

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.

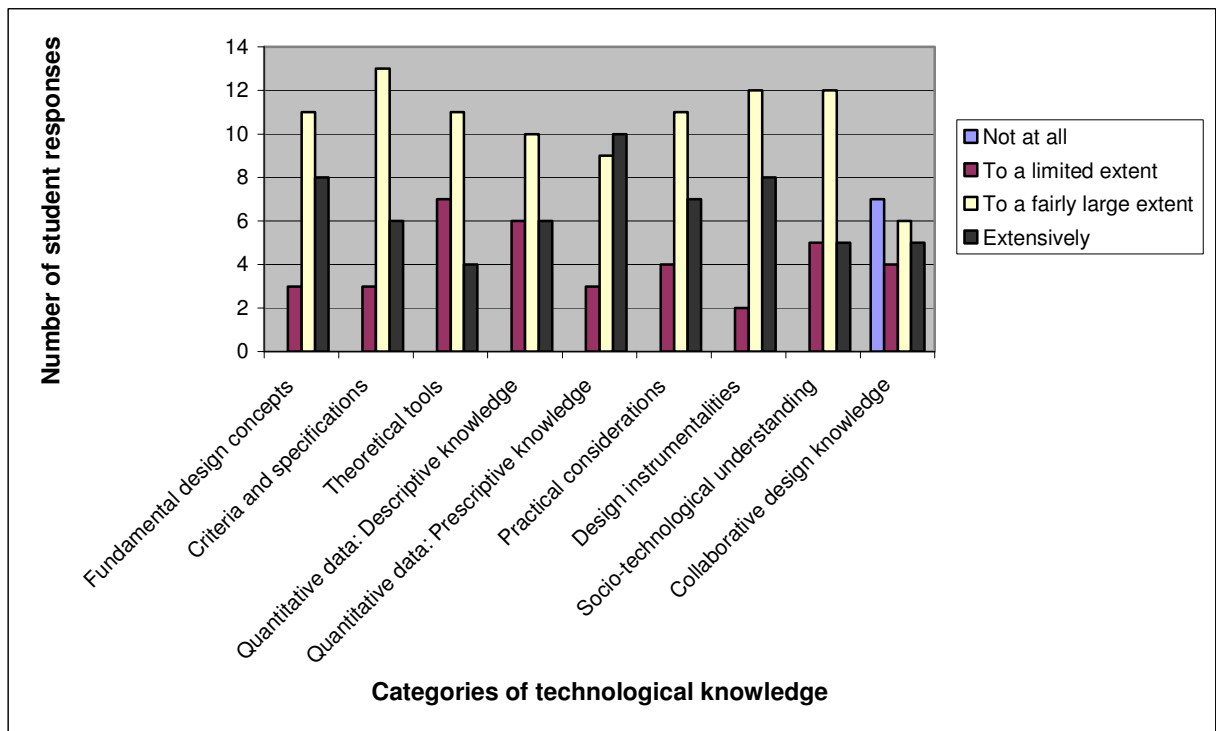
The questionnaire was administered at the end of each module, thus also at the end of the section of work on each content area. For the first content area, systems and control, the students had to design and make an educational toy. For the second content area (structures), the students had to design 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.

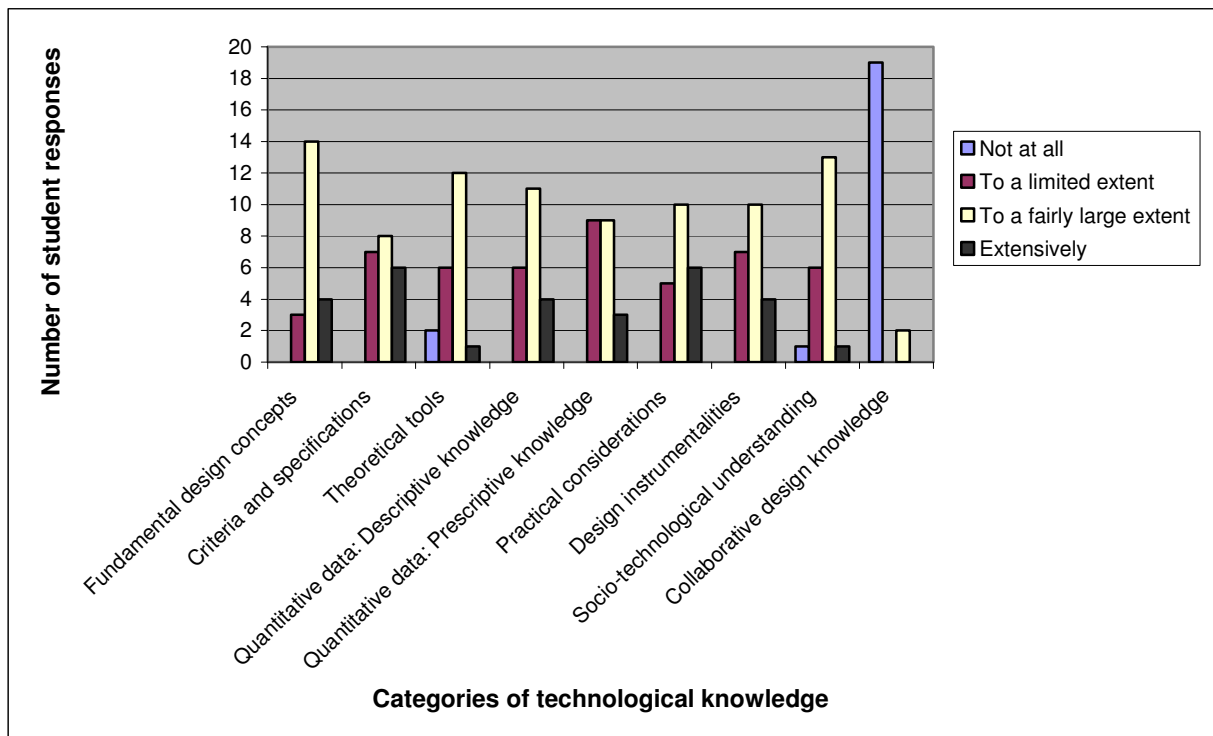
The results of the students’ responses to the rating scale questions indicating the extent to which each category of technological knowledge was used to design and make a structural artefact, are shown in table 7 and graph 2.

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

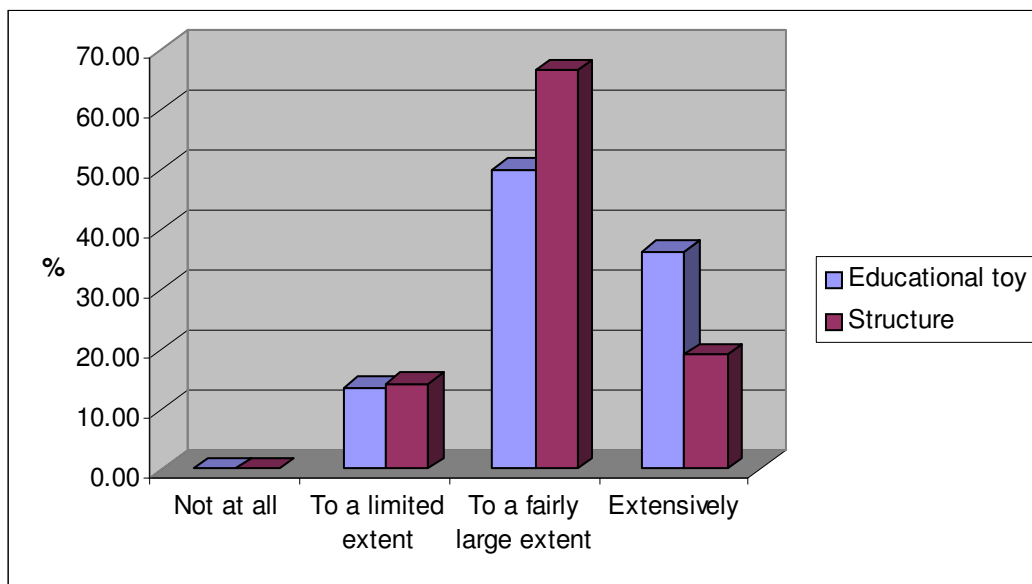
Fundamental design concepts are part of a technologist’s knowledge and have to be learned deliberately to form part of a technologist’s essential knowledge. This category of knowledge includes the:

- 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

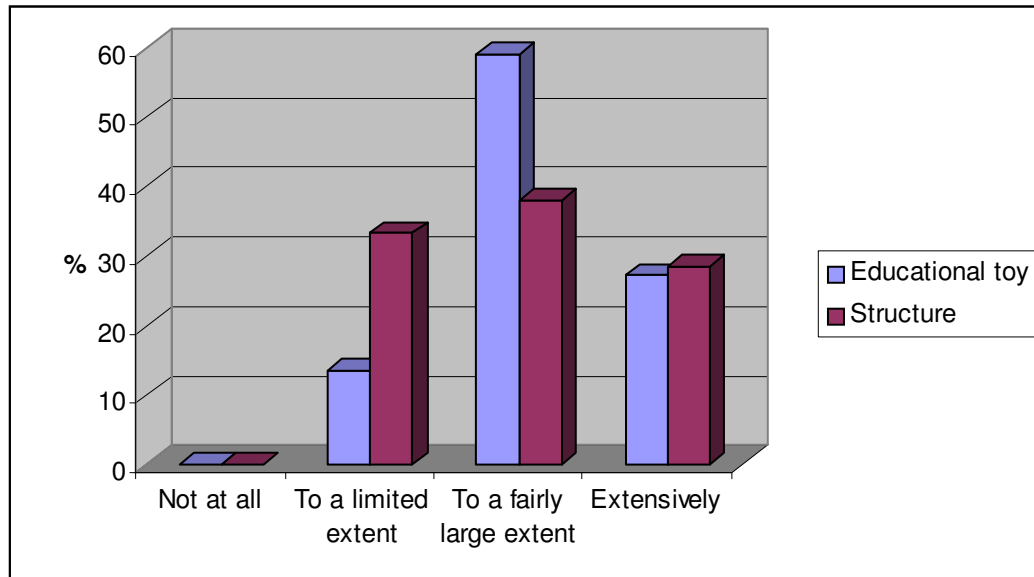
To design a device, a designer must have specific requirements, e.g. a customer’s needs and wants, in terms of the device. These qualitative (non technical requirements/needs) goals/data set by the customer must be translated into quantitative goals/data (concrete technical terms) (Vincenti, 1990:211-213).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

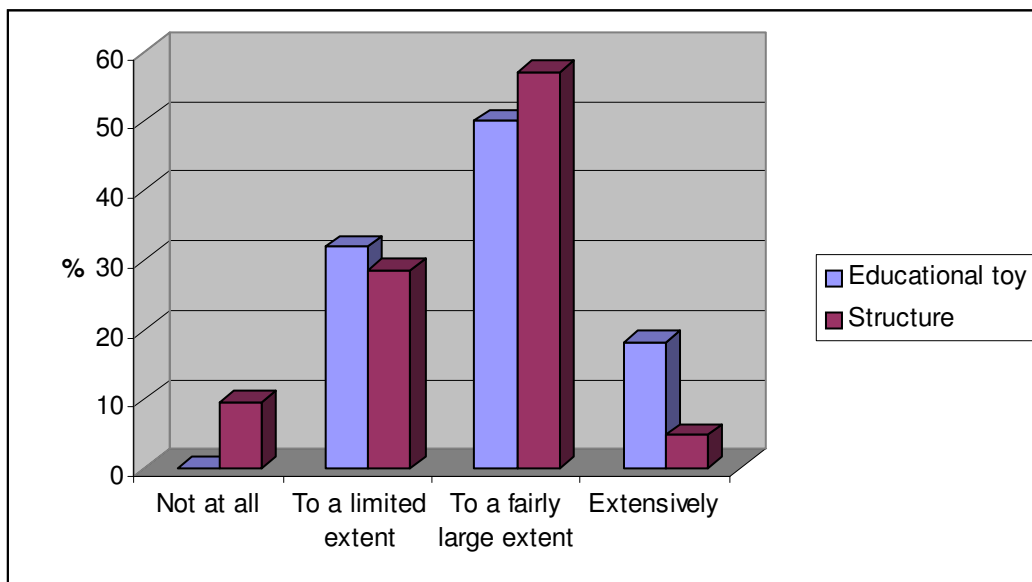
Technologists make use of a wide range of theoretical tools to accomplish their design task. These include:

- 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

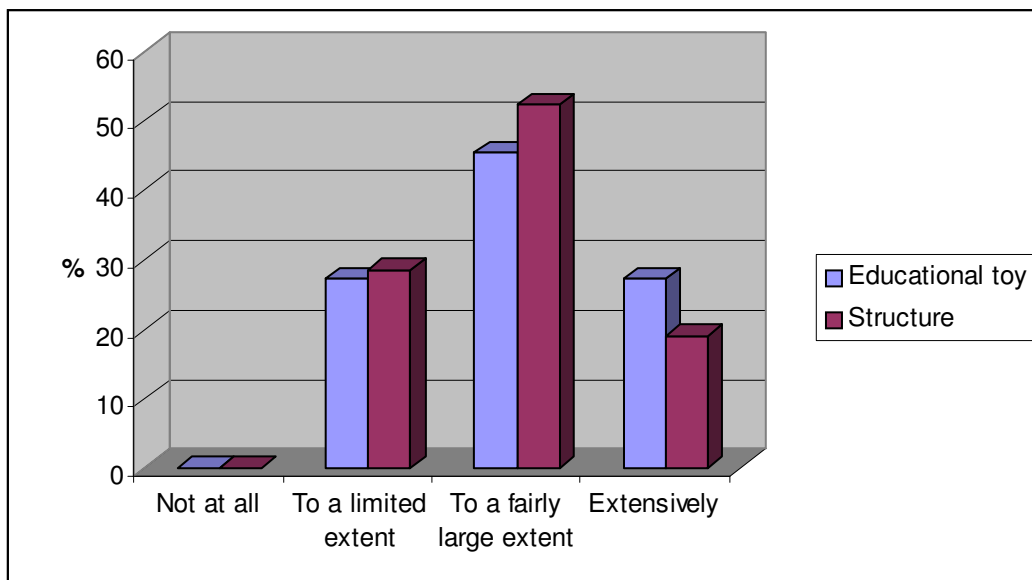
Mathematical tools will be of little value without data for the physical properties or other quantities required in the formulas. Vincenti (1990:216-217) distinguishes between two types of quantitative data, namely descriptive and prescriptive knowledge.

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”.

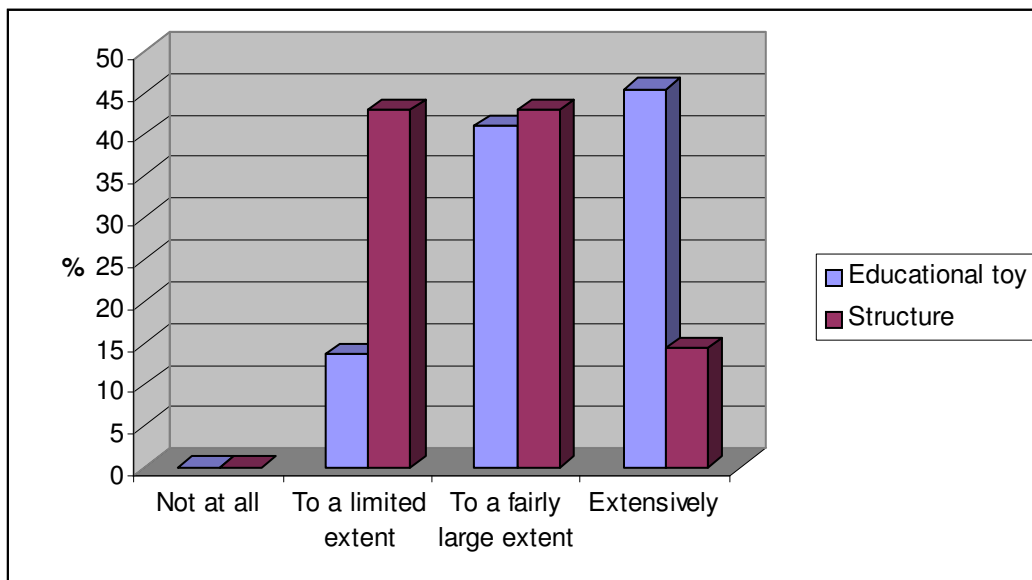
The differences observed between the two content areas on the “to a fairly large extent” and “extensively” scales are too small to make any suggestion as to why they differ. Only two students more selected the “extensively” scale for the educational toy than for structure. One student more selected the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

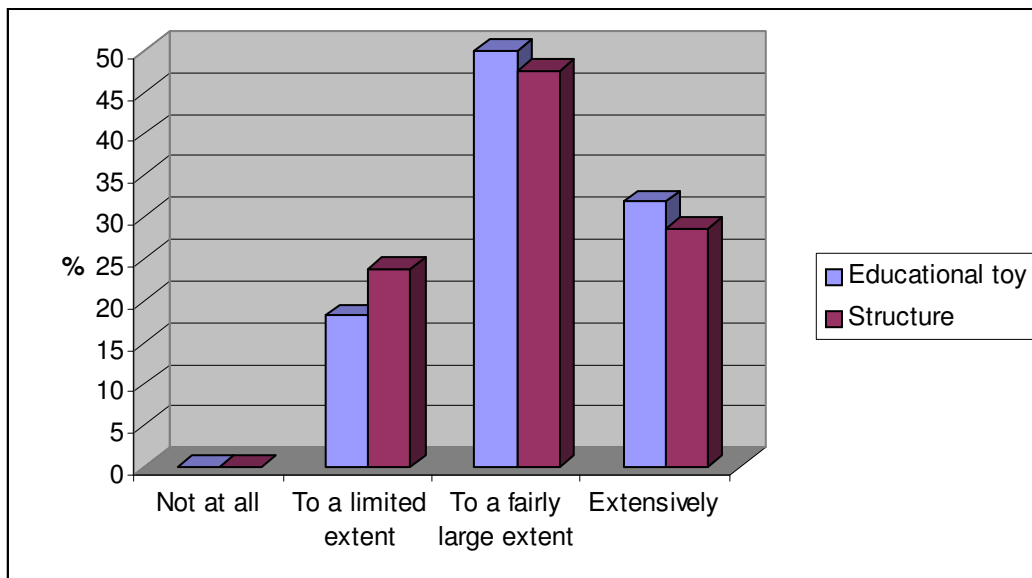
possibly due to the nature of the educational toy capability task. The components (such as an LED or electric motor) used in this project very often specify technical parameters (see the examples in section 5.2.1.2 and section 5.2.2.1) within which the component needs to operate and, according to Vincenti (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”.

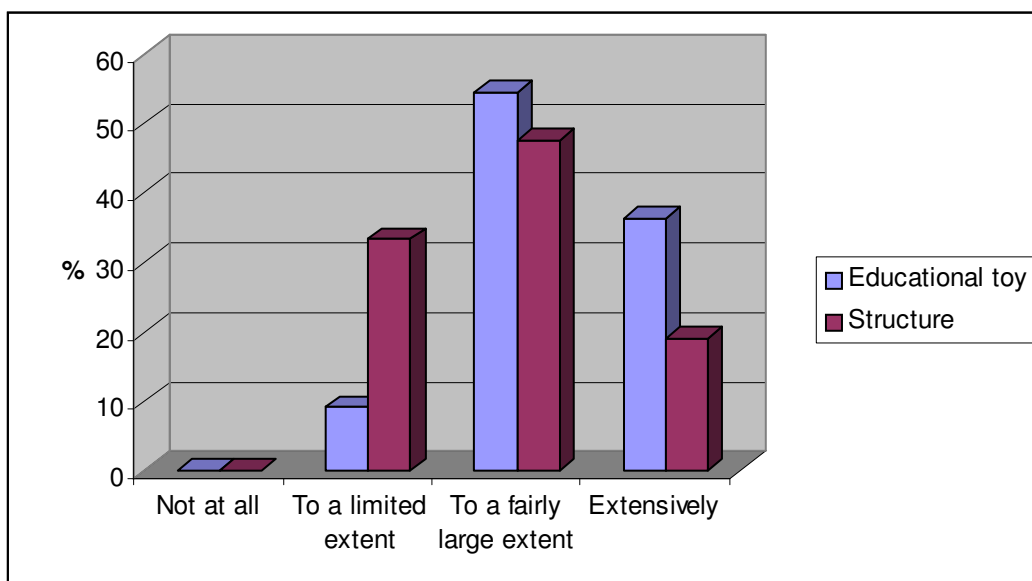
The differences observed in graph 8 between the two content areas are too small to make any suggestion as to why the ratings differ. In each case the differences between the two content areas are the result of only one student more selecting that scale in the particular content area.

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”.

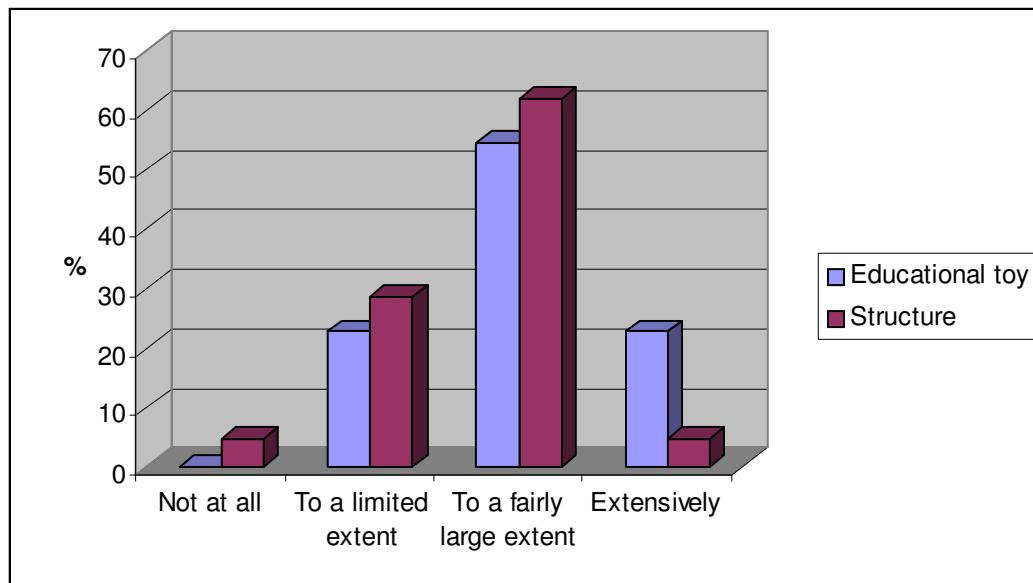
The difference between the two content areas on the “extensively” scale shows that more students indicated that they engaged in the category of design instrumentalities during the designing and making of the educational toy. This pattern is repeated on the “to a fairly large extent” scale, which suggests 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

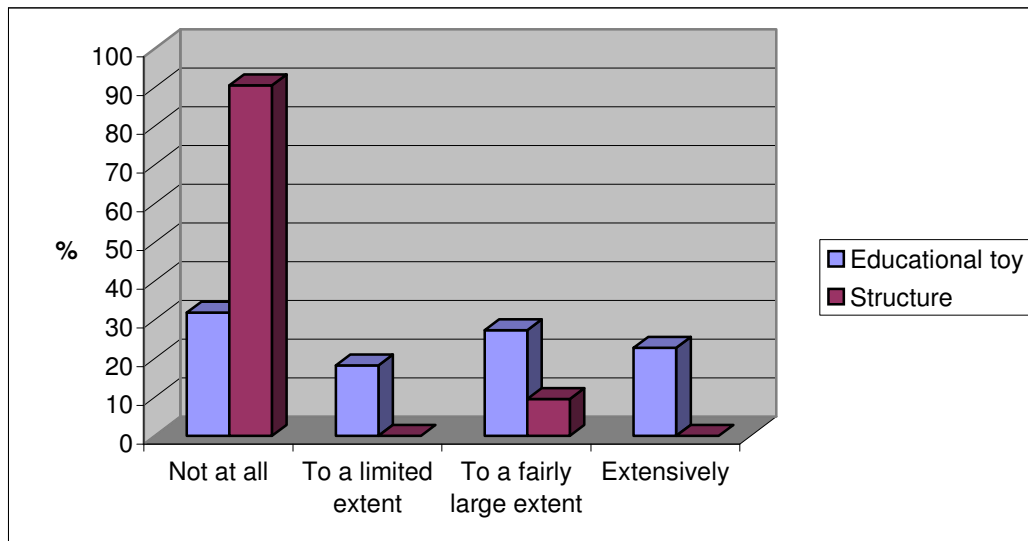
the other hand, were less demanding and rather straight-forward, as discussed earlier in this chapter.

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 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	<i>r</i>
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 significant²⁶ 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 than .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

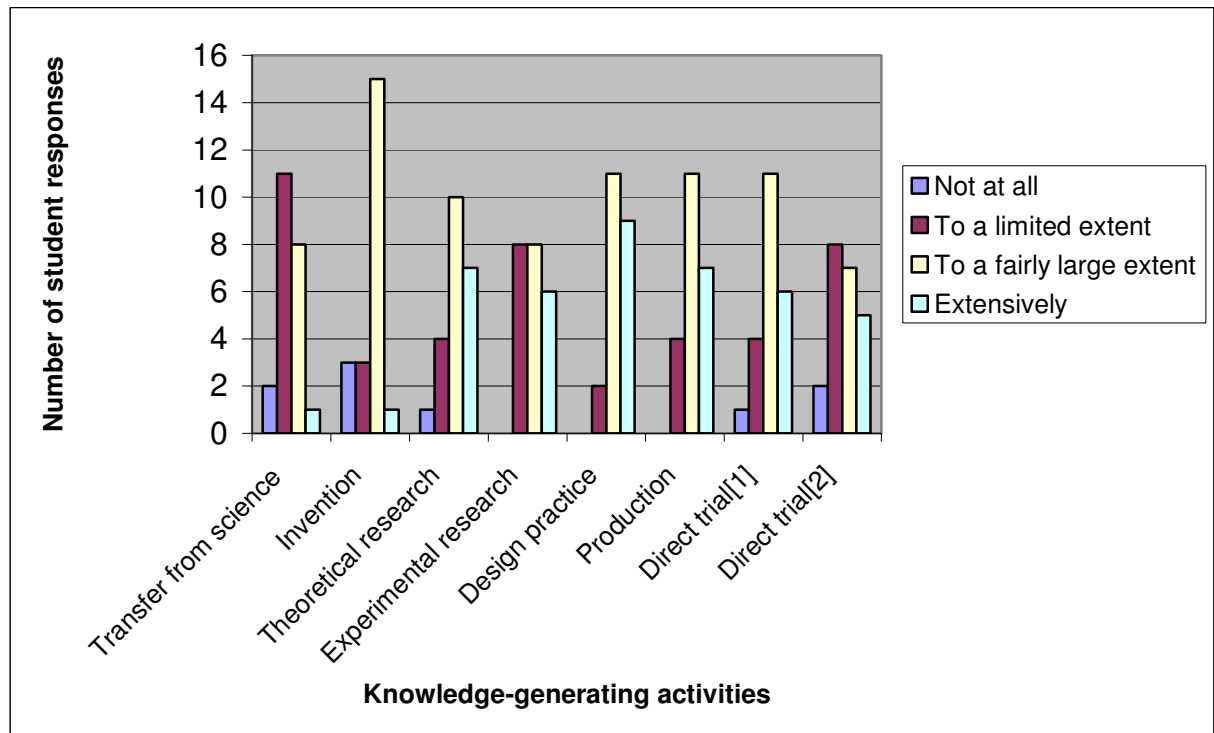
Knowledge-generating activities	Not at all	To a limited extent	To a fairly large extent	Extensively
Transfer from science	2	11	8	1
Invention	3	3	15	1
Theoretical research	1	4	10	7
Experimental research	0	8	8	6
Design practice	0	2	11	9
Production	0	4	11	7
Direct trial ²⁷	1	4	11	6
Direct trial ²⁸	2	8	7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

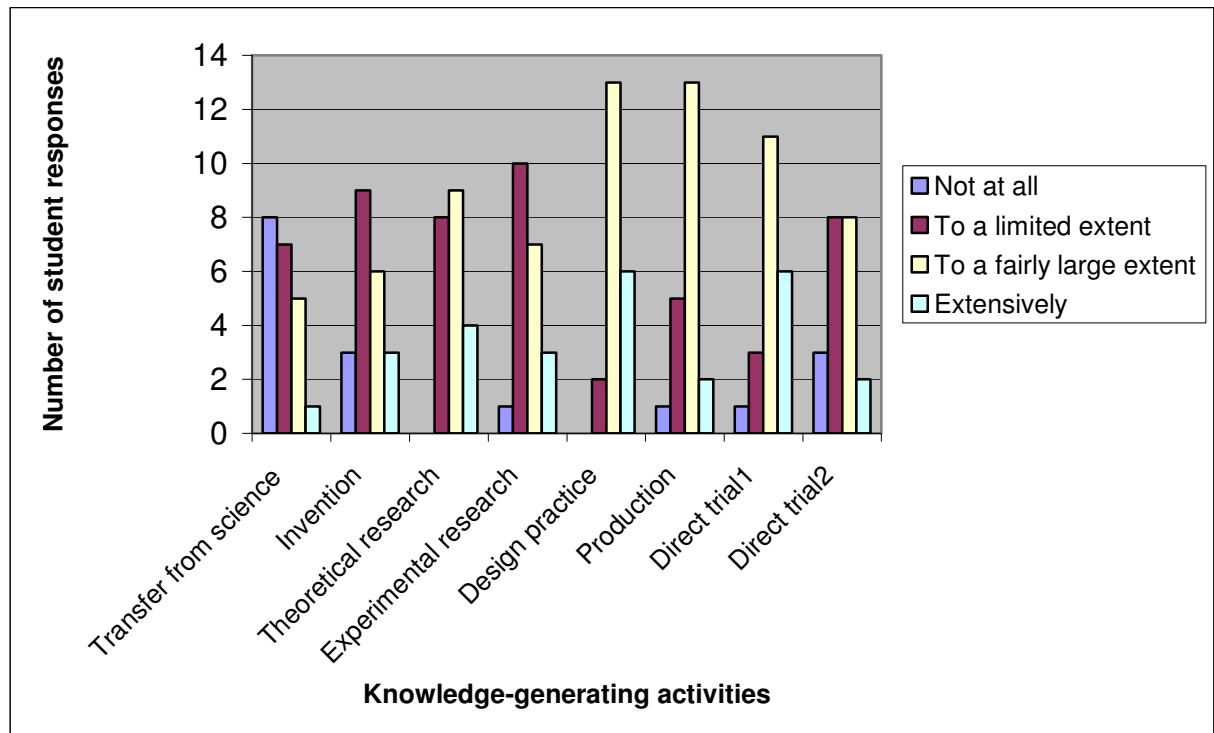
The results of student responses to the rating scale questions that indicate the extent to which they drew knowledge from the knowledge-generating activities to design and make a structure artefact, are shown in table 11 and graph 13.

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.

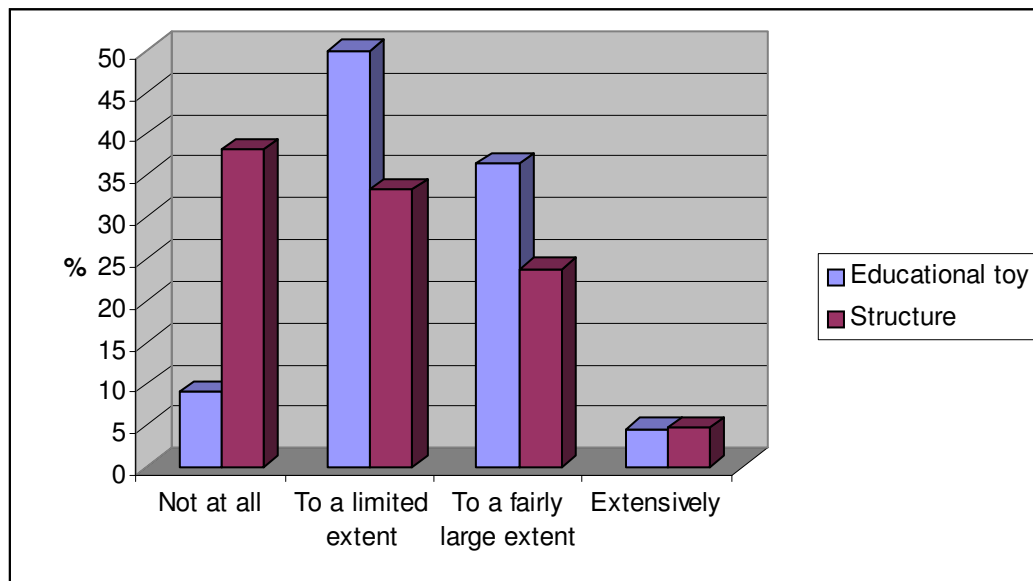
A more detailed description of student responses to each of the knowledge-generating activities, as well as a comparison between the two different capability tasks pertaining to the way in which the students drew from the knowledge-generating activities will now be provided. This section also includes 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

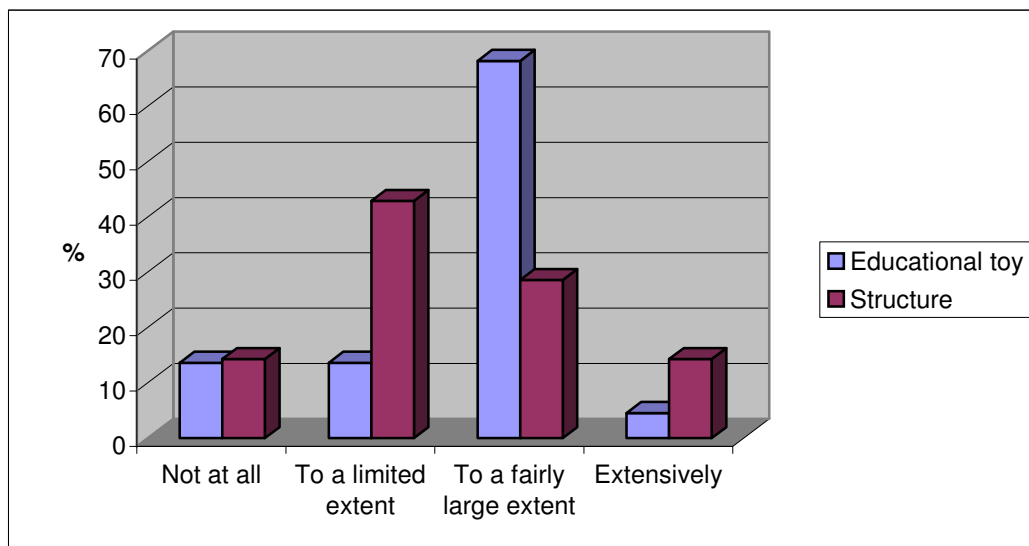
Invention is a source of the operational principles and normal configurations that underlie normal design (Vincenti, 1990:230). Refer to the description of this knowledge-generating activity in section 2.5.1.

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,
Chapter 4: Data and results of the quantitative phase

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.

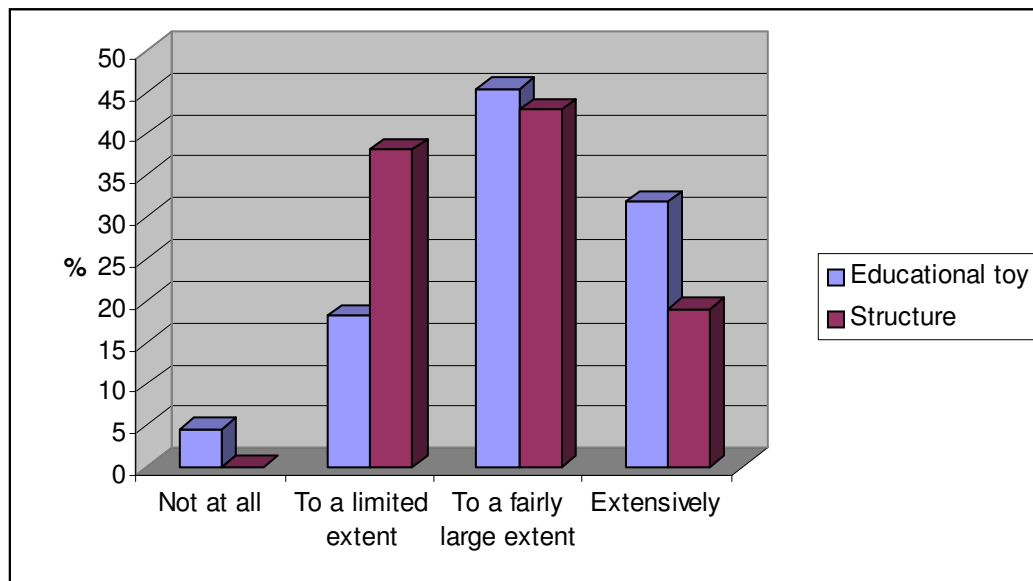
Since it is unfortunately not clear from the students’ relatively short answers to determine whether they discovered and made use of “new” knowledge as a result of their invention or “unique” artefact, the portfolio analysis in the next chapter will revisit this issue.

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).

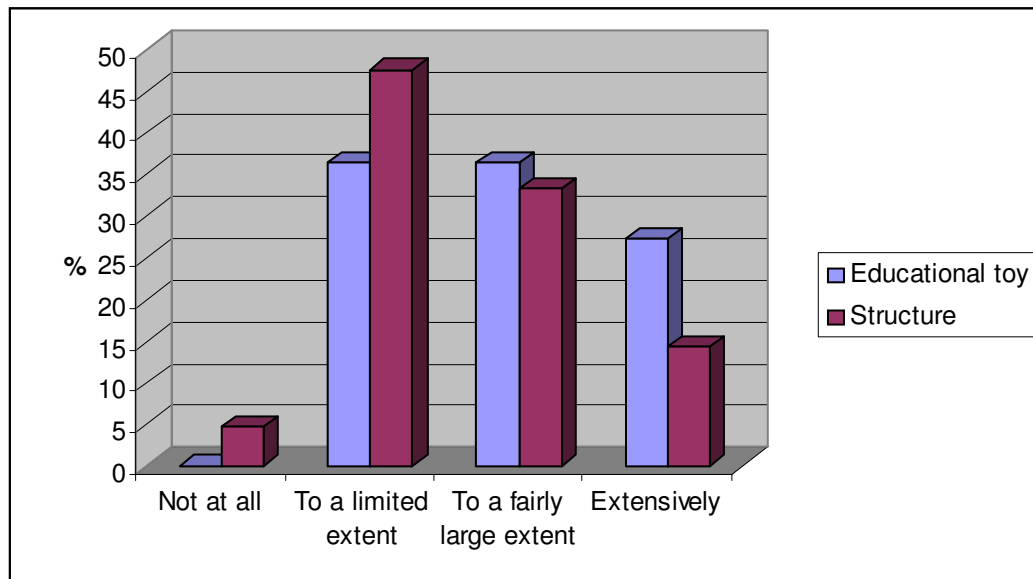
The students' answers above were again very general and lacked detail. It was for example, not clear what properties of which materials were researched.

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).

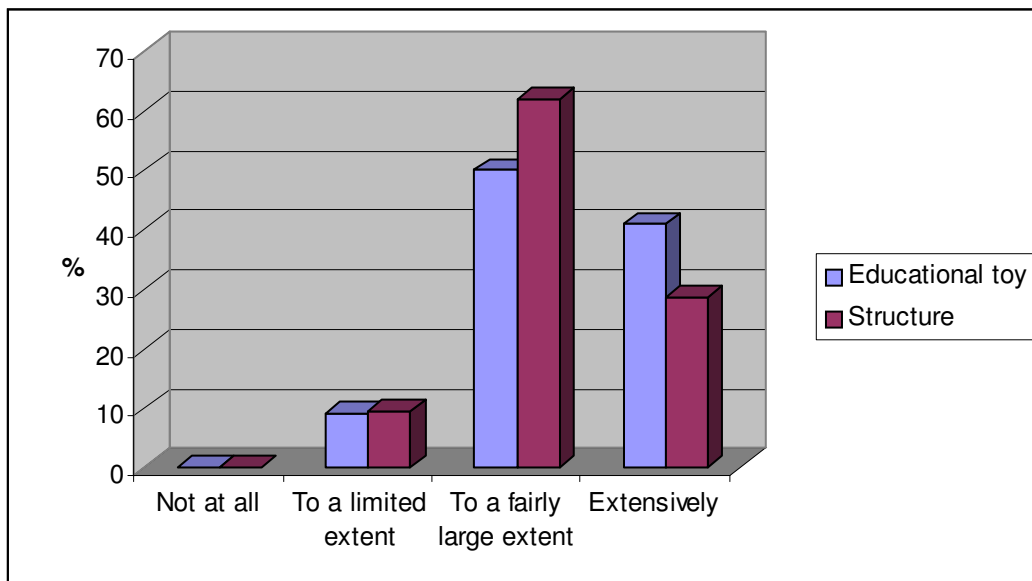
From the forgoing examples it is clear that the experimental research was performed in a very crude/basic manner since the students did not have access to special test facilities and sophisticated measuring devices. It seems that they conducted most of the practical experimental techniques themselves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

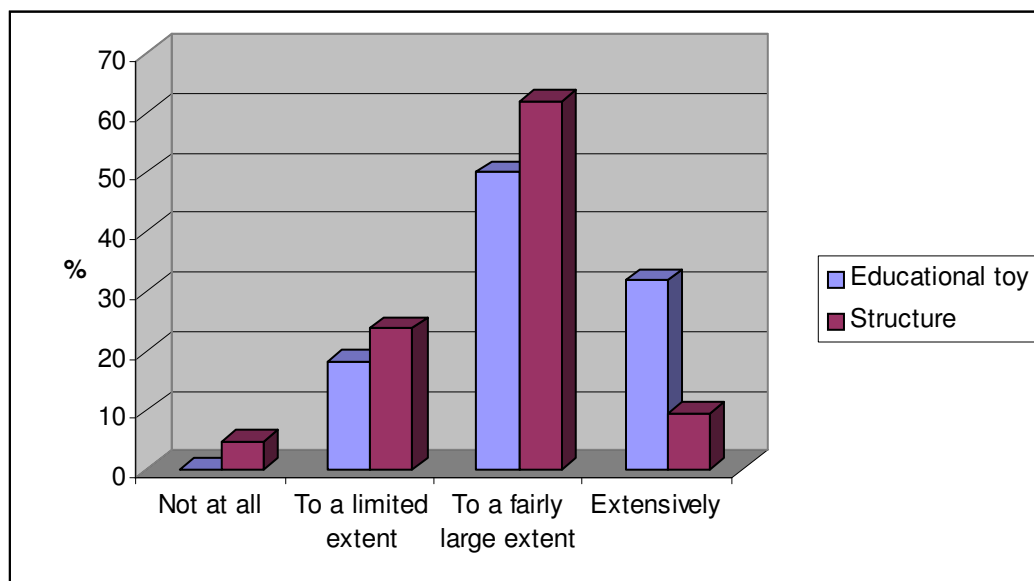
The students' answers focused mostly on the design aspects they were taught at university in previous years. A number of answers relating to colour theory were found. The short answers again lacked detail, making it difficult to comment on them.

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 consideration during the calculations (s23230879).

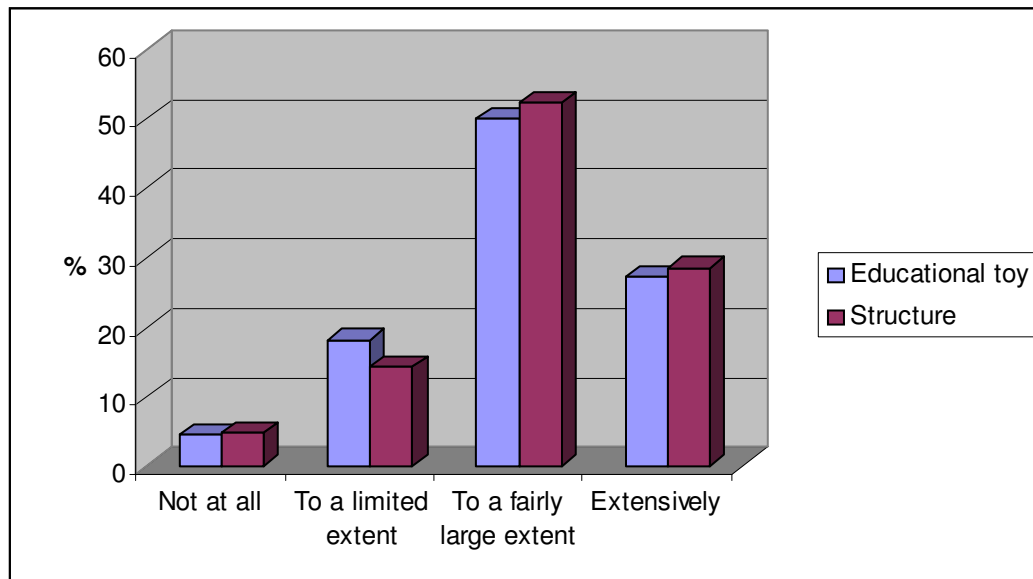
The students' answers seem to describe the typical problems that inexperienced people (students) encounter when making artefacts, due to a lack of relevant tacit knowledge. Many of their problems were not comprehended by the students during the designing phase, but were discovered and solved during the 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 trial¹ – 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).

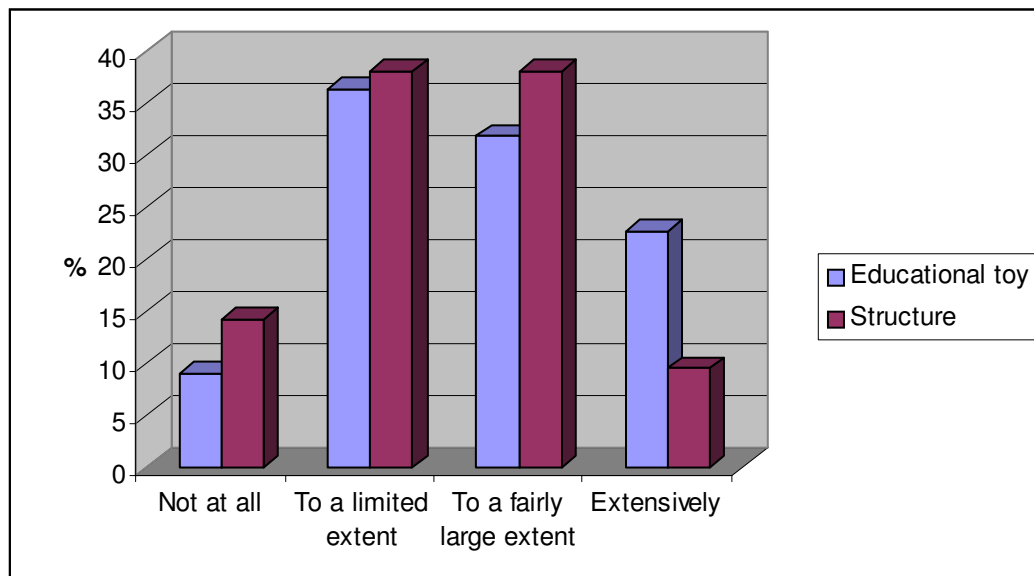
Translated as:

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.

---ooOoo---

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 → **Work = Force x Distance**. 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

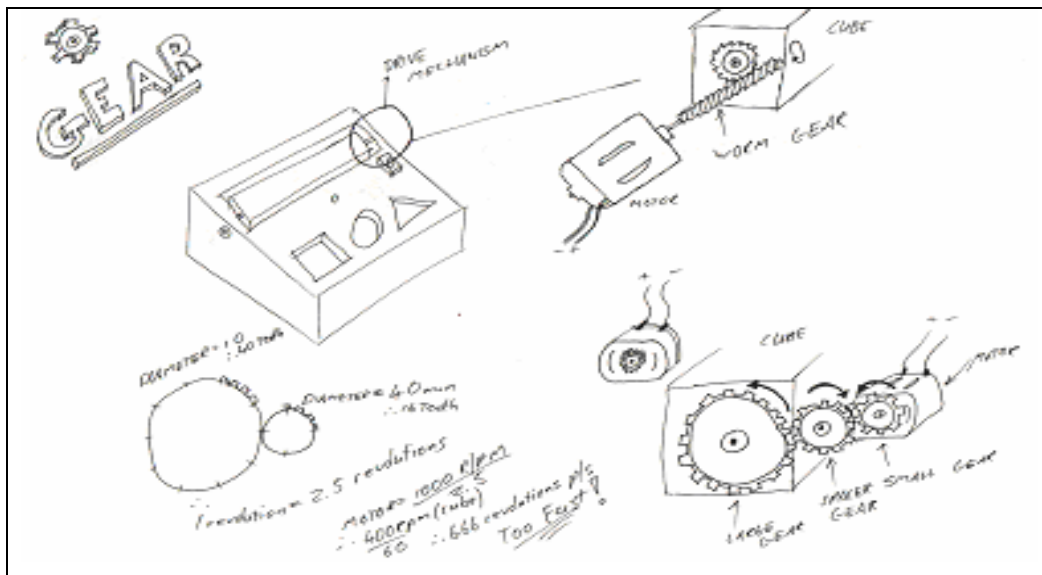
single pulley and a pulley system work, i.e. fundamental design concepts. The source the student consulted was referenced in the text and listed in the bibliography, indicating that the knowledge was obtained by means of theoretical research.

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).

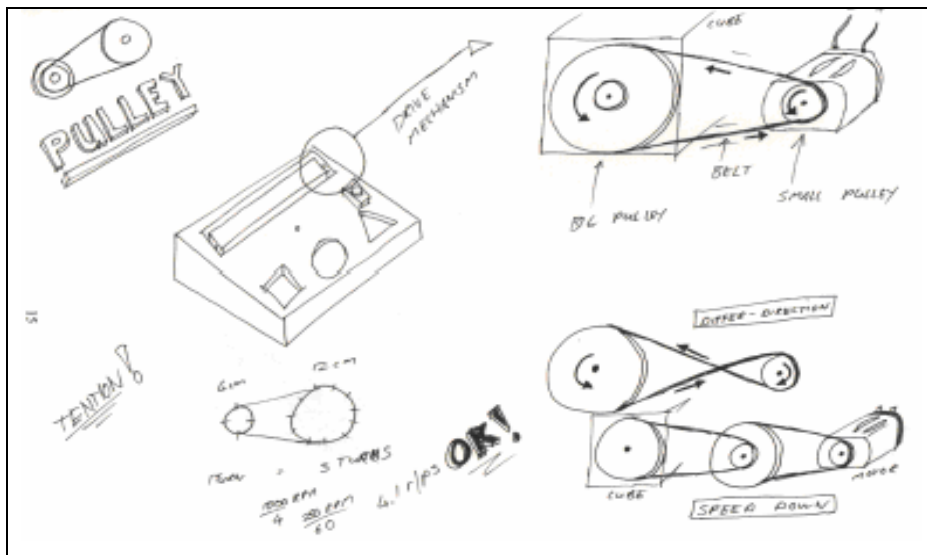
Translated as:

... 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 spindles 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 leerdere 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 parameters³⁰ of a LED are:

$V_L = \text{spanning oor LED} = 2V$

$I = \text{stroom deur LED} = 20 \text{ mA (s23080532:12)}$.

Translated as:

$V_L = \text{voltage across LED} = 2V$

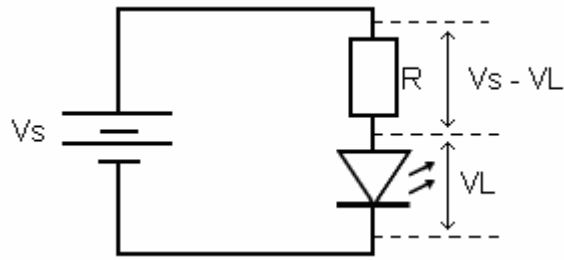
$I = \text{current through the LED} = 20 \text{ mA (s23080532:12)}$.

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 connection³¹.

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 formula³² (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 k Ω) 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:

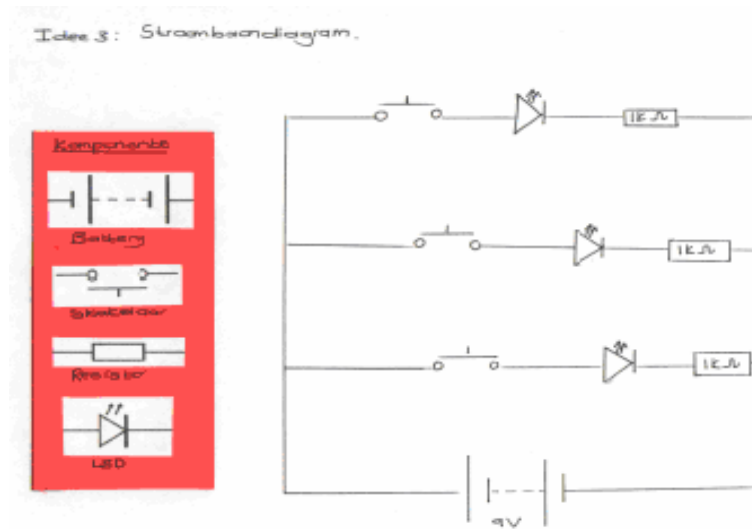
...this will unfortunately result in the LED burning less brightly (s23080532:12).

Since the voltage drop across the 1 k Ω 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 law³³, the higher value resistor (1 k Ω) 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 veiligheidspek 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 rps³⁴ (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)

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

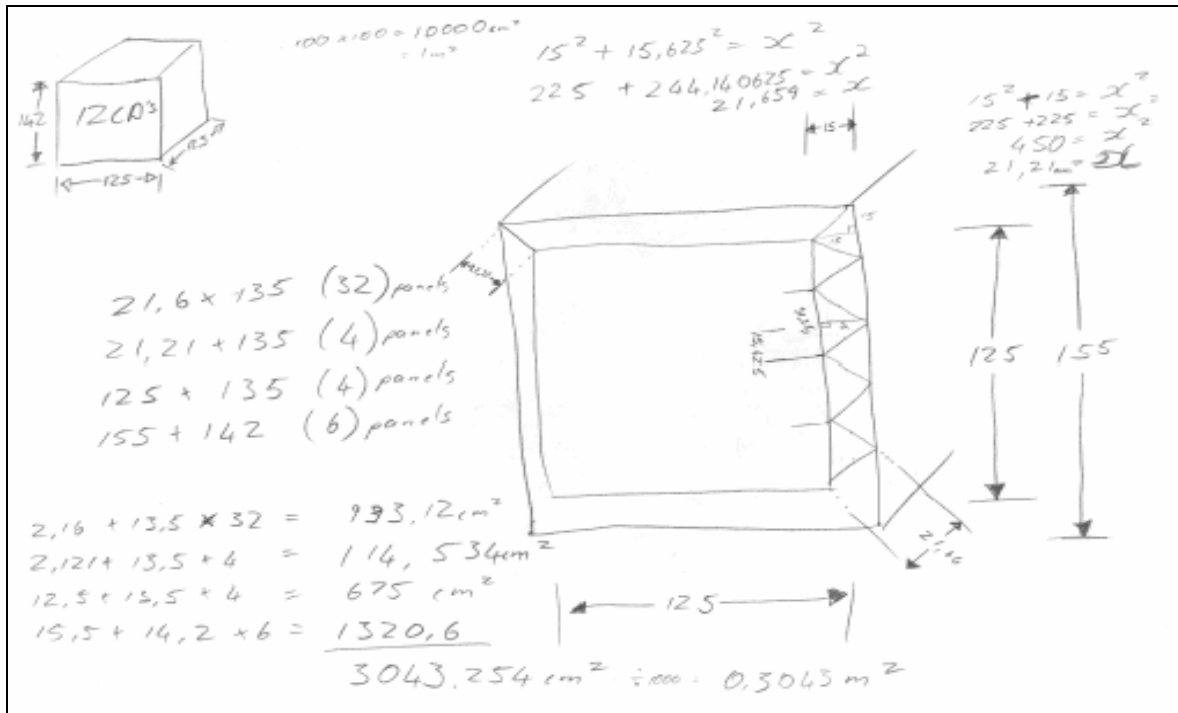


Figure 13 shows that the student (s23230879:16) used the dimensions of a single CD container (142 X 125 X 100) as point of departure to determine the dimensions of the inner box. As this was a box-within-a-box design, the sketches helped the student to visualise and calculate the dimensions of the outer 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 formula³⁵ (*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

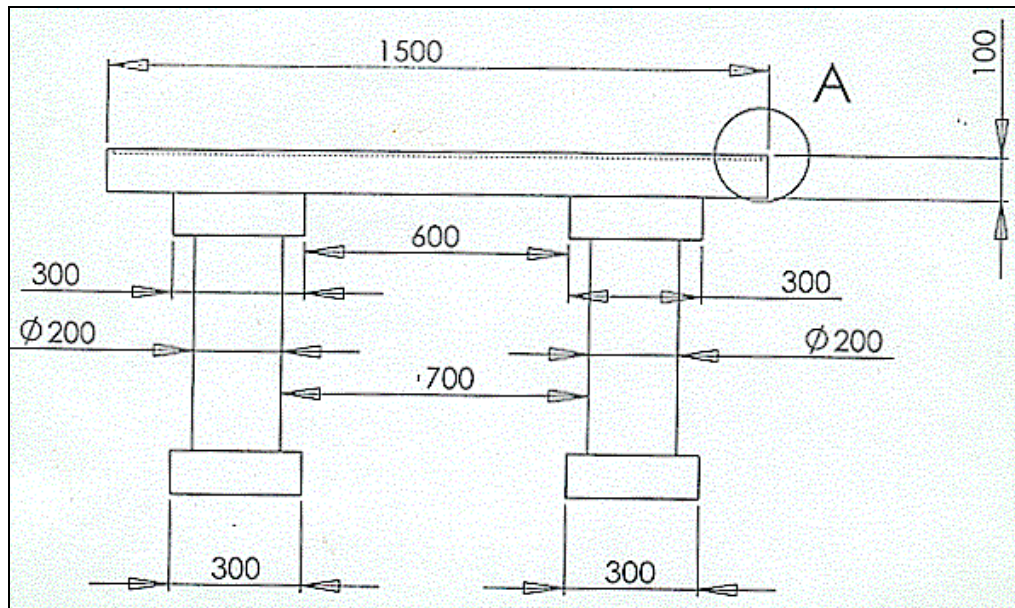


Figure 14 shows a flat drawing in which the dimensions of a table are indicated. As noted above, these quantitative dimensions are not the result of production, but a visual representation and quantification of the design specification and criteria. Given the limited time spent on making and the limited 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:

$$V_L = \textit{spanning oor LED} = 2V$$

$$I = \textit{stroom deur LED} = 20 \text{ mA (s23080532:12)}.$$

Translated as:

$$V_L = \textit{voltage across LED} = 2V$$

$$I = \textit{current through the LED} = 20 \text{ mA (s23080532:12)}.$$

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 improvements³⁶ (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 brief³⁷ 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

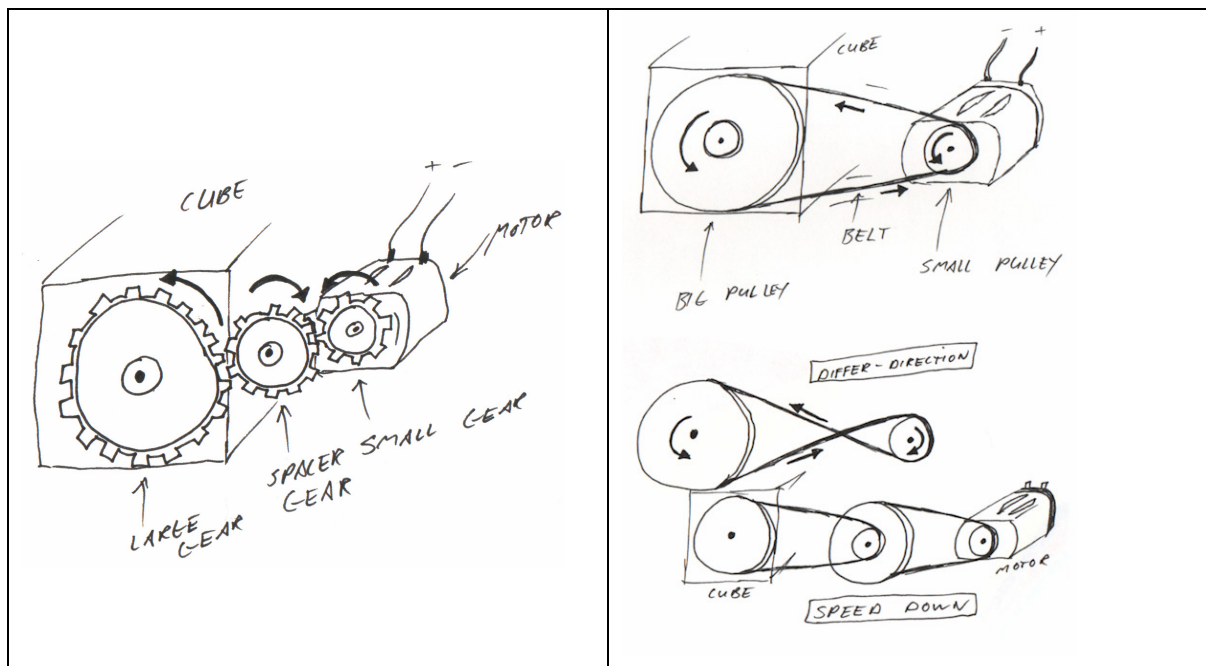


Figure 15 depicts how the students (s23230879 & s23046377) considered various mechanical components and arrangement of these components to make the spindle rotate at the desired speed. The direction of rotation is also clearly indicated in each drawing. The sketch of the gear train on the left shows 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:
 <p>Stap 1: Meet en saag die basis van die speelding.</p>	<p>Step 1: Measure and saw the base of the toy.</p>
 <p>Stap 2: Meet en saag die twee dele waaruit die speelvak gaan bestaan.</p>	<p>Step 2: Measure and saw the two parts that will comprise the playing area.</p>
 <p>Stap 3: Meet en saag die 'Moulding sap skirting', wat op die basis vasgeheg gaan word. Hierdie raamwerk gaan die basis vorm waarin die speelvak gaan pas.</p>	<p>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.</p>
 <p>Stap 4: Gebruik skuurpapier om die growwe gedeeltes glad en netjies te skuur.</p>	<p>Step 4: Use sandpaper to neatly sand the rough parts.</p>
 <p>Stap 5: Meet 'n hoek en saag die stukkie 'Moulding sap skirting' sodat dit soos 'n legkaart op die basis in mekaar pas. Gebruik skuurpapier om die rande glad te skuur.</p>	<p>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.</p>

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 domain³⁸ 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 <i>intellectual concepts</i> 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.

	Direct trial	<p>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.</p> <p>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).</p>
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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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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 remaining³⁹ 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 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 sources⁴⁰ 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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