures (DoE, 2002:46). As a solid table made of plaster of Paris would be too heavy (s25258193:15 &16), the student decided that the pillars (legs) of the table should be hollow. During the making of these pillars, the student experienced moulding and casting trouble:

> *The first mould that I made was in the gap between a fibre cement pipe and a PVC pipe in between, as they had different circumference sizes. That mould didn't work because I didn't apply plaster key to the PVC pipe so the pipe didn't slide out easily. It was also difficult to remove the fibre cement from the outside which I had to angle grind … it damaged the plaster of Paris mould (s25258193:33).*

The student discovered during the first attempt of the making process (production) of a hollow plaster of Paris pillar that the pillar remained stuck between the two pipes used as a mould. The student then realised the need for some kind of releasing agent on the surface of the mould:

… had to check that the moulds were waxed so that when I wanted to remove them they would come off easily (s25258193:33).

It was only after the failure of the first attempt that the student considered that a releasing agent such as floor wax was needed in order to allow an easy removal of the pillar from the encapsulating the mould. The student therefore derived the abovementioned consideration from practical experience during the making phase (production) of the design process.

5.2.5.3 Direct trial

As part of the evaluation phase of the design process, the students needed to test their artefacts to find out if their designs performed as intended. They were also expected to suggest sensible improvements[36] (DoE, 2002:43).

Evidence of a suggestion for improvement as a result of direct trial, was found in a student's (s23230879:28) portfolio of the structural artefact (see figure 5 in section 3.6.2 for a photograph of this structure). The student discovered during the evaluation of the CD box that the CDs did not fit properly into the box. The reason was that the student had not taken into account the thickness of the material (cardboard/cold pressed paper) during the design calculations (refer to figure 13):

In most of the design calculations the thickness of the material was not taken into account (s23230879:28).

The dimensions resulting from these miscalculations caused the CDs to fit too tightly into the CD box. This made inserting and removing CDs difficult and caused damage to the CD box. This problem was only revealed during the testing of the CD box in the evaluation phase of the design process. Although the design calculations were not reviewed, the student suggested that the "calculations need to be improved and corrected" (s23230879:28) to take the thickness of the material into account. Such a practical consideration, derived from direct trial, will ensure that the CDs fit into the CD box properly if this student attempts to make another CD box and takes the thickness of the material into account.

[36] Although the RNCS for technology does not require that these suggested improvements be implemented during/after the evaluation phase of the design process, the students at the University of Pretoria are penalized for not implementing these improvements. It seems, however, that many students are willing to sacrifice marks rather than to implement the improvement they have suggested – mostly claiming that they run out of time at the end of the module. It is, however, suspected that laziness (and not to a large extent, bad time management) might be the foremost reason.

5.2.6 Design instrumentalities

Designers need to know how to carry out their tasks. The instrumentalities of the process, which includes the procedures, ways of thinking and judgmental skills through which it is conducted, must therefore be part of any anatomy of engineering knowledge (Vincenti, 1990:219). Refer to the detailed description of the category of design instrumentalities in section 2.5.1.

The following knowledge-generating activities that contribute to design instrumentalities were found in the students' project portfolios:

- theoretical engineering research;
- experimental engineering research;
- design practice;
- production; and
- direct trial.

The abovementioned knowledge-generating activities are similar to Vincenti's (1990:235) proposed framework regarding the category of design instrumentalities. Evidence of the knowledge-generating activities that directly contributes to this category, and which was found in the students' project portfolios will be discussed next.

5.2.6.1 Theoretical engineering research

Designers need pragmatic judgmental skills to seek out design solutions and to make design decisions. Such skills range from highly *specialized technical judgements* to *broadly based considerations* (Vincenti, 1990:222).

Students are expected, as part of the investigating phase of the design process to perform an analysis of existing products relevant to the identified need or problem (DoE, 2002:35). The purpose of this kind of research is not only to create awareness among students of the kind of products available, but also to offer them ideas to use in the generation of a range of possible solutions during the design phase of the process. Investigative research also equips them with knowledge which enables them to make better design choices and judgements, especially when they have to choose a final solution from a range of possible solutions. The following is an extract from a student's (s23230879) description of the chosen design and the motivation for choosing the design (see figure 5 in section 3.6.2 for a photograph of this structure):

> *Design three … is in actual fact a box within a bigger box. Between the two boxes, on the four sides, it has triangular corrugations that provide additional strength to it*

… The inner box sits slightly lower than the outer box and the CDs, to make removing the CDs easier … For the purpose of fulfilling the brief[37] *in the best possible way, I have chosen to develop design three further. The reasons for this choice are as follows:*

- *the square shape is easier to stack when more than one is in use;*
- *the triangular corrugations will most probably supply more strength than any of the other designs; and*
- *the third design is the smallest and most compact, and therefore the easiest to handle (s23230879:10).*

The student decided, based on a technical judgement, that the triangular corrugations between the inner and outer box were the most suitable way to strengthen the sides of the CD box. Other *broadly based considerations* related to ergonomics include:

- the fact that the top of the inner box is slightly lower than the top of the outer box. This intentional choice makes it easier for the user to remove a CD from the box; and
- the compact, small size of the box makes it easy to handle.

Another consideration refers to the storing of the CD box, i.e. a square shape was deliberately chosen with ease of stacking and storage in mind.

5.2.6.2 Experimental engineering research

The example provided in section 5.2.2.2 of how experimental research contributes to the category of criteria and specifications, also applies to the category of design instrumentalities. Vincenti (1990:222) notes that judgmental skills must include an ability to weigh technical considerations in relation to the demands and constraints of the social context. These students (s23230879 & s23046377) had limited resources at their disposal, which had to be weighed against the safety of operation of the toy. After they had experimented with various components (such as gears, pulleys and solenoids) sizes and arrangements, taking the social constraints such as the safety of children between 2 and 6 years of age into consideration, the students decided by means of visual observation that a rotation speed of 4,1 rps would be acceptable (i.e. "satisficing"). *Satisficing* is a term described by Vincenti (1990:220) as "not the very best solution, but one that was satisfactory".

[37] Design and make a CD box which illustrates your understanding of strengthening techniques, using only cardboard and glue.

5.2.6.3 Design practice

Ways of thinking is one of the instrumentalities of the process and involves not only intellectual concepts (discussed as theoretical tools), but also has to do with the mental processes the designer follows (Vincenti, 1990:219-220). One of these modes of thinking is "visual thinking". Visual thinking uses for its language "an object or a picture or a visual image in the mind" (Vincenti, 1990:221). Aids to visual thinking include sketches and drawings, both formal and informal such as those engineers make, for example, on place mats and on the back of envelopes, but the thinking itself is a mental process; knowing how to do it is an aspect of tacit knowledge (Vincenti, 1990:221).

Evidence of visual thinking was found in the students' (s23230879 & s23046377) project portfolio for the educational toy (see figure 2 in section 3.6.1 for a photograph of this educational toy). Figure 15 shows enlarged sections taken from figure 9 and figure 10.

Figure 15: Sketches depicting visual thinking

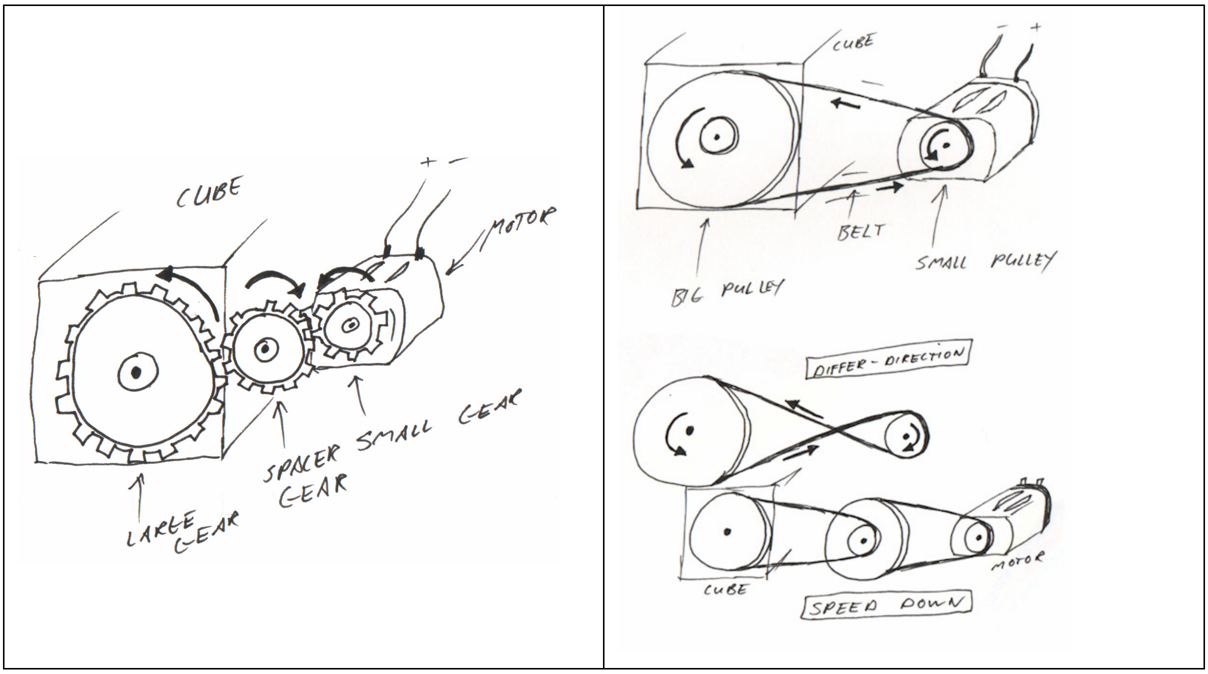


Figure 15 depicts how the students (s23230879 & s23046377) considered various mechanical components and arrangement of these components to make the spindle rotate at the desired speed. The direction of rotation is also clearly indicated in each drawing. The sketch of the gear train on the left shows how the students contemplated gear sizes to obtain speed reduction whilst ensuring that the direction of rotation remains the same as that of the motor by using a "spacer" gear. In the sketch on the right the pulley system also shows how different sizes and arrangements of pulleys were considered in order to obtain the desired speed and direction of rotation.

It was noted in section 5.2.2.3 that designers often use drawings as a means of problem solving (Cross, 2002:107). Figure 15 clearly shows some of the thought processes (*the visual thinking*), by means of sketches, that were involved in solving the problem ("know how to") regarding the spindle speed and direction of rotation. These thought processes occurred during the making of the quantitative design calculations and are shown in figures 9 and 10.

5.2.6.4 Production

Production is related to the making phase of the design process. During the making phase students are expected (in accordance with the assessment standards in the RNCS) to *inter alia*:

- choose and use appropriate tools and materials to make designed products with precision and control by measuring, marking, cutting or separating, shaping or forming, joining or combining, and finishing a range of materials accurately and efficiently;
- use measuring and checking procedures while making, to monitor quality and changes, and adapt designs in response to practical difficulties encountered when making the products; and
- demonstrate knowledge and understanding of safe working practices and efficient use of materials and tools (DoE, 2003:41).

Students also need to show evidence of the manufacturing sequence in their project portfolios by making use of flow diagrams or flow charts. An extract of the manufacturing sequence, found in a student's (s23080532:22-26) project portfolio, regarding the making of the educational toy depicted in figure 2, is illustrated in figure 16.

Figure 16: Extract of the manufacturing sequence in the making of an educational toy

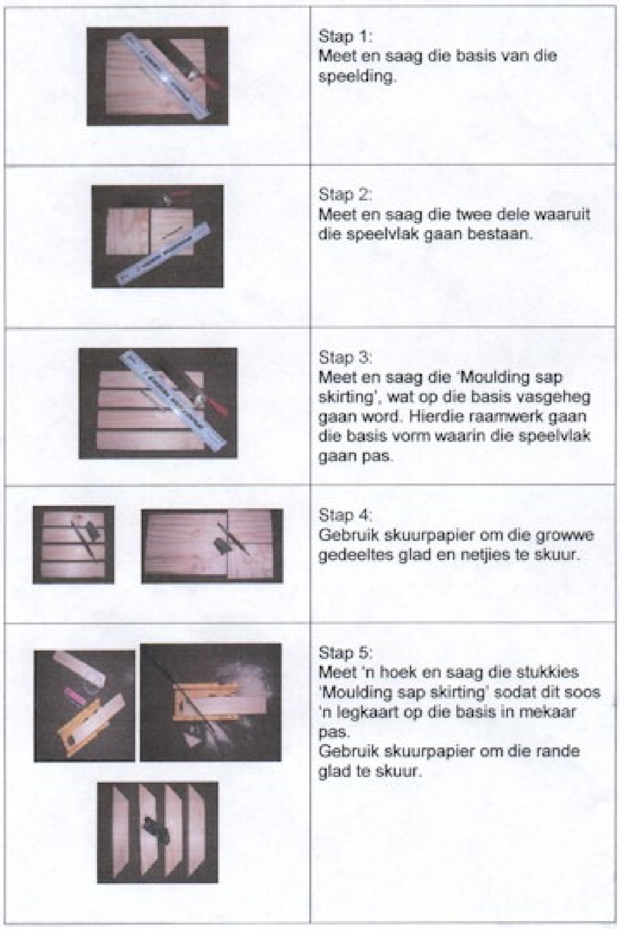
Manufacturing sequence	Translated as:
	Step 1: Measure and saw the base of the toy. Step 2: Measure and saw the two parts that will comprise the playing area. Step 3: Measure and saw the 'moulding sap skirting', which will be attached to the base. This frame will form the base into which the playing area will fit. Step 4: Use sandpaper to neatly sand the rough parts. Step 5: Measure an angle and saw the parts of 'moulding sap skirting' to allow it to fit like a jigsaw puzzle. Use sandpaper to smoothen the edges.

Figure 16 shows an extract of the *procedure* that the student (s23080532:22-26) followed to make the educational toy. Measuring procedures, at component level, are also evident throughout the depictions in figure 16 (e.g. see steps 1, 2, 3, and 5).

5.2.6.5 Direct trial

During the evaluation phase of the design process the students needed to test their artefacts, using a self-designed rubric to establish whether their designs could perform as intended. The students had to derive the testing criteria (for the rubric) from the design specifications and criteria. The results of these tests were then documented in the project portfolio. As part of the evaluation phase students were also expected to suggest sensible improvements (DoE, 2002:43).

The making of judgements is inherently part of the evaluation process, and here the students had to judge the extent to which the artefacts addressed the need/problem and design specifications and criteria. Ample examples of judgmental skills were therefore found in the project portfolios as all the students had to test their artefacts and present their criteria and results as part of the evaluation phase of the design process. Table 15 shows an extract from a student's (s25258193:41-43) project portfolio for the structural artefact (see figure 8 in section 3.6.2 for a photograph of this structure) of examples of a number of criteria presented in the evaluation rubric for the garden table:

Table 15: An example of criteria presented in the evaluation rubric

Given criteria	Met the criteria	Did not meet the criteria	More or less met the criteria	Provided explanation
Visually appealing	X			Has harmonizing colours used in unity.
Durability			X	The table is made of delicate material: plaster of Paris & tiles however, are coated with a protective layer of varnish.
Ergonomically suitable for its purpose	X			An ideal height that can easily be seen and an ideal height to easily place items on or take items off the table.
Portability			X	It can be dismantled and moved around, but with difficulty (due to weight).

Table 15 shows how the students (s25258193:41-43) judged the garden table using criteria derived from and based on some of the design specifications and criteria. It is interesting to note that the students generally refrained from making *specialized technical judgments*, but evaluated their artefacts using *broadly based considerations*. Possible reasons for the lack of *specialized technical judgments* (such as judging the hue of a colour used), might be due to the students' lack of experience. It may also be as a result of time constraints, since evaluation is usually done at the last minute. The latter reflects the linear way in which the students engaged in the design process, despite their knowing that the process ought to have been iterative.

5.2.7 Socio-technological understanding

Socio-technological understanding is systematic knowledge about the interrelationship between technical objects, the natural environment and social practice. It covers various elements of knowledge, including all the relevant fields which are affected by "technics", and it recombines these elements into an interdisciplinary synthesis, which could be referred to as “general technology” (Ropohl, 1997:70). Refer to the detailed description of socio-technological understanding in section 2.5.2.

The category of socio-technological understanding is specifically addressed in learning outcome 3 of the policy document, which recognizes the “need for learners to understand the interconnection between technology, society and the environment” (DoE, 2002:9). The aim of this learning outcome is to make learners aware of:

- indigenous technology and culture;
- the impact of technology; and
- biases created by technology (DoE, 2002:9).

Various examples that deal with some of the foregoing aspects were found in the students’ project portfolios. These examples came from the following knowledge-generating activities:

- theoretical engineering research;
- experimental engineering research;
- design practice; and
- direct trial.

Evidence of the knowledge-generating activities found in the students’ project portfolios that contributes to socio-technological understanding, is discussed in the next section.

5.2.7.1 Theoretical engineering research

Most students demonstrated an awareness of the impact that the materials that they considered could have on the environment. An example was found in a student’s (s23080532:7) project portfolio for the educational toy (see figure 3 in section 3.6.1 for a photograph of this educational toy):

> *… hout is ‘n natuurlike produk wat biologies herwinbaar is, die vervaardiging genereer baie min besoedeling* … (s23080532:7).
>
> Translated as:
>
> *… wood is a natural product that is biologically recyclable, the manufacturing generates very little pollution … (s23080532:7).*

The student cited the abovementioned ecological advantage of wood as part of a broader description of the properties of materials. This information seems to have been acquired through a literature survey, as all the references were cited in the student’s description.

5.2.7.2 Experimental engineering research

The safety of the artefact was an issue that most students addressed. The example of experimental research from the students' (s23230879 & s23046377) project portfolios for the educational toy, provided as evidence for various categories of knowledge throughout this study, is also relevant to the category of socio-technological understanding as it addresses the issue of safety. The students (s23230879 & s23046377:11-12) decided that since their toy was to be used by children between two and six years of age, the safety aspects of the toy were a major concern. One safety aspect that was considered was the rotation speed of the spindle. Refer to section 5.2.2.2 for the citation from the project portfolio.

It was through experimental research that the students observed whether the spindle rotated at the correct speed, since their theoretical calculations did not account for the motor torque, friction, mass of the wooden spindle, etc. Only after the experimental research had been done, did they decide that a rotation speed of 4,1 rps was acceptable in terms of safety and operation.

5.2.7.3 Design practice

Designers are cognisant of the interrelationship between technical objects, the natural environment and social practice. They know that people's behaviours, rituals and values vary from country to country and in a multicultural and socially diverse world, within countries as well – this understanding is essential to the process of design (Press & Cooper, 2003:12-13).

An example of such an interrelationship was found in the students' (s23230879 & s23046377:11) project portfolio for the educational toy. During the design phase of their toy the students consciously considered the effect of the choice of the colour of the toy and how it might contribute to gender bias:

> *… gebruik neutrale kleure … geslagsvooroordeel … wat vir seuns en meisies bedoel is … helder kleure, omdat die opvoedkundige speelding moet aandag trek (s23230879 & s23046377:11).*
>
> Translated as:
>
> *… use neutral colours … sexual bias … intended for boys and girls … bright colours, because the educational toy must attract attention (s23230879 & s23046377:11).*

The citation above shows that the students deliberately chose bright colours to draw attention to the toy. The students also addressed a value aspect, namely bias created by technology, which relates directly to learning outcome 3. It was important to them to choose a neutral colour that would not contribute to gender bias. The colours they therefore chose were bright primary colours, which would attract attention, but were, according to them, gender-neutral.

5.2.7.4 Direct trial

During the evaluation phase of the design process, the students tested the artefacts against *inter alia,* the design specifications and criteria stated during the design phase of the design process. Many of these specifications and criteria deal with the target market (people and age) as well as with human rights, access, safety and the environment (DoE, 2002:39). Some of these criteria, which were used during the evaluation phase, were found in a student's (s23080532) project portfolio for the educational toy:

> *Is die speelding geskik vir leerders ouer as 3 jaar tot en met graad 8?*
> *Is die speelding veilig?*
> *Word die LED te warm?*
> *Genereer die produksieproses min afval? (s23080532:27).*
> Translated as:
> *Is the toy suitable for learners older than 3 years and up to grade 8?*
> *Is the toy safe?*
> *Does the LED get too warm?*
> *Does the production process generate little waste? (s23080532:27).*

The criteria above are examples of the student's engagement in the category of socio-technological understanding by means of direct trial. The student evaluated the artefact by taking the target market, safety and the environment into consideration.

5.2.8 Collaborative design knowledge

Collaborative and individual design work are two different methodological approaches to design. The difference originates in the group structure and the distributed responsibilities of the work and work flow (Bayazit, 1993:126). Refer to the detailed description of collaborative design knowledge in section 2.5.4.

Bayazit (1993:123) notes that the participants of design teams are experts (e.g. engineers, architects, etc.) with different roles. Although the students, who worked in groups, were not domain[38] experts with specialist domain knowledge, it is assumed that they took on different roles within the group - each with their own set of responsibilities. Unfortunately no evidence of collaborative design knowledge could be found in the portfolios, since the students did not explicitly indicate these patterns of knowledge in their portfolios. This does, however, not mean that they did not engage in collaborative design knowledge, but points to the fact that it is problematic to attempt to identify such knowledge from the portfolios if the patterns have not been not clearly indicated by the students.

5.3 Conclusion

A content analysis was performed on the students' project portfolios to search for evidence of the knowledge-generating activities as they contributed to each of the categories of technological knowledge during the qualitative phase of this study. Evidence of these contributions, found in the students' portfolios, was mostly similar to Vincenti's (1990:235) matrix shown in table 4. Table 16 shows the items of knowledge that differ from those in Vincenti's (1990:235) matrix:

[38] The knowledge of the expertise area of a specific design system is called domain knowledge. Domain is the professional environment which comprises structural, mechanical, electrical engineers and other specialist experts (Bayazit, 1993:123).

Table 16: Items of knowledge that differed from those in Vincenti's (1990:235) matrix

Category of knowledge	Knowledge-generating activity	Note
Fundamental design concepts	Invention	Invention, of which no evidence could be found in the portfolios, is absent compared to Vincenti's (1990:235) framework. The students did not explicitly indicate in the portfolios what knowledge was acquired through invention, and the elusive nature of knowledge produced through this activity made it problematic to identify such knowledge in the portfolios. It does, however, not mean that the students did not engage in the act of invention.
Theoretical tools	Experimental engineering research	Experimental engineering research, of which no evidence could be found in the portfolios, is absent compared to Vincenti's (1990:235) framework. This finding was expected since the RNCS does not require learners to be able to derive theoretical tools from experimental research. In addition, the students did not have access to special test facilities and measuring devices that are necessary to develop, for example, mathematical methods and theories.
	Design practice	Evidence of design practice directly contributing to theoretical tools was found in the students' portfolios. This contribution was omitted from Vincenti's (1990:235) framework, as he argued that design practice has an indirect influence on theoretical tools only, and he therefore lists only the immediate contributions (Vincenti, 1990:234). The theoretical tools category, however, includes the *intellectual concepts* which provide the language "for thinking about design" (Vincenti, 1990:215). It can also be assumed that some of these intellectual concepts come from design practice and therefore the immediate contribution from design practice to theoretical tools cannot be ignored or omitted from the framework.
Quantitative data	Transfer from science	Although no evidence of quantitative data transferred from science could be found in the portfolios, it does not exclude the possibility that students could have transferred such data from science.
	Production	No evidence of quantitative data acquired from production was found in the portfolios.

		Although this does not exclude the possibility that the students contributed to quantitative data through the production activity, it is believed that the activity of production, in this context, is not a major contributor to the category of quantitative data.
	Direct trial	The lack of quantitative data from direct trial might be due to the students' inherent resistance to working with this kind of data (Van Putten, 2008:32).

In addition to the difference shown in table 16, Vincenti's (1990:235) matrix was further extended by adding the following knowledge-generating activities to Ropohl's (1997:70) category of socio-technological understanding:

- theoretical engineering research;
- experimental engineering research;
- design practice; and
- direct trial.

The results from this qualitative phase of the study seem to indicate that the conceptual framework used in this study could be useful in technology education. The conclusion is based on the evidence of the items of knowledge found in the students' project portfolios.

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Epilogue Chapter 6

6.1 Overview of the chapter

This chapter provides a brief outline of the foregoing chapters, a summary of the answers to the research questions, a reflection on lessons learnt and recommendations for both technology educators and policy makers, and for further research.

6.2 Overview of the study

Chapter 1 sets the stage for the study. It starts by pointing out that technology education is both globally and nationally still a fairly new subject without a well-founded subject philosophy or large research base. Various authors are cited who acknowledge the importance of developing a sound understanding of technology. One way in which technology can be conceptualised, as identified by Mitcham (1994:154-160), is to focus on *technology as knowledge* (epistemology). There is, however, a lack of frameworks in technology education through which technological knowledge can be explained and understood. In the absence of such frameworks one can draw on other disciplines in the field, i.e. engineering, design methodology and philosophy, for insight. These frameworks, however, need to be tested and validated by technology educators to establish their appropriateness.

The foregoing inspired the research questions for this study, as stated in section 1.4 (also see section 6.3). The research questions are followed by an explanation of key terms and an account of the context, which includes information on the participants of this study and two capability tasks from two different technology content areas, viz. systems and control, and structures. The section on research design and methodology comprises a description of a combination of quantitative and qualitative research design employed for this investigation and a rationale. Chapter 1 concludes with a delineation of the research limitations and organisation of the study.

Chapter 2 provides a review of the literature pertaining to technological knowledge. It begins by acknowledging that the term *knowledge* is not easily defined and offers descriptions of the term from various perspectives from the fields of cognition, education and epistemology. This is followed by a focus on technological knowledge, highlighting its distinctive nature. A brief exploration of indigenous knowledge precedes a scrutiny of the relationship between science and technology. In the knowledge and learning section, two contemporary views of learning inform ways to structure and support student learning in the technology classroom. Transfer of knowledge and its negative history are explored and followed by suggestions on how to ensure better transfer. The frameworks of technology section examines four frequently cited, divergent frameworks of technological knowledge. The conceptual framework for this study was derived from some of these frameworks (also see chapter 3).

A combination of quantitative and qualitative research design and methodology selected to answer the research questions are depicted in chapter 3. The chapter also focuses on the target population and sampling, and reports on the instrumentation and reliability and validity measures. Chapter 3 concludes with a description of the procedures pertaining to data collection and analysis.

The data and results of the quantitative phase of the study are presented in chapter 4. The results of the students' responses to the rating scale questions, indicating the extent to which each category of technological knowledge was used in each capability task, are recounted, followed by a comparison between the two different content areas of the individual categories of technological knowledge used by the students. The relationship between the categories of technological knowledge used in the two different content areas is then calculated and discussed.

The results of the student responses to the rating scale questions indicating the extent to which they have made use of knowledge-generating activities in each capability task are presented next. This is followed by a comparison between the two different content areas of the knowledge-generating activities drawn upon by the students. Subsequently the relationship between the knowledge-generating activities drawn upon in the two different content areas is calculated and discussed.

Chapter 5 presents the data and results of the qualitative phase of the study. It is comprised of a content analysis of the students' project portfolios for both the educational toy and the structural artefact, conducted to find evidence of knowledge-generating activities which contributed to the categories of technological knowledge described in the conceptual framework. The examples from the students' portfolios serve not only as evidence to validate student responses in the quantitative phase of the study, but also to inform (give context to) the quantitative data.

6.3 Revisiting the research questions

In this section the sub-questions stated in chapter 1 will be revisited first, since they elucidate the main research question. The main research question is placed after the last sub-question.

6.3.1 Sub-question 1

What is the frequency of categories of technological knowledge used by the students when they design and make an artefact?

Discussion

The students indicated in the quantitative phase of the study (chapter 4) that they engaged predominantly "to a fairly large extent" (78%) in most of the categories of technological knowledge in both content areas (see graph 1 and graph 2). The number of times a scale received the highest number of responses (as a percentage of the number of categories of technological knowledge) for the educational toy, are as follows:

- *Not at all* = 11%. This scale peaked (received the highest amount of responses) only once, for the category of collaborative design knowledge where the highest number of students indicated that they did "not at all" engage in the category of collaborative design knowledge. This low level of engagement was also observed in the qualitative phase of the study (chapter 5), as no evidence of the category of collaborative design knowledge was found in the student project portfolios.

  The students' very low level of engagement in the category of collaborative design knowledge could, at least partly, be attributed to their limited experience and knowledge in general and in technological design. While Bayazit (1993:123) notes that the participants in a design team are expert designers with different roles, the students were not experts, but teacher education students with more or less the same prior knowledge as one another in terms of technology.

  Another possible reason is that the capability tasks were performed during non-contact time (after hours), which meant that the students did not always have direct contact with each other, since not all of them lived in campus residences. The students did not enjoy being involved in group work and many complained about the work load distribution, although they themselves divided the work among group members. Consequently it is surmised that they did not conceive a solution to the problem as a team, but rather distributed the duties so that each team member took responsibility for only one aspect of the project, almost in isolation, e.g. the completion of project portfolios, making of the artefact, drawing of sketches, etc. The effect of this division of work was to limit their opportunity to engage with knowledge in the category of collaborative design knowledge.

- *To a limited extent* = 0%. This scale did not receive a majority number of responses for any category of knowledge, as all of the other highest numbers of responses were found in the next two scales, indicating a very high level of engagement (89%) in the categories of knowledge during this capability task.
- *To a fairly large extent* = 78%. Apart from the categories of collaborative design knowledge and prescriptive quantitative data, all the other categories of knowledge peaked at this scale. This high level of engagement indicated by the students, suggests that the categories of technological knowledge identified chiefly by Vincenti (1990:208), were relevant in the execution of this capability task. This was confirmed in the qualitative phase of the study by the proliferation of examples in the students' portfolios for all the remaining[39] categories of knowledge. Various examples (an average of four) for each category of knowledge were provided through different knowledge-generating activities as they contributed to the categories of knowledge. The concentration of examples seems to confirm that the students indeed made use of the majority of categories of knowledge "to a fairly large extent".
- *Extensively* = 11%. This scale received the most responses for the category of quantitative data only (in terms of prescriptive knowledge). A possible reason for the students' indicating that they engaged in prescriptive knowledge so extensively could be the nature of the capability task. The components, e.g an LED or electric motor, used in this project, very often impose technical parameters (see examples in section 5.2.1.2 and section 5.2.2.1) within which the component is required to operate. According to Vincenti (1990:217), technical specifications are prescriptive by virtue of prescribing how a device should be to fulfil its intended purpose.

The number of times a scale received the highest amount of responses (as a percentage of the number of categories of technological knowledge) for the structures artefact are as follows:

- *Not at all* = 11%. As with the educational toy, this scale peaked (received the highest number of responses) only once, in the category pertaining to collaborative design knowledge. Nineteen (out of 21) students indicated that they did not engage in collaborative design knowledge, making this the least relevant category

[39] Excluding the categories of collaborative design knowledge and prescriptive quantitative data.

of knowledge for this capability task. This lack of engagement was confirmed in the qualitative phase of this study, as no evidence of the category of collaborative design knowledge was found in the students' project portfolios.

In addition to the reasons mentioned in regard to the educational toy, students appear to have worked more individually (isolated from their team members), due to a general increase in work load closer to the end of the year: projects, tasks and tests in other subjects demanded more of the their time than before.

- *To a limited extent* = 11%. This scale received the most responses only for the category of quantitative data (in terms of prescriptive knowledge). This is in contrast to what was found in regard to the educational toy, where this category was used extensively. It is also the only category that shows a moderately positive relationship between the two content areas (refer to section 4.1.9 and section 6.3.3). All the other categories show a strong positive relationship between the two content areas.

  As noted earlier, this might be due to the nature of the capability task, which this time did not involve components required to operate within certain parameters. Another, more plausible reason, is the difference in the level of difficulty between the two capability tasks. The capability task for the educational toy was conceived and selected by the lecturer to be cognitively demanding, while the capability task for the structure was conceived and selected by the students themselves. The students selected a project from a learning programme they had to design for JMC 300 (methodology in technology) and it was clear that they chose simpler projects that were easier to design and make, and therefore limited their engagement in terms of quantitative prescriptive data.
- *To a fairly large extent* = 78%. Similar to the educational toy, all the categories for the structures artefact, except collaborative design knowledge and prescriptive quantitative data, peaked at this scale. This finding is reflected in the qualitative phase of the study as well. It was evident through the proliferation of examples in the project portfolios that the students indeed made use of the majority of categories of knowledge "to a fairly large extent". This high level of engagement seems to indicate that the students also recognised the categories chiefly identified by Vincenti (1990:208), as relevant to this capability task.
- *Extensively* = 0%. This scale did not receive a majority number of responses for any category of knowledge, possibly due to the fact that the students selected

simpler projects and therefore did not engage in any category of knowledge to this extent.

6.3.2 Sub-question 2

What is the frequency of knowledge-generating activities drawn upon by the students when they design and make an artefact?

Discussion

The students indicated in the quantitative phase of the study that they drew "to a fairly large extent" from most of the knowledge-generating activities in both the content areas (educational toy = 75% and the structures artefact = 63%) (see graph 12 and graph 13). The number of times a scale received the highest amount of responses (as a percentage of the number of knowledge-generating activities) for the educational toy are as follows:

- *Not at all* = 0%. This scale did not receive a majority number of responses for any knowledge-generating activity, indicating that the students did indeed draw knowledge from Vincenti's (1990:229) knowledge-generating activities.
- *To a limited extent* = 25%. Two knowledge-generating activities peaked at this scale, they are transfer from science and direct trial (the second part of direct trial only; see the explanation in the next paragraph). Although Vincenti (1990:235) indicates that science contributes to both the categories of theoretical tools and quantitative data, only limited evidence of theoretical tools was found in the qualitative phase of the study (confirming the students' responses in the quantitative phase of the study). Simple formulas (theoretical tools: mathematical methods and theories) and language (theoretical tools: intellectual concepts) transferred and adapted from science were found (see section 5.2.3.1). No evidence of quantitative data transferred from science was found in the students' project portfolios. This might be due to the students' inherent resistance to work with this type of data (Van Putten, 2008:32), or it may be a problem regarding transfer (to be discussed under the "not at all" scale of the knowledge-generating activities).

  Direct trial, according to Vincenti (1990:235), is a source of knowledge contributing to all the categories of knowledge. In this study direct trial was divided into two parts: the first part probed the extent to which the students evaluated (tested) their artefacts in order to determine whether they (the artefacts) did what they were designed to do (i.e. did they fulfil their design purpose?). In the first part the student responses peaked at the "to a fairly large extent" scale, indicating that they did indeed test their artefacts. This high rating is possibly due to the fact that the RNCS for technology requires them to test their artefacts in the evaluation phase of the design process and to record their findings in their project portfolios.

The second part explored the extent to which the students used the knowledge acquired about the artefacts' shortcomings during the direct trial to improve the design or at least make suggestions to improve the design. It was this second part that peaked at the "to a limited extent" scale. Although most students made suggestions for improvements in their project portfolios (as required in the RNCS for technology), few went so far as to actually improve the artefact, mostly claiming that they ran out of time at the end of the module. Laziness, and not bad time management, could be the foremost reason, since even though they were penalised during the assessment at the end of the module, it seemed that they were willing to sacrifice marks rather than implement the improvements they suggested in their project portfolios.

- *To a fairly large extent* = 75%. Apart from the transfer from science and direct trial (the second part), all the other knowledge-generating activities peaked at this scale. The high level of responses to this scale was confirmed in the qualitative phase of the study where a substantial number of examples from the students' portfolios were found, demonstrating from which knowledge-generating activities the knowledge had been sourced. As most knowledge-generating activities contribute to more than one category of knowledge, more than one example was provided for most of the knowledge-generating activities. This substantial number of examples implies that the students did indeed use most of the knowledge-generating activities "to a fairly large extent", which suggests that Vincenti's (1990:229) knowledge-generating activities were relevant to this capability task.

  There was, however, one knowledge-generating activity listed as a peak on this scale of which no evidence was found in the project portfolios. Invention as a knowledge-generating activity was selected by 15 of the 22 students as drawn upon "to a fairly large extent" in the execution of this capability task. This is the only item of conflict between the data gleaned in the quantitative phase and qualitative phases of the study. A possible explanation for this disagreement might be that the lack of evidence in the qualitative phase does not necessarily mean that the students did not engage in the act of invention. The fact that the students did not explicitly indicate in the portfolios what knowledge was acquired through invention, and the elusive nature of knowledge produced through this activity, makes it difficult to identify such knowledge in the portfolios.

- *Extensively* = 0%. This scale did not receive a majority number of responses for any of the knowledge-generating activities.

The number of times a scale received the highest amount of responses (as a percentage of the number of knowledge-generating activities) for the structures artefact are as follows:

- *Not at all* = 12%. Only one knowledge-generating activity, namely transfer from science, peaked at this scale. A possible reason why the students did not transfer more knowledge from science is that not all the students who selected technology as an elective selected science as an elective. Only about half of the students in the technology class also specialise in science at university level. All the students should, however, have a basic background in science, since it is a compulsory learning area up to grade 9. It is therefore disappointing that transfer from science (even on an elementary level), did not occur to a greater extent, as scientific knowledge is an important contributor to engineering knowledge (Layton, 1971:578; Vincenti, 1990:225-229).

  Another potential reason for students' reluctance to transfer more knowledge from science could be the problem of transfer discussed in chapter 2. In section 2.4.2 it is noted that various authors from different theoretical backgrounds state that learners find it difficult (or impossible) to transfer knowledge successfully from one context (e.g. the science classroom) to another context (e.g. the technology classroom) (De Corte, 1999:556; Hatano & Greeno, 1999:645; Stark, Mandl, Gruber, & Renkl, 1999:591). Transfer needs to be encouraged by equipping students with a rich and cohesive body of domain knowledge (Alexander & Murphy, 1999:571) and by helping students de-contextualize their knowledge (Volet, 1999:640).

- *To a limited extent* = 25%. Two knowledge-generating activities peaked at this scale, namely invention and experimental research. Invention was discussed in the educational toy section under the heading "to a fairly large extent". As no evidence of invention was found in the students' project portfolios, the same reasons provided in that section apply here as well. Experimental research, according to Vincenti (1990:235), contributes directly to most (all, except for practical considerations) of the categories of knowledge. For this capability task, however, the students indicated that they mostly made use of experimental research "to a limited extent", which is lower than for the educational toy, where most students selected the "to a fairly large extent" scale. The discrepancy between the two content areas might again be the result of the difference in the level of difficulty. The students, as noted earlier, selected simpler tasks for the structure artefact that was simpler to make. It was therefore easier to sidestep some of the activities, such as experimental research, that they would otherwise have engaged in if the lecturer had conceived and given a cognitively demanding capability task.

- *To a fairly large extent* = 63%. The students indicated that they drew from most of the knowledge-generating activities to a fairly large extent. Only transfer from science, invention and experimental research did not peak at this level (discussed above). The high level of responses to this scale, as noted in the educational toy section under the discussion of the same scale, was confirmed in the qualitative phase of the study, suggesting that Vincenti's (1990:229) knowledge-generating activities were also relevant to this capability task.
- *Extensively* = 0%. This scale did not receive a majority number of responses for any of the knowledge-generating activities.

6.3.3 Sub-question 3

What is the relationship, if any, between the categories of technological knowledge used in two different content areas in technology education?

Discussion

In the quantitative phase of the study the Pearson product moment correlation coefficient (r) was used to establish whether a relationship existed regarding the extent to which students made use of the categories of technological knowledge between the two content areas. The results indicate (see table 8) that eight of the nine categories of knowledge show a strong positive relationship between the two content areas. Only the category of quantitative data (that relates to prescriptive knowledge) shows a moderate positive relationship ($r = + .35$) between the two content areas. This suggests that the students used knowledge from the categories of technological knowledge to nearly the same extent in both content areas, which implies that the knowledge contained in one content area (e.g. systems and control) does not significantly favour the categories of knowledge above the knowledge contained in the other content area (e.g. structures). It also suggests that it made little difference whether the capability task was formulated by the lecturer or by the students.

A possible reason for this is that Vincenti (1990:7, 207) derived the categories from historical cases which focused on knowledge for normal, everyday design. In addition, all his categories refer to knowledge related to steps or phases in the design process (Broens & De Vries, 2003:469). Since the students had to follow the prescribed design process to design and make their artefacts, they were bound to engage in these categories of knowledge in more or less the same way, as they are directly and indirectly embedded in the assessment standards of the RNCS for technology (DoE, 2002). The implication is that the categories of technological knowledge used in the conceptual framework of this study apply to all three content areas.

6.3.4 Sub-question 4

What is the relationship, if any, between the knowledge-generating activities drawn upon in two different content areas in technology education?

Discussion

The Pearson product moment correlation coefficient (*r*) was again used to establish whether a relationship existed regarding the extent to which students drew knowledge from the knowledge-generating activities between the two content areas. The results indicated (see table 14) that five of the seven knowledge-generating activities (direct trial counts as one source only) show a strong positive relationship between the two content areas. Transfer from science shows a moderate positive relationship (r = + .42) and invention shows a weak positive relationship (r = + .24) between the two content areas. The difference in the nature and levels of difficulty between the two capability tasks could have influenced the weak relationship between the two content areas. The educational toy presented the challenge of learning mostly "new" concepts (especially the electrical/electronic systems and control section, of which the students had little or no prior knowledge), compared to the mostly familiar concepts in structures for which they chose simple projects. It is therefore understandable that the students, with their limited/lack of experience, could easily have thought that they had invented new concepts during the educational toy task, compared to the structure artefact task.

The strong positive relationship of most (six out of eight) of the knowledge-generating activities, and the moderate positive relationship of another between the two content areas, suggests that the students drew knowledge from these knowledge-generating activities to nearly the same extent in both content areas. These findings confirm Vincenti's (1990:236) conjecture that both categories of knowledge and knowledge-generating activities apply to all branches and areas of modern engineering. This implies that the knowledge-generating activities used in the conceptual framework of this study will also apply to the third content area (processing) of learning outcome 2 in the RNCS (DoE, 2003), which is not included in this study.

6.3.5 The main research question

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

Discussion

Compton (2004:14) argues that frameworks from technology can only be "operationalised" into technology education after exploring and establishing the fitness of these frameworks for technology education. The purpose and significant contribution (thesis) of this study, therefore, was to investigate the usefulness of a framework chiefly derived from professional engineers to be able to describe the nature of technological knowledge in an attempt to contribute towards the understanding of this relatively new learning area. The contribution of this study was therefore not limited only to the identification of the categories of knowledge and knowledge-generating activities described in the conceptual framework of this study, but also to establish the usefulness of these categories of knowledge and knowledge-generating activities in an educational context. The usefulness was confirmed through the high extent to which the students engaged in both categories of knowledge and the knowledge-generating activities during the execution of the two capability tasks. The study furthermore contributes to the understanding of technology education, which could enhance the professional development of educators by deepening their understanding of the substantive and syntactical structure of technology education.

The results from this study seem to indicate that the conceptual framework chiefly derived from and used by professional engineers, is "to a fairly large extent", useful to technology education. This is evident in the high level of student engagement in most of the categories of technological knowledge in both content areas as reported in regard to sub-question 1. It is further evidenced by the findings in relation to sub-question 2, which indicate that the students drew largely from most of the knowledge-generating activities in both content areas. Both these findings suggest that the categories of technological knowledge and the knowledge-generating activities identified chiefly by Vincenti (1990:208, 229), are useful to technology education. In addition, the findings suggest that both the categories of technological knowledge and the knowledge-generating activities apply to all three technology content areas (i.e. systems and control, structures and processing) as reported in the discussion of sub-question 3 and 4.

By considering the categories of technological knowledge and the knowledge-generating activities presented in the conceptual framework of this study, educators can deepen their understanding of the nature of technological knowledge as recommended by the DoE (2003:31). In this regard Herschbach (1995:31) contends that "a deeper understanding of technological knowledge opens the curriculum to possibilities that are obscured by a more restricted view. Greater direction is also given to the task of curriculum development".

In order to "operationalise" the conceptual framework used in this study, educators must consciously attempt to include items of knowledge from each category of knowledge when conceptualising capability tasks for their learning programmes. The designing and making of each artefact must demand that a student/learner, for example:

- demonstrates knowledge and understanding of operating principles (of devices) and normal configurations of artefacts relevant to the assessment standards specified in the RNCS;
- translates qualitative goals for the device to quantitative goals in concrete technical terms and presents detailed criteria and specifications for the artefact;
- makes use of a wide range of theoretical tools which include both intellectual concepts for thinking about design as well as mathematical methods and theories for making design calculations;
- engages in both descriptive and prescriptive quantitative data; and
- demonstrates "ways of thinking" (mental processes which include visual thinking) through sketches and drawings (both formal and informal).

The inclusion of knowledge from each category of knowledge will ensure an integration of the three learning outcomes, since they are all addressed in the conceptual framework. The following examples serve as illustration.

- The category of fundamental design concepts requires technological knowledge and understanding from learning outcome 2, which deals with operational principles and normal configurations, to enable students/learners to generate concepts of solutions to the design problem in the designing phase of the design process in learning outcome 1, which states that the learner:
  Generates a range of possible solutions that are significantly different from each other, and that show clear links to the design brief and the specifications and constraints (DoE, 2002:39).
- The category of theoretical tools also calls for knowledge and understanding from learning outcome 2 to enable students/learners to develop detailed plans of the

conceptual designs in the making phase of the design process in learning outcome 1 which states that the learner:

Develops plans for making that include … formal drawings showing dimensions or quantities (e.g. orthographic, oblique or isometric views, sequence drawings, exploded views) (DoE, 2002:41).

- The category of design criteria and specifications refers to the designing phase in the design process (learning outcome 1) which states that the learner:

  Lists product and design specifications and constraints for a solution to an identified problem, need or opportunity… (DoE, 2002:39).
- The categories of quantitative data (both descriptive and prescriptive), practical considerations, and design instrumentalities do not refer to one specific phase in the design process, but are related to the whole design process (Broens & De Vries, 2003:469).
- The category of socio-technological understanding addresses learning outcome 3, which deals with technology, society and the environment (indigenous technology and culture, the impact of technology and bias in technology). The interrelationship between technical objects, the natural environment and social practice, however, demands consideration during the designing of concepts of solutions in the designing phase of the design process in learning outcome 1, since, as pointed out by Ropohl (1997:70), every technical object has to be optimized while considering the ecological and psychosocial context within which the artefact is located.

Using the categories of knowledge presented in the conceptual framework can therefore assist the integration of the learning outcomes (and assessment standards) and help to overcome/prevent a fragmented approach to teaching technology education.

In addition, educators must ensure that the capability task requires that knowledge be drawn from all the knowledge-generating activities. The capability task must be cognitively demanding (for the specific grade) and the student/learner must, for example, not be able to design and make the artefact without transferring knowledge from science or doing research (both theoretical and experimental).

Another possibility for educators is to use the categories of technological knowledge and the knowledge-generating activities presented in the conceptual framework of this study as a matrix, such as the one presented in table 4, as a ‘checklist’ to evaluate their learning programmes. This will ensure that all knowledge items (categories and activities) are addressed in each capability task in the technology learning programmes.

6.4 Reflection

This section reports on reflective lessons learnt in this study. It reflects on the research strategy, target and sampling, and the research instrument.

The research strategy, discussed in chapter 3, was based on a combination of quantitative and qualitative research design. Although a quantitative design only would have answered the research questions of this study, it would have lacked information about the context of the knowledge used by the students. On the other hand, a qualitative design only could have answered the main research question, but it would have been problematic to determine the frequencies of knowledge engaged in, and the correlation of the knowledge engagement by the students between the two content areas (i.e. the sub-questions). The qualitative data was therefore useful not only to validate the students' responses to the questionnaire, but also to inform *what* knowledge the students used and *how* they used it in conducting the capability tasks.

The target selected was found to be suitable due to the complexity of the conceptual framework. Younger participants (learners in school) might, for example, have found it too difficult to understand the terms used to describe the categories of knowledge and knowledge-generating activities, which would have compromised the reliability of the study. It was, however, not only maturity that ensured that the selected target (students) understood the terms used, but also the measures that were taken. These measures include the piloting of the questionnaire before it was administered, the consequent simplification of the questionnaire and the explanation and testing in an informal interview-like situation as to whether the students understood the terms in the questionnaire. Refer to section 3.8.1.1 for an explanation of ways in which the reliability of the questionnaire was enhanced.

The sample was unfortunately too small for the quantitative data to be representative of a larger population. The larger population also includes technology education teachers, student teachers from other universities and learners from schools. The group comprised only undergraduate students at the University of Pretoria, which is not representative of the larger population (e.g. school learners from, for example, poor and under-resourced schools or small schools in rural areas).

Two instruments were used to obtain data, namely a questionnaire and the students' project portfolios. The questionnaire had some shortcomings. The open-ended questions, which required students to name examples of the knowledge-generating activities they

drew their knowledge from, should have been extended to the categories of knowledge. When the questionnaire was drafted it was wrongfully believed that it would be more difficult to find examples in the students' portfolios, of the knowledge-generating activities than examples of the categories of knowledge. The student responses to the open-ended items could then have been used to fill in the "blanks". This was found not to be the case. Not only was it relatively easy to find both the knowledge-generating activities and the categories of knowledge in isolation, but it was also possible to identify which knowledge-generating activities contributed to which categories of knowledge in the students' portfolios. This was due to the simple and straightforward explanations and well-selected examples provided by Vincenti (1990), which contributed to the ease of understanding of exactly what each category of knowledge and knowledge-generating activity meant.
The open-ended answers were, however, useful to ascertain whether the students did indeed understand the concepts used in the questionnaire and should, for this purpose, have been extended to the section covering the categories of knowledge. This would have enhanced the validity of the questionnaire.

The analysis of the project portfolios highlighted shortcomings in the way students conceptualise solutions to problems and the manner in which they documented the design process in the project portfolio. In exploring ideas, students need to analyse more (a larger variety of) existing products to find the best possible solution to their problem. In addition, students must be encouraged to engage in visual thinking to a larger extent since, as Ferguson (1992:42) points out, visual thinking can be successful to the extent that the thinker possesses an adequate array of sensual experience, converted by the mind's eye to usable visual information. It is also important to note that a major portion of engineering information is recorded and transmitted in a visual language that is in effect, "the *lingua franca* of engineers in the modern world" (Ferguson, 1992:41). The best way to engage the students in such visual experiences is, according to Ferguson (1992:88), for them to learn how to make and read drawings. It is therefore suggested that a visual diary, in addition to the project portfolio, be used to document such visual thinking in a continuous and comprehensive manner.

6.5 Recommendations

The following recommendations, emerging from the findings of the study, are proposed.

6.5.1 Recommendations for technology educators and policy makers

Technology educators and policy makers need to consider the categories of knowledge and the knowledge-generating activities presented in the conceptual framework of this study to deepen their understanding of the nature of technological knowledge. Compton (2004:17) notes that the development and implementation of technology learning programmes require a sound understanding of technological practice, the nature of technology and technological knowledge. From a teacher education perspective, a deeper understanding of technological knowledge can empower educators to develop learning programmes that can fully integrate the learning outcomes in line with technological practice (Compton, 2004:10). Refer to section 6.3.5 for an example of how this can be operationalised.

6.5.2 Recommendations for further research

The literature shows that the issue of transfer has been explored extensively, but since scientific knowledge has been identified as one of the sources of technological knowledge, transfer from science (to technology) merits further research. This is significant especially in light of the fact that this study has indicated, in keeping with what the literature indicates in regard to transfer, that the students have drawn from science only to a meagre extent.

A closer look at the RNCS for technology might, for example, give an indication of the kind of knowledge items that can be (or should be) transferred from science to technology. With an understanding of the nature of such specific items of knowledge (maybe in terms of theoretical tools or quantitative data), further research might reveal domain-specific strategies to optimise such transfer.

Another recommendation for further research is to use Audi's (2003:251) five sources[40] of non-inferential knowledge and justification (noted in section 2.2.1) as an alternative to Vincenti's (1990:229) knowledge-generating activities. The aim would be not only to compare Audi's (2003) sources of knowledge to Vincenti's (1990:229) knowledge-generating activities, as suggested by De Vries (2003:19), but to show the extent to which Audi's (2003) sources contribute to Vincenti's (1990:229) categories of knowledge (similarly to what has been done in this study).

Such a framework should not replace Vincenti's (1990:235) framework, but should be used to offer an extended view, by adding another "layer" of sources of knowledge "on top" of Vincenti's (1990:229) knowledge-generating activities. Since Audi's (2003) sources of knowledge were derived from a different perspective than Vincenti's (1990) knowledge-

[40] Perception, memory, consciousness, reason and testimony.

generating activities, such an extended framework would provide a more comprehensive view on the *how students know* part of technological knowledge.

Finally, it is recommended that, once trained technology education teachers have replaced the existing technology teachers (who usually have a background in consumer science, woodwork or industrial arts), and have acquired the necessary experience in teaching technology education, this study be repeated to determine whether these "experts" engage in knowledge from the conceptual framework in the same manner as the participants in this study.

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Questionnaire

Section A: Sources of technological knowledge

INDICATE YOUR ANSWER WITH AN **X** IN THE APPROPRIATE BLOCK.

1. To what extent did you make use of knowledge from theoretical science (e.g. transfer knowledge from science, reformulate or adapt) in the design and making of your artefact?

Transfer from science	Not at all	To a limited extent	To a fairly large extent	Extensively

An example of the kind of knowledge I transferred from theoretical science to *design* and *make* my artefact was …

2. To what extent did you discover (and use) "new" knowledge (e.g. operating principles) during the invention (designing and making process) of your artefact?

Invention	Not at all	To a limited extent	To a fairly large extent	Extensively

Concepts, such as the operating principles or best design/shape that best embody the operational principle, contrived (or come upon coincidentally), due to my invention include …

3. To what extent did you make use of theoretical research to acquire the necessary knowledge which enabled you to design and make your artefact?

Theoretical research	Not at all	To a limited extent	To a fairly large extent	Extensively

3.1 The main sources I used to do my theoretical research include (e.g. *Internet*, textbooks) …

3.2 The knowledge I produced via theoretical activity (research) is, for example …

4. To what extent did you make use of experimental research (e.g. testing of various products and materials), to acquire the necessary knowledge which enabled you to design and make your artefact?

Experimental research	Not at all	To a limited extent	To a fairly large extent	Extensively

4.1 I performed my experimental (evaluating/testing) research by means of (e.g. test facilities, experimental techniques, measuring devices) …

4.2 The knowledge I gained through experimental research is, for example …

5. To what extent did you make use of knowledge from design practice (e.g. design process, design aspects, etc.)?

Design practice	Not at all	To a limited extent	To a fairly large extent	Extensively

Design practice reveals problems that call for research in order to solve these problems. An example of knowledge acquired in this way is …

6. The making (production) of your artefact can result in practical considerations which were not comprehended during theoretical research, design, etc. (e.g. material is too thin and too large, which can lead to cracking). To what extent did you make use of such practically discovered knowledge?

Production	Not at all	To a limited extent	To a fairly large extent	Extensively

Practical knowledge I gained during the production (making) of my artefact includes …

7. A *proof test* can be performed to determine whether a device (artefact) performs as intended. To what extent did you evaluate (test) your artefact in order to determine whether it does what it was designed to do?

Direct trial	Not at all	To a limited extent	To a fairly large extent	Extensively

7.1 During this direct trial I discovered that …

7.2 To what extent did you use the knowledge acquired about the artefact's shortcomings during the direct trail to improve the design or at least make suggestions to improve the design?

Direct trial	Not at all	To a limited extent	To a fairly large extent	Extensively

Section B: Categories of technological knowledge

1. Fundamental design concepts are part of a technologist's knowledge and have to be learned deliberately to form part of a technologist's essential knowledge. This knowledge includes:
   - operating principles of artefacts (i.e. how does it work); and
   - the general shape and arrangement of the artefact that are commonly agreed to best embody the operational principle.

In designing and making your artefact, indicate the extent to which you drew knowledge from fundamental concepts.

Fundamental design concepts	**Not at all**	**To a limited extent**	**To a fairly large extent**	**Extensively**

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2. To design a device, a designer must have specific requirements (e.g. a customer's needs and wants) in terms of the device. These qualitative (non-technical requirements/needs) goals/data from the customer must be translated to quantitative goals/data (concrete technical terms).

In designing and making your artefact, indicate the extent to which you:
- made use of criteria and specifications (such as the customer's needs and wants); and
- translated these qualitative criteria and specifications into technical terms.

Criteria and specifications	**Not at all**	**To a limited extent**	**To a fairly large extent**	**Extensively**

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3. Technologists make use of a wide range of theoretical tools to accomplish their design task. These include:
   - mathematical methods and theories for making design calculations - mathematical methods and theories may vary from elementary formulas for simple calculations to complex calculative schemes; and
   - intellectual concepts for thinking about design - intellectual concepts provide the language for articulating the thought in people's minds.

In designing and making your artefact, indicate the extent to which you made use of theoretical tools.

Theoretical tools	**Not at all**	**To a limited extent**	**To a fairly large extent**	**Extensively**

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4. Mathematical tools will be of little value without data for the physical properties or other quantities required in the formulas. Two types of knowledge/data can be distinguished, namely descriptive and prescriptive knowledge.

   Descriptive data includes data such as physical constants, properties of substances, strength of materials, etc. (i.e. how things are).

4.1 In designing and making your artefact, indicate the extent to which you made use of descriptive knowledge.

Quantitative data: ***descriptive knowledge (how things are)***	**Not at all**	**To a limited extent**	**To a fairly large extent**	**Extensively**

Prescriptive knowledge, on the other hand, is knowledge of how things should be to in order to obtain the desired result (e.g. data or process specifications that manufacturers issue for guidance to assist designers and other workers).

4.2 In designing and making your artefact, indicate the extent to which you made use of prescriptive knowledge.

Quantitative data: prescriptive knowledge (how things should be)	Not at all	To a limited extent	To a fairly large extent	Extensively

5. Some knowledge can be learned mostly in practice (e.g. learning from accidents, experience in practice, tricks of the trade) rather than through training or textbooks.

In designing and making your artefact, indicate the extent to which you made use of knowledge derived from practical experience.

Practical considerations	Not at all	To a limited extent	To a fairly large extent	Extensively

6. In order to carry out a given task, you need to “know how” to carry out the task (e.g. follow the design process). The instrumentalities of the process include the procedures, ways of thinking and judgmental skills by which it is done.

In designing and making your artefact, indicate the extent to which you made use of this “know how” or procedural knowledge.

Design instrumentalities	Not at all	To a limited extent	To a fairly large extent	Extensively

7. To what extent did you consider the interrelationship that exists between technical objects (e.g. your artefact), the natural environment (e.g. learning outcome 3: impact of technology) and social practice (e.g. learning outcome 3: biases created by technology) during the design and making process of your artefact?

Socio-technological understanding	Not at all	To a limited extent	To a fairly large extent	Extensively

8. To what extent did you make use of knowledge acquired from other members in your group (if you were in a group)?

Collaborative design knowledge	Not at all	To a limited extent	To a fairly large extent	Extensively