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)

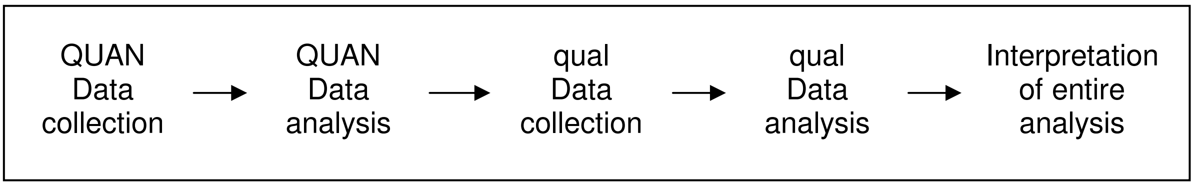

Figure 1 shows that the quantitative data (QUAN) took precedence, since it represents a major aspect of the data collection and because most of the research questions of this study could be answered during this phase of the study. The qualitative data (qual), on the other hand, answered certain research 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:*

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[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

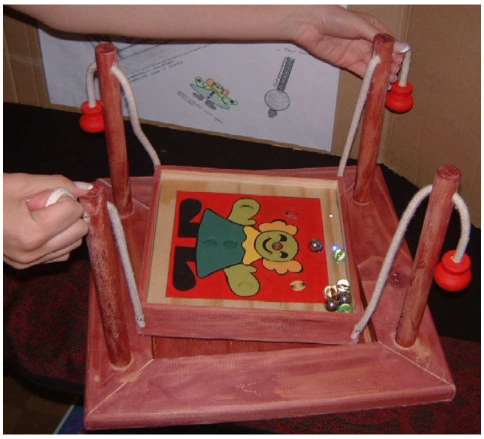

Figure 4: Educational toy 3

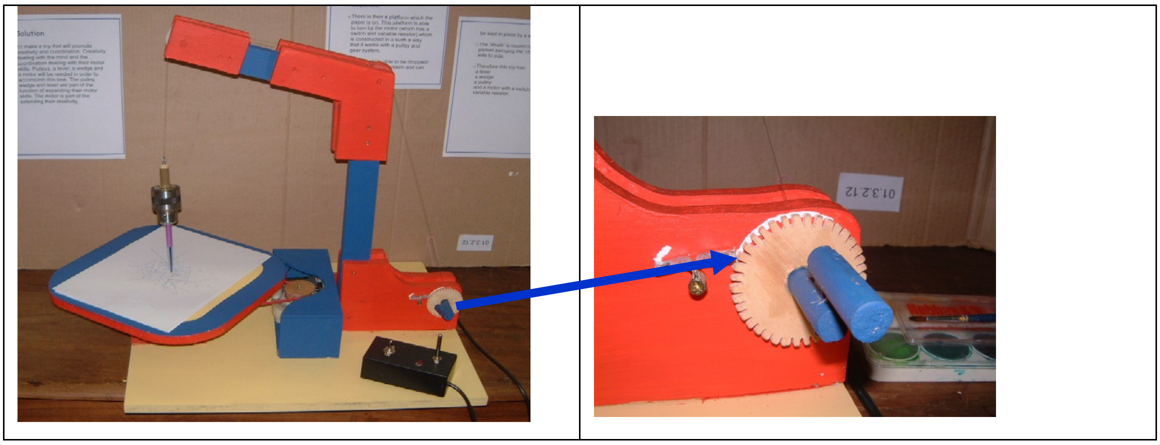

Figure 2 shows a toy that requires the player to match shapes and colours. A motor turns a spindle if the button is pressed. If the button is released the spindle will stop on one of four colours. The player then needs to insert the correct colour and block shape into the corresponding space on the toy. 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.

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[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

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[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.

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[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.

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[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.

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[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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