Spatial Visualisation Ability
and
Problem Solving in Civil Engineering

by:

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Abstract

This thesis investigates the relationships between the teaching and learning of spatial visualisation (SV) skills, problem solving in civil engineering and attitudes towards sketching and drawing (S&D) in Malaysian polytechnic students. The aims of this study were (i) to test whether learning materials could influence SV ability and problem solving skills in civil engineering structural design and structural theory and (ii) to investigate whether there is any relationship between attitude towards (S&D) and SV ability. Three constructs, the View of the professional role of S&D, the Value of the personal usage of S&D and the Tendency to use S&D were chosen as attitude indicators.

A pre and post-test quasi-experimental design with a control was employed to determine the effect of teaching and learning of SV skills on SV ability, and a post-test only quasi-experimental design with a control to determine the teaching influence on Civil engineering problem solving skills. A post-test only design was used to investigate the relationship between attitude towards S&D and SV ability.

The results show that the group taught SV skills had statistically significant gain in SV ability and statistically significantly higher mean score on structural design problem solving skills. However, there is no statistically significant difference between the taught group and the control group in structural theory problem solving skills. The results also show that there are statistically significant correlations between the View of the professional role of S&D and the tendency to use S&D and between the tendency to use S&D and SV ability.

It was concluded that teaching and learning of SV skills enhances SV ability and structural design problem solving skills and that SV ability is directly related to the Tendency to use S&D and indirectly related to the View of the professional role of S&D.
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<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>DP</td>
<td>Diploma Programme</td>
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<td>DTE</td>
<td>Department of Technical Education</td>
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<tr>
<td>HSC</td>
<td>Higher Certificate of Examination</td>
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<tr>
<td>IDP</td>
<td>Integrated Diploma Programme</td>
</tr>
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<td>PDP</td>
<td>Port Dickson Polytechnic</td>
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<td>PMR</td>
<td>Lower Secondary Assessment</td>
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<td>PTS</td>
<td>Level One Assessment</td>
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<td>S&amp;D</td>
<td>Sketching and Drawing</td>
</tr>
<tr>
<td>SDI</td>
<td>Structural Design Test Instrument</td>
</tr>
<tr>
<td>SP</td>
<td>Special Programme</td>
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<tr>
<td>SPM</td>
<td>Malaysian Certificate of Examination ('O' Level equivalent)</td>
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<tr>
<td>SPMV</td>
<td>Malaysian Vocational Certificate of Examination ('O' Level eq.)</td>
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<td>ST Paper</td>
<td>Structural Theory Paper</td>
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<td>SV</td>
<td>Spatial visualisation</td>
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<td>SVATI</td>
<td>Spatial Visualisation Ability Test Instrument</td>
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<tr>
<td>UOP</td>
<td>Ungku Omar Polytechnic</td>
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<td>UPSR</td>
<td>Primary School Assessment Test</td>
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CHAPTER 1

Introduction

1. INTRODUCTION

One of the tasks of engineers is design (of machines, buildings, bridges, etc.), therefore one of the goals of engineering education should be to develop design skills in engineering students (Addis, 1996, 1995). However, the success of engineering education in meeting this goal is uncertain (Eyre, Morreau and Addis, 1994). According to a survey by American industry (Nicolai, 1998), engineering graduates in general are found to be good in engineering science, mathematics and analytical techniques but lack the ability to design.

There are several factors pertaining to educational practices that may contribute to the lack of design skill among engineering graduates in general. Firstly, design requires synthesis skills, i.e., the ability to integrate knowledge from different domains such as mathematics, the natural sciences and technology (Cooper, 1970; Wright, 1994), but the educational practice of teaching topics separately (Korn, 1994; Kartam, 1998 and Noble, 1998) does not support development of these synthesis skills.

...students are typically taught a wide range of courses (basic science, engineering science, engineering discipline specific, humanities) but little is done to provide any synthesis between the courses. There is rarely a discussion or exercise on how all of the topics interrelate.


Secondly, there appears to be an over-reliance - in engineering teaching and learning - on abstract models and quantitative reasoning skills and less emphasis on qualitative reasoning skills (Shaw, 1984). Examples of qualitative reasoning skills are the ability to make inferences through reasoning with propositions and through manipulation and inspection of diagrams and the ability to execute mental simulations of physical events.
In summary, the teaching of topics separately and the lack of emphasis on intuitive and qualitative understanding may have led to poor design skills in engineering graduates in general.

2. CIVIL ENGINEERING AND STRUCTURAL DESIGN EDUCATION

Within the field of civil engineering education, the challenge and difficulty lies in the teaching of structural design (Wheen, 1978; Williamson and Hidspeth, 1982). Structural design is a problem solving method in civil engineering, which is described by Draycot (1990) as "...the study of how the various component elements of a building act together to form a supportive structure and transmit forces down to the foundations." (p. 1). Structural engineers integrate and apply knowledge from other areas such as mathematics, the natural sciences, technology, etc., to build bridges, buildings, towers and other large structures.

Enhancing structural design skill is extremely important because decisions at the design stage are shown to have the greatest impact on the quality and cost of a project. Figure 1.1 illustrates that the design period provides the greatest opportunity for influencing the outcomes of a project which means design skills largely determine the success of a project.

![Figure 1.1. Opportunity to influence a project's quality and cost (The ASCEE cited in El-Metwally and Sclaich, 1993)](image-url)
Continual occurrence of structural failures that are design related (The Institute of Structural Engineers (ISE), 1984; Abdul Karim, 1996; and The Building Research Advisory and The Public Safety Advisory, in Ransom, 1978) has raised concern over the adequacy of structural engineers’ education. According to the ISE survey, the prime cause of failures was inadequate appreciation of loading conditions and lack of understanding of real behaviour of structures (Shaw, 1984 and Seifert, 1984).

The lack of understanding of structural behaviour (one of the fundamentals of structural design) among graduate engineers has already been of concern for some time as indicated by the literature (Eyre, Morreau and Addis, 1994). The over-reliance on mathematical models has been frequently suggested as the major contributing factor to the lack of understanding of structural behaviour. According to a prominent structural engineer, Nervi (1956),

_The pre-eminence given to mathematics in our school of engineering, the purely analytical basis of the theory of elasticity, and its intrinsic difficulties, persuade the young student that there is limitless potency in theoretical calculations, and give him blind faith in their results. Under these conditions neither student nor teachers try to understand and to feel intuitively the physical reality of a structure, how it moves under load, and how the various elements of a statically indeterminate system react among themselves. Today everything is done by theoretical calculations. That student is rated best who best knows how to set up and solve mathematical equations._ (Nervi, 1956, p. 24)

Thirty years later another engineering educator, Addis (1990) echoes similar sentiment,

_Nowadays the teaching of virtually the whole of civil and structural engineering is approached by means of mathematical models of reality - what is usually referred to as theory and structural analysis. Yet the relationship between such models and real structures is seldom discussed._ (Addis 1990, pp. 26-27)
In addition to the abstract ones, less abstract models of reality are being increasingly used in order to improve learners' understanding of structural behaviour. For example, Hilson (1993) uses concrete models of structures, while Tessler, Iwasaki and Law (1998) and Burgess, Plank, and Westaway 1985 use diagrammatic and graphical representations in their effort to develop the understanding of structural behaviour. Tessler, Iwasaki and Law (1998) suggest that the ability to reason with diagrammatic representations is "...an indispensable first step..." in structural design for it provides "...an intuitive understanding of the behaviour of the structure..." (Tessler, Iwasaki and Law, 1998, p. 3) which helps the designer to decide on the appropriate strategy for further analysis.

The ability to reason with diagrammatic representations is part of spatial visualisation ability. Spatial visualisation ability refers to "...the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimulus objects." (McGee, 1979, p. 893). According to Lienhard (1995), spatial visualisation is one of the three elements that characterise engineering design, the two other elements being trial-and-error and co-operation. Lienhard suggests that bad designs may be the consequence of lack of spatial visualisation ability.

3. SPATIAL VISUALISATION ABILITY AND PROBLEM SOLVING

Studies have shown that spatial visualisation (SV) ability is related to academic achievements. Examples of these studies are those carried out by Turner (1982) in integral calculus, Tillotson (1985) in mathematics, Pribyl and Rodner (1985), Seddon and Eniaiyeju (1985) and Seddon and Eniaiyeju (1986) in chemistry, Sorby (1999) in computer aided design and Hsi, Linn and Bell (1997) in engineering problem solving. The literature also shows that SV skills can be improved by teaching and learning (Hsi, Linn and Bell, 1997; Baartmans and Sorby, 1996a; Lord, 1985; Ben Chaim, 1988 and Tillotson, 1985).

Overall, the literature shows that SV skills:

- are essential to successful problem solving especially in mathematics, sciences and some technical subjects,
• can be improved by teaching and learning

• need to be emphasised to gain educational success

Although, visual-spatial thinking "...are inherently embedded in the culture of science." (Reiner (1998, p.1044), they have been neglected in science education (Mathewson, 1999) and education in general (Smith, 1992).

4. PURPOSE OF STUDY

Many studies that evaluate the effects of SV skills on science and mathematics achievements have been carried out as indicated by the literature. However, despite extensive searches, no published report on a study that investigates the influence of SV skills on structural design problem solving was found. The purpose of this study was therefore to investigate the immediate effects of teaching and learning of SV skills on SV ability and the long-term effects of the teaching and learning of SV skills on structural design problem solving in civil engineering students from Malaysian polytechnics. It was also one of the purposes of the study to investigate the effects of the SV skills training on structural theory problem solving - a topic that is closely related to structural design - in the same subjects.

Investigating the roles of the affective domain in the teaching and learning of SV skills and learning in general was also of interest to the study, as positive attitudes towards learning materials have been shown to facilitate learning (Simpson, 1978 and Young, 1998). Therefore an investigation into the relationships between attitude towards sketching and drawing (S&D), a common visualisation tool, was also part of this study. Investigating students’ attitudes has additional benefit, in that, it may provide a better model of the learner, which could be used to develop better teaching and learning strategies (Yokomoto, Buchanan and Ware, 1995).

This study consisted of four mini-studies:

1. Mini-study 1, which investigated the impact of teaching and learning of SV skills on SV ability.
2. Mini-study 2, which investigated the relationship between attitudes towards S&D, SV ability and teaching and learning.

3. Mini-study 3, which investigated the long-term influence of teaching and learning of SV skills on structural design problem solving.

4. Mini-study 4, which investigated the long-term influence of teaching and learning of SV skills on structural theory problem solving.

Figure 1.2 illustrates the relationships between the four components of the study.

The results of this study could be useful to educators responsible for planning course work for structural design and other civil engineering courses in Malaysian polytechnics that are of a similar nature. The results may also be important in explaining the observed variances among polytechnic civil engineering students in SV ability and other subject-area that demand SV skills.

To facilitate understanding of this study, some background information on the country (Malaysia) in general, its education system and the polytechnic education system in particular will be presented.
5. COUNTRY BACKGROUND

Malaysia is a tropical country, situated in the Southeast of Asia. Geographically, Malaysia is situated between 1° North to 7° North Latitude and 100° East to 120° East Longitude (Ministry of Education, 1996).

Malaysia occupies an area of 332,000 square kilometres of west (Peninsular Malaysia) and east regions (states of Sabah and Sarawak) which are separated by 750 km of the South China Sea. The states of Sabah and Sarawak form part of the Northwest of the island of Borneo.

Malaysia's governing system is parliamentary democracy styled after the British system. It had a population of about 19.3 million in 1998 with a high proportion found in Peninsular Malaysia. The Malaysian population is a mix of different races comprising the three main groups, Malays, Chinese and Indians in Peninsular Malaysia, and numerous indigenous groups such as Ibans, Kadazans, Kenyahs, Murut and Bidayuhs in Sabah and Sarawak.

The Malay language is chosen as the official language of the country, with the ultimate aim of uniting the people with multi-ethnic and multi-cultural diversities. As such, the Malay language is the medium of instruction in all Government educational institutions.

Traditionally, agriculture has been the dominant sector in the economy. However, the industrialisation process has transformed the Malaysian economy from one based primarily on agriculture to one in which the industrial manufacturing sector is predominant (Abdullah, 1998).

The process of industrialisation carries with it a significant impact on skills demand and consequently on human resource development. Demand for manpower with high levels and mid-level technical skills is already exceeding supply (Abdullah, 1998) which has implications on the educational institutions especially those that train technical personnel. Human resources are therefore closely related to education. The immediate and long-term education strategies are very much influenced by the
National Development policy, particularly the nation’s economic and social policies (Malaysian Ministry of Education, 1999).

The need to train more people affects the ratio of teacher to students, the speed at which training needs to be delivered and the way education is delivered. The use of modern technology will be widespread which is not always beneficial because, in some cases, it may actually hide crucial deficiencies in students, which consequently affects the quality of graduates. Efficiency in teaching and learning in the technical areas is therefore crucial to the development of the country.

6. MALAYSIAN NATIONAL EDUCATION SYSTEM

Prior to independence, Malaya (as it was then known) did not have a national education policy. The objective of education then was the general objective of the colonial authority, which was to minimise changes and to maintain the status quo. As a result, there were basically three types of schools, Malay schools for the Malays, Chinese schools for the Chinese and Tamil schools for the Indians. An English medium school is the only place where there was mix of races.

As a result of several working papers starting with the 1956 Razak report (in Malaysian Ministry of Education, 1999), the new education system emerged. The development of the education system from the pre-1957 years to its present state (the new education system) is illustrated in Figure 1.3.

The new education system has the following objectives, which are:

- to achieve national unity in a multi-ethnic society
- to produce skilled manpower for national development
- to further extend the policy of democratisation of education in order to strike a balance in all aspects of education between rural and urban areas and human resource development

The structure of the new education system is illustrated in Figure 1.4 which shows the education route a child goes through from pre-school to tertiary education.
6.1 Pre-school education

Pre-school is part of the education system under the Education Act (1996). The aim is to provide a foundation for primary education. Pre-school is provided by government agencies, non-governmental organisations as well as private institutions. Children are enrolled between the age of four to six.

Figure 1.3. Development of the educational system from the pre-independence period to the post-independence period, (Educational Planning and Research Division (EPRD), 1998).
6.2 Primary school education

Primary school education follows the pre-school education. Bahasa Malaysia (Malay Language) is the medium of instruction at all National schools while Mandarin, Tamil and other indigenous languages are made available. English is a compulsory subject. Mandarin or Tamil is the medium of instruction in the National Types School while Bahasa Malaysia and English are compulsory subjects.

Figure 1.4. The structure of Malaysian National Education system. (Ministry of Education, 1999)

Primary education provides the opportunity for pupils to develop their SV skills, i.e. through arts and recreation. However development of SV skills have not been officially identified as one of its focus. Consequently the extent of SV skills being developed through arts and recreation is uncertain.

Primary education takes six years and promotion from year 1 to year 6 is automatic. However, pupils who excel in their studies are given the opportunity to complete their primary education in five years. To identify these students, Level one assessment (PTS) - a standard examination - is administered in year 3. Pupils who excel could forgo year 4 and go straight to year five if they wish to.

At the end of Year 6, pupils sit for a common public examination, the Primary School Achievement Test (UPSR). They are tested on the Malay language, English
language, Mathematics, Science and Chinese language or Tamil language (for pupils from National Type primary school). Good performance in this examination qualifies pupils for entry into government selected secondary schools.

6.3 Secondary school education

Secondary schools offer a comprehensive education programme. The curriculum includes a wide range of subjects from the arts and the sciences as well as vocational and technical subjects that provide a practical bias and hands on approach to learning. Secondary education consisted of the lower secondary (Year I to III) and the upper secondary level (Year IV to V). Promotion from Year I to Year V is automatic and pupils progress in the basic skills is monitored through continuous school based assessments. There are a few private secondary schools whose students are mostly from the more affluent sector of the society. The private school leavers therefore do not normally enrol into polytechnics. Having no impact on the study, private secondary education will not be discussed here.

6.3.1 Lower secondary school education

Pupils continue to lower secondary education on finishing their primary education. Those from the National Types Primary Schools will proceed to a transition year (Remove Class) before going into Year I. The Remove Class is to help pupils acquire sufficient proficiency in the Malay language, which is the Medium of Instruction for secondary education. Those who obtained satisfactory results in the UPSR in year 6 do not have to go through the Remove Class. As in the primary education, arts and recreation is the only medium available for developing SV skills and again, without a specific focus on developing these skills, the extent of SV skills developed is uncertain.

Pupils are required to sit for a common public examination, Lower Secondary Assessment (PMR) at the end of their Year III. Following the PMR, students move into more specialised fields of study at the upper secondary level, based on choice and aptitude.
6.3.2 Upper secondary school education

Upper secondary school education is of prime importance to the present thesis because some school leavers from this stage pursued their studies in polytechnics and consequently became the research subjects. There are six types of secondary school: (i) the academic schools, (ii) the national religious schools, (iii) the technical schools, (iv) the vocational schools, (v) the residential schools and (vi) the special schools. The last two schools will not be discussed for they have no impact on the outcome of the study. The residential schools are catering to above average students and their school leavers normally pursue their studies in universities. Due to their special needs and the heavy requirements of the course, the school leavers from the special schools do not normally pursue a polytechnic civil engineering course. Therefore, only the first four types of schools are relevant to the study and will be discussed next.

6.3.3 The academic schools

The academic schools offer general education and courses in the arts and the science streams. At the same time, vocational and technical subjects are incorporated into the curriculum. At this level, opportunity for students to develop their SV skills is provided directly through the engineering drawing course and indirectly through other technical courses such as engineering construction. However, engineering drawing is only offered as an elective module (Kementerian Pendidikan Malaysia, 1992). As a consequence, only some school leavers have an engineering drawing background. The academic schools constituted 89.4% of the upper secondary schools in Malaysia in 1997 (Malaysian Ministry of Education, 1997) and their school leavers made up 52% (typical percentage) of the polytechnic civil engineering population in the Dec. 1997 - May 1998 academic session in Ungku Omar Polytechnic (UOP).

6.3.3.1 The national religious schools

The Religious schools also offer general education and academic courses but offer no specific programme to develop SV skills. As mentioned earlier in the section, school leavers from the religious schools also feed into the polytechnic system. Religious schools made up 2.9% of the upper secondary schools in Malaysia (Malaysian Ministry of Education, 1997) and their school leavers constituted 1% of the
polytechnic civil engineering population in the Dec. 1997 - May 1998 academic session in UOP.

6.3.3.2 The technical schools

The Technical schools offer general education as well as technical and vocational based subjects. The education programme specifically prepares students for entry into technological, vocational and science related courses at the diploma or degree levels. Engineering drafting is one of the compulsory subjects, which provides the students with the opportunity to develop their SV skills. Students are also expected to take a maximum of five technical and engineering based courses. The technical education programme therefore offered a high percentage of technical and engineering based courses (Kementerian Pendidikan Malaysia, 1992). According to a longitudinal study by Blade and Watson (1955), experiences encountered during engineering study improve SV ability. Therefore, the researcher expected the school leavers from the technical schools to have relatively higher SV ability compared to those from the academic or religious schools. Although technical schools are only 2.0% of all upper secondary schools in Malaysia in 1997 (Ministry of Education, 1997), the proportion of their school leavers in the polytechnic population is much higher, i.e., approximately 10.4%. This statistic was computed based on the total sample in the Dec. 1997 - May 1998 academic session in UOP.

6.3.3.3 The vocational schools

The vocational schools offer general educational and basic vocational skills. Courses offered are in two streams,

(i) skills training stream

(ii) vocational education stream.

The skills training stream is specifically designed to prepare students for work. The vocational education stream on the other hand, prepares students for further studies while providing some vocation related experiences, i.e., through carpentry, welding, automotive, drafting, etc. Although these practical experiences are designed primarily to enhance students' spatial-mechanical skills, some of these experiences have been

1-13
shown to enhance SV skills (Blade and Watson, 1955). Therefore, those who graduated from the vocational educational stream were expected to have developed some SV skills.

Vocational schools made up 3.1% of the total number of secondary schools (Malaysian Ministry of Education, 1997). The vocational school leavers made up 9.1% of the polytechnic civil engineering population, a percentage based on the total sample of the Dec. 1997-May 1998 academic session in UOP.

6.4 Post-secondary school education

Post-secondary school education includes the matriculation programmes, form six programmes, the certificate programmes and the diploma programmes. However only the certificate programmes and the diploma programmes are of relevance to the study because these are the only two programmes that are offered by the Malaysian polytechnics.

Certificate programmes are normally one-year or two-year programmes offered by colleges and polytechnics where the aim is to train for a vocation. Diploma programmes on the other hand are two to four-year programmes offered by polytechnics and colleges where the aim is to train for a vocation as well as for further education.

6.5 Technical education in Malaysia.

As explained earlier, technical education in Malaysia begins at the upper secondary school level. At post secondary level, technical education is provided by private institutions and polytechnics. These places train technical personnel at the lower level (certificate level) as well as at the mid-level technical skills (diploma level). There are currently nine polytechnics under the Ministry of Education with seven polytechnics in West Malaysia and two in East Malaysia. At tertiary level, technical education is provided by private and government universities. These institutions train technical personnel at the high level technical skills (degree level and above).
In summary, technical education begins in upper secondary education after which, school leavers have the choice to further their studies either in polytechnics, colleges or universities.

### 6.6 Education system in Malaysian polytechnics

Malaysian polytechnics were set up under the Ministry of Education with the aim of training school leavers (from secondary schools) to be qualified technicians and middle level business personnel. Starting with the first polytechnic, the UOP in 1969, Malaysian polytechnics have always played a significant role in supplying the lower-level and mid-level technical skills in Malaysia. Since then, the number of polytechnics has been constantly increasing in line with the human resource needs of the country which is moving away from that of being agriculturally based to a more industrialised market economy. In fact, since 1990, the polytechnics' capacity in supplying the mid-level technical skills have more than doubled with the introduction of new diploma programmes in civil engineering, electrical engineering, mechanical engineering and architecture.

Figure 1.5 shows the distributions of diploma courses offered by polytechnics, broken into the four main engineering components and a non-engineering component.

![Pie chart showing proportions of polytechnic enrolments in engineering and non-engineering diploma courses.](image)

**Figure 1.5.** Proportion of polytechnic enrolments in the engineering and non-engineering diploma courses.
Engineering courses make up 61% of diploma enrolments while non-engineering courses make up the rest. Currently polytechnics only supply approximately 4.3% of the country's demand of technical skills. However, under the seventh and eight Malaysia plans, more polytechnics are to be built to cater to the increasing demand for mid-level technical manpower of the country (Department of Technical Education, 1998). Increase in polytechnics and consequently polytechnic enrolments, is bound to affect teaching and learning in some way.

6.6.1 Polytechnic programmes
As mentioned earlier in the preceding section, Malaysian polytechnics offer engineering and non-engineering programmes at both certificate and diploma levels. A certificate programme is a 2½-year programme (inclusive of six months industrial training) while a diploma programme is a 3½-year programme, inclusive of six months industrial training. This section will only focus on the Civil Engineering Diploma programme, which is the course of immediate relevance to the thesis. Malaysian polytechnics offered three routes to a civil engineering diploma. Each route has an entry point and entry requirement, which are specific to it. Differences in the entry requirements have implications on the selection of the research samples, which will be discussed in Chapter 5, Section 3.5.

Obtaining a civil engineering diploma entails enrolling into one of the following programmes (all the resulting diplomas are equivalent):

- the diploma programme (DP)
- the integrated diploma programme (IDP)
- the special diploma programme (SDP)

The DP is the most direct route to a diploma for school leavers. This programme is offered to upper secondary school leavers whose qualifications are equivalent to G.C.E. 'O' levels. It is a 3½-year programme, which includes six months of industrial training and graduates are awarded with the diploma upon successful completion of the programme.
The IDP on the other hand, is essentially two programmes integrated into one, i.e., a 2½-year Certificate programme plus the final year of the DP programme - totalling 3½ years. Like the DP, the IDP is also offered to secondary school leavers, however, continuation into the final year of the DP is not automatic. Students are awarded with a certificate at the end of the Certificate programme and could only continue into the final year of the DP if they excel in their studies. From then onwards the programme is essentially the final year of the DP and students are awarded the diploma on successful completion of this year.

Finally, the SDP is a special programme, which is only offered to former polytechnic graduates, i.e., those with Malaysian polytechnic certificates. The programme is a one-year programme identical to the final year of the DP. Students are awarded with the diploma on successful completion of the one-year programme.

Students with diplomas can go directly into the second year of a four years engineering degree programmes if they wish to further their studies. However, if they seek employment in the construction industries, they will work under engineers and assist them in the supervision of site-works and in the design of simple structures.

The specific entry requirements for the three diploma programmes are given in Table 1.1.

Table 1.1. Entry requirements for polytechnic programmes.

<table>
<thead>
<tr>
<th>Entry requirements for the IDP</th>
<th>Entry requirements for the DP</th>
<th>Entry requirements for the SDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) A credit in Mathematics and a) A pass in Mathematics and</td>
<td>a) A credit in any one subject from the following grouping:- Physics, Physical Science, Additional general Science, General Science, Engineering Science and any related technical subject.</td>
<td>The course is offered to candidates with certificates from Malaysian polytechnics. Candidates must also be:</td>
</tr>
<tr>
<td>b) A pass in any one subject from the following: Physics, Physical Science, Additional general Science, General Science, Engineering Science and any related technical subject.</td>
<td>b) A credit in any one subject from the following grouping:- Physics, Physical Science, Additional General Science, General Science, Engineering Science, and any related technical subjects.</td>
<td>a) Malaysian citizens</td>
</tr>
<tr>
<td>a) A credit in Mathematics or additional Mathematics</td>
<td>b) A pass in English</td>
<td>b) Having at least a 'B' grade in three (3) subjects.</td>
</tr>
<tr>
<td>b) A pass in English</td>
<td>c) Two additional credit in the following grouping:- Physics, Physical Science, Additional General Science, General Science, Engineering Science, and any related technical subjects.</td>
<td>c) Three years working experience.</td>
</tr>
</tbody>
</table>
To summarise, the three routes to a polytechnic civil engineering diploma plus their general entry requirements are illustrated in Figure 1.6. The subjects for the present study were selected from the sixth semester, which is the last semester in the diploma programme.

Figure 1.6. Three routes to getting a diploma from a polytechnic.

6.7 Teaching and learning of structural design in the polytechnic

In teaching and learning of structural design, the emphasis is on structural analysis rather than design and design tasks are limited to the design of structural members (column, beam and slab). Typical of learning in engineering, mathematical equations (abstract representations of problems) dominate solution finding strategies - problem solving. From casual observations, limited use is made by students and teachers of diagrammatic or graphical representations such as S&D in problem solving. Where S&D are used, such as in sketches of bending moments, shear forces, etc., S&D rarely function as problem solving tools but more often as a direct response to a requirement, i.e., required by the questions. Therefore, in this study, an attempt was made to measure students' perception of the usefulness of S&D, personal and career wise.
6.7.1.1 Teaching and learning of SV skills in the polytechnic curriculum

Figure 1.7 shows the semester six courses and the time allocated (in percentages) to each course. Apart from the minimal 6% (of total teaching time) that is allocated to CAD (SV tool), the rest of the semester 6 programme is filled with courses that are mathematically and numerically oriented.

![Diagram showing proportions of time allocated for each of the semester six modules](image)

Figure 1.7. Proportions of time allocated for each of the semester six modules

Naturally, a preference for mathematical representations (abstract models) of reality exceeds other forms of representations. As a consequence, developing SV skills is not a priority and therefore not sufficiently emphasised in the semester 6 curriculum.

At the lower semesters, however, more time was allocated to improving SV skills in the polytechnic students. Courses on engineering drafting and CAD were offered six periods a week to the semester 1 and 2 students. Although the time allocated for CAD and engineering drawing was relatively high (28%), the approach to teaching SV skills was restricted by the learning objective, which was to develop draughtsmanship skills (Malaysian Ministry of Education, 1991). This objective does not support creative use of drawing in problem solving. According to Cassie (1970),
draughtsmanship and design skills need to be differentiated if drawing is to be a tool for improving design skills.

*The great difference of draughtsmanship and design skill must be constantly kept in mind. The designer certainly requires the mechanical ability to read and produce drawings, but this is not an end in itself and above all he needs to develop his creative talents. If a technique of teaching drawing in applied science is such that all men produce the same answer to a given problem, one can well say that a failure has been recorded. The encouragement of creative ability through graphical expression should lead to as many solutions to a common problem as there are students in the study group.*

(Cassie 1970, p. 45)

Therefore some changes need to be made to the approach of teaching and learning of the current engineering drawing module if it were to be a tool in design problem solving. In this study, enhancing design problem solving skills through the use of S&D was also made one of the aims of teaching and learning of SV skills, as shown in Table 1.2. This aim calls for a change in the teaching approach, i.e., from a context-free teaching (teaching geometry) to a contextualised one (teaching structural behaviour).

The teaching strategy employed was such that teaching and learning progressed from the concrete to the abstract. For example, teaching and learning activities started with manipulations of concrete materials such as building blocks and miniature models, and progressed to sketching from imagination. The new approach was hypothesised to improve SV ability as well as problem solving skills in civil engineering. The teaching strategy used in the study is different from the normal one in two ways: (i) concrete learning materials preceded abstract materials and (ii) informal, non-standardised representations (sketches) complemented standardised drawings.
Table 1.2. The proposed treatment for teaching spatial visualisation versus the normal practice.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>To train students to be draughtsman</td>
<td>To enhance design problem solving skills by developing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• the ability to reason with figural information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• the ability to externalise internal spatial representations</td>
</tr>
<tr>
<td>Approach</td>
<td>It is taught separately from the subject that is most likely to be applied to.</td>
<td>Integrate teaching and learning of spatial skills into the subject it is most likely to be applied to such as in structural design, rather than teaching them as isolated skills.</td>
</tr>
<tr>
<td>Teaching strategy</td>
<td>Concrete experience is not provided prior to the abstract activities (drawing) The normal practice is to go straight into using mechanical drawing instruments to produce engineering drawing</td>
<td>Starts with manipulating concrete materials (building blocks), and progresses to more abstract materials (sketching and drawing)</td>
</tr>
</tbody>
</table>

7. OUTLINE OF THIS THESIS

This thesis consists of 15 chapters. Chapter 1 lays the foundation for the thesis explaining the background to the study followed by Chapter 2 which reviews the literature on spatial ability and SV ability. Chapter 3 identifies the tasks of structural design and the composite skills that are required to perform them through a task analysis of the structural design process. This is followed by the identification of the component skills of structural design, achieved through a cognitive analysis of a structural design objective in Chapter 4. The outcomes of the analysis from Chapter 3 and 4 are used as guidelines for designing the learning materials and for designing the research instruments in the study.

Chapter 5 describes the research methods used in the study followed by Chapters 6, 7 and 8 on development of the research instruments. Chapters 9 and 10 evaluate these instruments using data from the actual study while Chapters 11, 12, 13 and 14 present and analyse the data gathered in the study. The overall conclusions, implications and recommendations are presented in Chapter 15.
8. DEFINITIONS

Definitions adopted by researchers are often not uniform. Here are the key definitions used in the study. These definitions are favoured over the others for reasons explained in Chapters 2 and 3.

Spatial Ability is the ability to form stable and accurate mental representations of spatial information for the purpose of utilising them in three dimensional (3-D) and two dimensional (2-D) spatial problem solving.

Spatial visualisation ability is the ability to manipulate objects in imagination by executing mental transformation of rotation and folding-and-unfolding.

Sketching is drawing in which all the proportions and lengths are judged by eye and all lines are drawn without the use of drawing instruments, the only tool being pencils, eraser and paper.

Sketching and drawing is the phrase used to describe the products as well the activities of making pictures of something using pen or pencil, which include those that are rough and quickly done without many details or those that are carefully done with many details.

Problem solving is a learning activity that requires the ability to organise knowledge of several principles in order to reach a successful solution.

Problem solving skill is an intellectual skill that enables the problem solver to develop or synthesise existing rules.

Structural Design is the study of how the various component elements of a building act together to form a supportive structure and transmit forces down to the foundations.

Structural Design problems are written problems of varying difficulty and cognitive levels associated with the design of a structure. Their solutions demand the applications of concepts and principles from the various scientific and arts domain. It involves higher level skills of synthesis and evaluation.
**Structural theory problems** are written problems on structures whose solution requires the applications of principles of structural theory and mathematics.

**Attitude** is a summary of all the knowledge, evaluative beliefs and action tendencies a person has about an attitude object.

9. **CONCLUSION**

This chapter has located the problem of structural design within the framework of the Malaysian educational system and identified SV ability as an important element in the successful structural design process. SV ability, however, is neither practically well understood by (Malaysian) students nor well-taught in Malaysian polytechnics. It is hypothesised that teaching and learning of SV skills will improve SV ability as well as problem-solving skills in civil engineering.

The next chapter will examine the issues associated with SV ability in more detail.
CHAPTER 2

Spatial Visualisation Ability and Problem Solving

1. INTRODUCTION

The previous chapter identified the need for further investigations into the impact of spatial visualisation (SV) skills, on civil engineering problem solving. This chapter aims to do the following to facilitate the investigation.

- establish the working definition for SV ability
- identify the variables that may influence the outcome of the study
- relate SV ability to problem solving

This chapter is divided into three sections and a summary. The first section discusses the theories and previous research findings related to spatial ability - of which SV ability is a sub-set - with the purpose of finding the appropriate definition for SV ability. The second section reviews some of the past studies on SV ability in order to identify the variables that may affect the outcome of this study. The third section provides some of the evidence from past studies that relate SV ability to problem solving.

2. SPATIAL VISUALISATION ABILITY AND HUMAN INTELLIGENCE STRUCTURE

Guildford, Burt, Spearman and Thurstone (in Dobson et al., 1982) and McGee (1979) identify SV ability as one of the components of spatial ability that has been recognised to be one of the factors of human intelligence structure. Although spatial ability is recognised as an important aspect of human thought (Lohman et al. 1987) and an important dimension of human abilities for more than half a century (MacFarlane, 1964), spatial ability has never attained the level of recognition afforded verbal and numerical ability (Simpson, 1992).
2.1. Spatial ability and spatial representations.

Spatial ability has been studied in various contexts - teaching and learning, geography, environmental design, etc. Although inter-related, these spatial ability studies may not be focussing on the same research problems. Consequently, findings from one spatial ability study are not necessarily applicable to another. Misinterpretation of the research problems that are addressed in the different spatial ability studies may result in misapplications of research findings.

According to Liben (1981), studies on spatial ability could be broadly categorised into (i) studies on spatial behaviour in the environment and (ii) studies on spatial representations. Cognisance of the relationships between the two areas is very important in order to avoid any misapplications of research findings mentioned above.

While there is still disagreement on what constitutes spatial representations and whether there is any relationship between spatial representations and spatial behaviour, researchers and authors generally agree that spatial behaviour can be defined as the actions of a person in space (Liben, 1981). Some authors such as Piaget and Inhelder (1971) contended that movements/actions in space (spatial behaviour) are not necessarily an indication of the existence of spatial representations. However, Liben (1981) suggests that spatial behaviour and spatial representation are related and the relationship can be understood by redefining the term spatial representation. According to Liben (1981), there are three forms of spatial representations:

- spatial products
- spatial thoughts
- spatial storage

Liben (1981) defines:

- spatial products as the “...external products that represent space in some way regardless of medium;...sketch maps, miniature models, and verbal descriptions.” (p. 11).
• spatial thoughts as "...thinking that concerns or makes use of space in some way ...knowledge that individuals have access to, can reflects upon, or can manipulate, as in spatial problem solving." (p. 12). Examples of spatial thoughts are mental rotations and mental translation of visually presented figures.

• spatial storage as "...any information about space contained "in the head"..." where "...the individual is not cognizant [sic] of this information." (p. 13).

Liben (1981, 1990 and 1991) further suggests that forms of spatial representations are interchangeable without restriction. For example, retrieving a spatial representation from long term memory and manipulating it as in spatial problem solving would change it from spatial storage to spatial thoughts. On the other hand, putting the outcome of the problem solving activity to paper would change the spatial thought to spatial product.

Although what constitute spatial products are fairly clear, there are still discords on the nature of spatial thoughts and spatial storage. Currently, there are two major viewpoints on the nature of spatial thoughts and storage, the pictorialism and the descriptionalism. The descriptionalists propose that spatial information is represented in the form of propositions/structured descriptions while the pictorialists propose that some visual/spatial information is stored as and mentally represented in the form of mental images which bear a non-arbitrary correspondence to the object being represented (Tye, 1984).

2.2. Framework of the study

The present study was within the framework of the pictorialists' viewpoint and could be simply described as a study on spatial thoughts (SV ability) using spatial products (items that are in the SV ability test instrument).

The pictorialists' framework was deemed appropriate in view of the nature of the engineering problem solving skills to be investigated. Civil engineering problems such as design problems frequently contain complex spatial information on objects, structures, etc., which necessitate the use of spatial representations in the form of
diagrams, drawings and pictures. It is often easier to accurately depict pictorially the spatial relationships among objects than to describe the relationships in text (Bieger and Glock (1986). In other words, although words alone could "...describe many nuances of a design where graphical images fail, but [words] lack the ability to communicate precisely the same image to each member of the audience." (Isham, 1997, p. 3). Pictorialism therefore, appears to be the more appropriate framework for the present study.

2. 3. Definition of spatial ability
Spatial ability generally refers to a person’s skills "...in representing, transforming, generating, and recalling symbolic, non-linguistic information." (Linn and Peterson, 1985, p. 1482). This ability has been defined in many ways, which may be partly the consequence of the methods used to investigate and identify this ability - factorial analysis method of study. Factor analysis is a statistical method that "...yields information about which measures from a conglomerate of measures that tend to cluster together." (Caplan, MacPherson and Tobin, 1985, p. 796). These clusters which are called factors are then assigned labels which correspond to the processes that are assumed to underlay the tasks used to detect the processes. For example, if the processes that are assumed appear to be spatial in nature, the factor is then labelled as a spatial factor and so on. As a consequence of this method, a large number of spatial ability components (factors) were identified ranging from as low as two (McGee, 1979), to as high as one hundred and twenty (Guilford as cited in Lohman et al. 1987). SV ability is one of the components identified through this method.

The different focus of the researchers and authors that are studying this ability could also be contributing to the varied definitions of spatial ability. In general, spatial ability is defined as the ability to process spatial information but other definitions have been found which seem to reflect the focus of the authors. For example, one author focussed on the importance of the ability to produce spatial products in his definition when he defined spatial ability as "...the ability to interpret and make drawings, visualise changes and generalise about changes in the environment.” (Khone’s Report, no date).
Other authors focussed on the 3-dimensional aspect of this ability. For example, Suzuki et al. (1992) define spatial ability as the “...ability to think in three dimensions.” while another author defines it as “...depth perception, awareness of the position of objects in three-dimensional space, and the ability to work with three-dimensional geometry.” (Birk, 1999)

The visual aspect of spatial ability is also sometimes the focus of some researchers when it is defined as the “...ability to perceive, transform, and recreate different aspect of the visual-spatial world.” (Carvin, 1998). While other authors emphasise the dynamic aspects of spatial ability in their definitions. For example:

- Gardner, Kornhaber, and Wake (1996) define spatial ability, which they called spatial intelligence as “...the ability to perceive visual or spatial information, to transform and modify this information, and to recreate visual images even without reference to an original physical stimulus.” (p. 207)

- Larson (1996) defines it as the ability to visualise the movements of objects in space

- the Vermont Department of Education (1997) defines it as the ability “...to mentally visualize and rotate three-dimensional objects and accurately imagine what they look like in different positions.” (paragraph 8)

Finally, the ability to retain spatial information is also seen as an important aspect of spatial ability when this ability is defined as “...the ability to generate, retain, transform abstract visual image.” (Lohman in Kyllonen, Lohman and Snow, 1984, p. 130).

Taking into considerations of the different aspects and the context of its study, spatial ability was defined as the ability to form stable and accurate mental representations of spatial information for the purpose of utilising them in three dimensional (3-D) and two dimensional (2-D) spatial problem solving.

Three criteria are involved in the definition: the ability to form stable and accurate representations, the ability to carry out 2-D spatial problem solving and the ability
to carry out 3-D spatial problems solving. This definition is deemed appropriate, as will be explained next.

The criteria accurate and stable representations are essential to the definition of spatial ability. Being able to form mental representations of an object is not sufficient for successful spatial problem solving unless these representations are accurate representations of the source objects which they represent and are stable over the duration of its use (Mumaw and Pellegrino, 1984).

The criteria, able to carry out 2-D and 3-D problem solving is also essential to the definition for the following reasons. Firstly, the criteria reflect the kinds of spatial problems that are faced by engineers and engineering students in general. Engineers have to deal with the conceptualisation and construction of 3-D structures, which are the skills that need to be developed in engineering students. In the design process, engineers and students alike have to deal with the 2-D representations of the 3-D objects such as the elevation views and the cross-sectional views found in engineering drawings. This makes 2-D and 3-D spatial problem solving skills a pertinent construct of spatial ability for this study.

Specific to the study, the definition reflects the types of spatial skills required in solving civil engineering structural design and analysis problems (to be identified in Chapter 3 and 4). It is found that 2-D spatial representations are the most commonly used form of representations in any structural analysis problem which justifies the inclusion of 2-D spatial problem solving in the definition of spatial ability. The phrase 2-D spatial representation is defined as the representation of space showing only two combinations of dimensions on a figure (breadth/width/height).

2.4 Components of spatial ability
Lohman et al. (1987) suggest that the multitudes of spatial factors that have been identified could be broadly categorised into the following categories of spatial factors, which is shown in Table 2.1.
Table 2.1. Broad categories of spatial ability factors as defined by Lohman et al. (1987).

<table>
<thead>
<tr>
<th>Spatial factors</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial visualisation (SV)</td>
<td>the ability to transform mentally such as rotate, reflect, fold or unfold, synthesise visually presented figures</td>
</tr>
<tr>
<td>Spatial orientation (SO)</td>
<td>the ability to predict what an object would look like if seen from a different perspective</td>
</tr>
<tr>
<td>Flexibility of closure (Cf)</td>
<td>the ability to hold a given visual percept on configuration in mind to dissemble it from other well defined material</td>
</tr>
<tr>
<td>Closure speed (Cs)</td>
<td>the ability to identify quickly an incomplete or distorted picture</td>
</tr>
<tr>
<td>Serial integration (SI)</td>
<td>the ability to integrate temporarily spaced visual stimuli</td>
</tr>
<tr>
<td>Spatial relations (SR)</td>
<td>the ability to solve simple rotation problems by whatever means.</td>
</tr>
<tr>
<td>Spatial scanning (SS)</td>
<td>speed planning- identified by items such as simple maze-tracing</td>
</tr>
<tr>
<td>Perceptual speed (PS)</td>
<td>the ability to match visual stimuli rapidly</td>
</tr>
<tr>
<td>Visual memory (Vm)</td>
<td>the ability to recognise a previously presented picture or geometric form.</td>
</tr>
<tr>
<td>Kinaesthetic (K)</td>
<td>the ability to make rapid left right discriminations</td>
</tr>
</tbody>
</table>

According to him, the lower level spatial skills are detected by responses to tasks which are simple and answered under speeded condition, i.e., where tasks are solved by perception rather than thinking. Perception here is defined as "...how we look at things." and thinking is defined as "...how we process our perception." (De Bono, 1994, p. 37). The higher level skills on the other hand are identified by the more complex spatial tasks, which require multi-step processing in reaching their solutions.

Lohman et al. (1987) also suggest that these factors could be arranged hierarchically in a three-dimensional space hierarchy as illustrated in Figure 2.1. The axis on the horizontal plane represents the necessary mental processes for solving a spatial task, which he identified as the ability to identify, store, orient, rotate and compare. The axis on the vertical plane on the other hand represents the degree of complexity of the spatial tasks that are used to infer the presence of the associated factor. In other words, a higher spatial factor (along the axis) is associated with a more complex task, which means, accuracy of responses rather than speed of responses is the differentiating factor for individual differences in the higher level factors.
This is because the higher level factors are detected using tasks that are more complex and requiring multi-step processing in reaching their solutions. For example, having the ability of SV would imply the ability to solve complex spatial tasks accurately, which implies accuracy rather than speed as the differentiating factor in individual differences in ability. However, having the ability of serial integration on the other hand means being able to solve a simple task quickly, which means speed is the differentiating factor for individual differences. In brief, these spatial factors are differentiated by the attributes of the spatial tasks that are used to identify them which are (i) the required mental processes, (ii) the required speed in solving these tasks and (iii) the complexity of the stimuli in the associated task.

In general, authors and researchers seem to be in agreement that these spatial factors are inter-related and could be sorted out into positions along a single "speed-power" performance continuum or "simple-to-complex" task complexity continuum (Larson, 1996, p. 1) as illustrated in Table 2.2. The speed-power continuum represents the response time and the accuracy in solving the tasks associated with them and the simple-to-complex continuum represents the degree
of complexity of the task stimulus that are used to test the presence of these abilities.

Table 2.2. Power continuum for deciding the relationship between simple and complex spatial tasks

<table>
<thead>
<tr>
<th>Speed (Simple)</th>
<th>Intermediate</th>
<th>Power (Complex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptual speed tests requiring only rapid visual comparison.</td>
<td>Mental rotation on pictures in the picture plane. (eg. Spatial relations)</td>
<td>Mental transformations of detailed pictures. (eg. Spatial visualisation)</td>
</tr>
</tbody>
</table>

Authors and researchers also seem to be in agreement on at least two broadly defined spatial ability factors - spatial relations/spatial orientations and spatial visualisation ability, which are independent of the verbal and quantitative factors. They also seem to be in agreement that these factors could be measured using static tasks with pencil and paper tests (McGee, 1979; Miller & Bertoline, 1991; and Salthouse et al., 1990).

Although, SV ability is the spatial component of relevance to this thesis, some literature on spatial orientation/spatial relation ability will be presented, as understanding of spatial relations/orientations will facilitate the understanding of SV ability.

2.4.1. Spatial relations and spatial orientations

Hart and Moore (1973) who study environmental cognition, refer to spatial orientation ability as "...the way in which an individual determines his location in the environment." (p. 250). Lohman et al. (1987) on the other hand, refer to spatial orientation ability as the ability "...to determine how an object or scene will appear from a new perspective." (p. 265). Lohman's and colleagues' definition appears to be a more universal definition while that of Hart and Moore (1973) implies spatial behaviour in a large environment.

Lohman et al. (1987) also differentiate spatial relation ability from spatial orientation ability slightly by defining spatial relation as the ability to imagine what
an object (pictorially presented to the viewer) would look like from a different perspective after the object has undergone a rotational transformation.

A common factor between the two abilities (spatial relation and spatial orientation) is the ability to recognise an object when presented from a different perspective, while the difference is in the strategy used in solving the associated spatial task. If a person imagines himself/herself moving in relation to the object in solving the spatial task, then he/she is said to have spatial orientation ability. On the other hand, if he/she imagines the object is moving in relation to himself/herself then he/she is said to have spatial relation ability.

Unless a researcher is interested in the fine difference between the two strategies, studies on spatial ability usually adopts the position that spatial orientation and spatial relation as being the same skill which is the ability to recognise an object when shown a different perspective of it. This is the position taken by the researcher in this study.

2.4.2. Spatial visualisation ability.

Spatial visualisation (SV) ability, which is the spatial ability component of interest to the study, occupies the top most position of the spatial ability hierarchy (Figure 2.1). To understand the relationships between the different levels of spatial skills one could compare these spatial skills hierarchy to Bloom's (1956) Taxonomy of cognitive skills. SV ability will then be analogous to the higher level cognitive skill of analysis, synthesis or evaluation, while spatial relation ability could be said to be at either the comprehension or application level.

Having established that SV ability is a higher level cognitive skill it is now necessary to determine the type of mental processes involved in solving a SV task in order to develop the most appropriate definition of SV ability for the study.

According to the factorial analysis method, ability is defined by the tasks that are used to detect its very presence. By analysing the tasks that load on a particular factor (cluster together), a set of common factors between these tasks could be identified which later form the basis for the definition of the said ability. This
method led SV ability to be defined as the ability to perform moving mental transformations - reflection, rotation, folding or unfolding of complex figures - on spatial information and the ability to perform synthesis mental transformation - synthesise multiple figures (Lohman et al. 1987).

Although mental transformation is part of the definition, Lohman et al. (1987) do not however, view mental transformation as a necessary criterion of SV ability. Linn and Peterson (1985) who define SV ability as simply the ability to execute complex multi-step processing of spatial information share the view that mental transformation is not an essential component of SV ability. Linn and Paterson (1985) give examples of tests that load on the SV factor as the embedded figure test, the paper folding test, the hidden figures test and the spatial relations test.

Nevertheless, authors such as McGee, (1979) and Michael, Zimmermann, and Guildford (in Salthouse et al., 1990) contend that the ability to transform is a necessary component of SV ability. McGee (1979) defines SV ability as "...the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimulus objects." (p. 893).

It brief, there is disagreement on the exact definition of and measures for SV ability. However, where engineering is concerned, McGee's definition is the most commonly used definition for SV ability, probably because spatial problem solving in engineering often demand the executions of mental transformation processes such as the mental rotation process.

From the above discussion, two necessary components of SV ability in the study are identified. These components are the ability to:

- perform complex multi-step processing of spatial information
- execute mental transformation such as mental rotation and folding and unfolding of flat patterns

Therefore, for the purpose of this study SV ability is defined as the ability to perform complex multi-step processing of spatial information where the ability to mentally transform (manipulate, rotate, twist, or invert) pictorially presented
visual stimuli is an important criterion. This definition is deemed appropriate because it encompasses the two frequently reported features of the SV ability.

To clarify the meaning of the two defining phrases “complex multi-step processing” and “mental transformation” it is necessary to look at studies in information processing and information processing theory. Findings from these studies will be used as the basis for modelling the mental processes involved in solving a spatial task. Consequently, information-processing theory will form the basis of the analytical framework of the construct definition.

2.4.2.1 Mental processes in spatial visualisation ability.

Lohman et al. (1987) argue that although there are a large number of spatial factors, the number of spatial mental processes is but a few. In information processing terms, solving a spatial task would require encoding, comparison and response processes in addition to other processes (Lohman et al., 1987) depending on the complexity of the task. These processes and their descriptions are given in Table 2.3.

Table 2.3. Name and description of spatial mental processes identified through information processing studies (Lohman et al., 1987)

<table>
<thead>
<tr>
<th>Label given to process</th>
<th>Mental process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern matching</td>
<td>holding the visual stimuli in working memory while encoding processes (or pattern matching productions) operate to identify all or parts of the stimuli</td>
</tr>
<tr>
<td>Image construction</td>
<td>constructing an image in working memory</td>
</tr>
<tr>
<td>Storage (iconic to long term memory LTM)</td>
<td>retaining a relatively novel image for a short duration</td>
</tr>
<tr>
<td>Retrieval</td>
<td>retrieving an image from memory</td>
</tr>
<tr>
<td>Comparison</td>
<td>comparing two stimuli</td>
</tr>
<tr>
<td>Transformation</td>
<td>transforming an image in some way either by decomposing it, or combining it with other images</td>
</tr>
</tbody>
</table>

Using the number of processes as a criterion, task A could be said to be more complex than task B if task A requires a larger number of processes that need to be executed for its problem solution. For example, a task that requires the encoding, search, rotation, comparison, and response processes is more complex.
than a task that merely requires the encoding, comparison and response processes. Therefore, task complexity is a relative measure rather than an absolute one. Figure 2.2 illustrates five two-dimensional (2-D) spatial tasks in decreasing complexity as an example.

Figure 2.2. A set of 2-D spatial tasks arranged in decreasing order of complexity and difficulty (Lohman et al., 1987).

According to Lohman et al. (1987), for equal number and identical types of processes, a task using 2-D stimuli is in general less complex than a task using 3-D stimuli. In their study, Lohman et al. (1987) found that subjects took much longer solving a task on two Shepard-Metzler cubes (3-D stimuli) than solving a comparison task on 2-D stimuli. Lohman and colleagues suggest that the difficulty there lay in the complexity of the stimuli (3-D is more complex than 2-D) rather than due to the demand on spatial memory by the processes.
Lohman and colleagues also found that for comparable tasks, a task that requires transformation processes causes more subjects to make mistakes compared to those tasks that do not. Therefore, they concluded that a task that requires a transformation is more difficult than a task that does not and the difficulty in solving the task lies in the process rather the task complexity.

In conclusion, for the purpose of the study, complex processing was defined as processing that requires at least one mental transformation process besides the basic processes of encoding, search, comparison and response.

The transformation process is necessary for two reasons:

• it reflects a feature of a higher level skill as shown by the increase in errors committed by research subjects mentioned above, and therefore, should be a characteristic component skill of SV ability as SV ability is the highest level factor in the spatial skill hierarchy (see Figure 2.1)

• it is intuitively an essential spatial skill in engineering problem solving

Bringing all the definitions together, SV ability was finally defined as the ability to execute multi-step processing which involves the ability to manipulate objects in imagination by executing mental transformation in the form of:

• rotation of a visually depicted object; (rotation of a 2-D representation in the picture plane and a 3-D representation in the depth plane)

• folding and unfolding of a 2-D representation to form a 3-D object; (building a cube from a flat unfolded pattern of that six square faces)

• construction of a 3-D representation from its 2-D representations (isometric from multiple-orthographic views)

For the purpose of this study, Lohman and colleagues' findings were used as guidelines for designing the spatial tasks in the SV ability instrument. All items were designed such that the chosen spatial task would require the execution of at least one comparison and one transformation process. The desired difficulty level
for an item is then achieved by varying the number of processes for its problem solution or/and the stimuli complexity.

3. FACTORS INFLUENCING SPATIAL VISUALISATION ABILITY

Identifying the factors that may influence the outcome of the study was important for practical and theoretical reasons. The following factors are identified in the literature as having the possibility to influence the outcome of the study.

- Cognitive development
- Training - formal and informal training
- Gender
- Aptitude


According to the Piaget's developmental theory (Phillip, 1969), humans progress in a fixed order through a series of cognitive developments. The rate of development is not however, a fixed variable. Most researchers agree that the concept of cognitive development is not limited to certain age ranges, but is controlled by the theory of natural development.

According to Piaget and Inhelder (1971), human cognition is developed in four stages (i) the sensori-motor stage (ii) the pre-operational stage (iii) the concrete operational stage and (iv) the formal operational stage. A person at the concrete operational stage "...always starts with experience and makes limited interpolations and extrapolations from the data available to his senses." (Phillips, 1969, p. 104). A person at the formal operational stage (ages 13 through adulthood) on the other hand, does not need to experience to generate and evaluate propositions (Phillips, 1969). It is therefore, suggested that at this stage, an individual can make use of infinite spatial possibilities and can acquire abstract mathematical concepts, such as the Euclidean geometry.

However, a study by Reesink (1985), involving eight, tenth and twelfth graders (n = 99), indicated that a mastery of the Euclidean and projection spatial concepts is frequently not achieved at the age of 17 and rarely at the age of 12 as claimed by
Piaget (1971). The four Piagetian tasks used to measure mastery of these concepts were: (1) Volumes of revolution (Euclidean spatial concept), (2) Geometric section (Euclidean and projection spatial concept), (3) Folding patterns (Euclidean and projection spatial concept) and (4) Projections of shadows (projection spatial concept).

Piaget suggests that, by the age of 12, mastery of these tasks is highly likely. Reesink (1985) however, found that only 4% of his sample mastered all of these tasks by the age of 12. Reesink (1985) suggests that experiences (cultural, academic) could account for the difference between his and Piaget’s results. Piaget’s study was carried out thirty years earlier using subjects from the Swedish population while Reesink (1985) was using subjects from the American population.

The percentage passing in each task by age 17 in Reesink's study is shown in Figure 2.3. This Figure indicates that only the ‘pure’ Euclidean spatial task (and not the others) was mastered by the age of 17.

Figure 2.3. Percentage of Grade 12 students who mastered the Piagetian tasks.

The average age of the samples in the polytechnic study was 21.7 years. Although the polytechnic subjects were several years older than the subjects in Reesink’s study, to assume that all polytechnic subjects are at the formal operational stage is unsubstantiated. Furthermore, according to Sutherland (1999), Piaget’s theory of learning and stage theory while applicable to children is equally applicable to adults. This means, some mature adults develop late into the formal operational
stage suggesting that some learners in higher and further education could still be at
the concrete operational stage. However, it is possible that most of the polytechnic
subjects have reached the formal operational stage (regarding spatial cognition)
because compared to the subjects in the Reesink's study the polytechnic subjects:

- were adult learners who were several years older than the subjects in Reesink's
  study

- had undergone at least one year of the course in engineering drafting, in
  addition to the six months working experience in construction industries and
  offices as part of their diploma programme, while only the boys in Reesink's
  study had learned mechanical drawing.

With regard to those subjects who had not reached the formal operational stage,
the random placement procedure into the polytechnics (to be discussed in Chapter
5) would have resulted in similar distributions such subjects in the samples. In
conclusion, although formal operational stage cannot be assumed for all subjects,
non-equivalence in cognitive development between groups was not anticipated to
be a threat to external validity.

Maturation effects (a change in developmental stage) as a source of confounding
variable was also not anticipated due to the short (1 week) pre and post test
interval.

3. 2. Training

Formal and informal training have both been reported to have significant impact on
SV ability. Formal training refers to a planned teaching and learning programme
such as learning engineering drawing in schools or colleges while informal training
refers to training which is obtained through life experiences, such as playing with
building blocks or participating in any activities which are spatial in nature.

3. 2. 1. Formal Training

Numerous studies have been carried out across all ages, gender and disciplines to
determine the effect of teaching strategies on SV ability. While some of these
studies do not show any positive effects, most studies show positive impact of training on SV ability.

Three factors have been found to influence the outcome of a study on the effect of instruction of SV skills on SV ability: the instructional materials, the age at which instruction is given and validity and reliability of the test instruments. Inconsistent results have been found on the effect of instructions that could be attributed to the instructional materials used for the treatment, the age when treatment was administered or the measure used.

Ben-Chaim (1988) instructed a group of grade 5 to 8 students for three weeks during their mathematics lessons to construct and evaluate building model created from cubes and to draw their representations in two different ways. Using MGMP Spatial Visualisation Test (SVT) he found that: students gain considerably from the instruction, whereby the gain was similar for boys and girls despite initial gender differences and retention of effect persisted tested at after four week and 1 year period.

Lord (1985) observed improvement in SV ability in his subjects (n = 84) after 12 sessions of 30 minutes each on planes through solids type of interventions. Seddon, Eniaiyjeju and Jusoh (1984) also found similar outcome using orthographic projections in students whom were between 19-30 years old.

Mack (1995) who completed a study on SV ability training in a group of gifted students (above sixteen years of age) failed to find statistically significant improvement in his experimental group after a three week intensive course on computer aided design. He used the Paper Form Board Test as his measure of SV ability. He attributed the insignificant outcome to several factors where one of them was using a single instrument to measure SV ability. He contended that multiple spatial tasks are a more appropriate measure of SV ability because SV ability is a multi-faceted ability. However, his failure to find improvement in SV ability could also be due to the short period of the study.
Braukmann (1993) did a comparative study on two methods of teaching engineering design employing (i) the traditional drafting equipment and (ii) a computer aided design software. Both groups were taught using the same materials, which were basically orthographic projection drawings. The computer group had the opportunity to deal with 3-D models that could be rotated about the three principle axes as they were viewed on the computer. The traditional group only dealt with 2-D presentation on paper that cannot be physically rotated about the x or y-axis and could not therefore, observe the rotation effect. Surprisingly, Braukmann (1993) found that both groups improved in their SV ability as measured by the Mental Rotation Test and the difference in means of both groups were not statistically significant. He proposed that similar gains in SV ability resulted from both teaching methods because the execution of mental transformation is demanded by tasks set by both methods. Considering that the treatment was only given for two weeks, it is uncertain whether the gain in SV ability was truly the effect of the teaching methods or learning from the instruments.

Zavotka (1987) on the other hand found that although her students improved on their orthographic projections after following a programme on computer animated graphics, they did not improve on their mental rotation ability. The students' performance on the mental rotation measure was found to be significantly affected by the sequence of the films that were shown to the students - wire-frame to solid or vice versa.

Sorby and Baartmans (1996b) developed a ten-week programme to improve their students' performance on SV ability adopting diverse media for their teaching materials. But their basic approach was to start with concrete materials such as cubes and paper-folding before progressing to computer aided design. At the end of the program, they found significant improvement in their students' SV ability as measured by The Purdue Spatial Visualisation Test: (PSVT:R).

Generally speaking, the findings support the hypothesis that with suitable instructional materials and the appropriate test instruments to detect gains in the target skills, SV ability can be improved through instruction.
3. 2. 2. Informal training (Experience).

According to Liben (1981), every individual will possess different spatial abilities due to the interaction between their social, environmental, and emotional experiences. Similarly, Bertoline (1988) suggests that SV ability is a cognitive function that is developed through life ordered experiences. Therefore, exposure to different learning environments may cause some people to be better at SV ability than others.

Deno (1995) in his study on a group of engineering students found that past experiences in non-academic subjects could serve as possible predictors of SV ability as measured by the mental rotation test (MRT). He also suggests that identical spatial activities might affect males and females differently. For example, correlation between playing with construction blocks type of toys and SV ability is high for males but not so for females. Activities that are more visual and less tactile seem to be a good predictor for the female counterpart.

These research findings suggest that SV ability could indeed be improved through training when appropriate types of spatial activities are provided.

3. 3. Gender

According to Caplan et al. (1985), due to the unresolved issues of fundamental definition and construct validity of spatial ability, questions on gender differences in spatial ability should not even be asked. Nevertheless, this did not stop the development of theories and studies on gender differences. As expected, the findings from these studies are inconsistent. For example, Ben-Chaim, Lappan and Houang (1988) found that boys in middle school is better in SV ability as measured by the MGMP Spatial Visualisation Ability Test (SVT).

Eisenberg and McGinty (1977) on the other hand found mixed result when they studied SV ability of university students who enrol in four types of mathematics programme (i) calculus, (ii) business statistics, (iii) remedial mathematics and (mathematics for elementary school teachers). They found that females in the business and calculus groups scored statistically significantly higher than the males while findings in the other group were reversed. Their SV instrument consisted of
27 of four types of spatial reasoning item (i) prediction of alphabets in a given sequence, (ii) figural analogy, (iii) 2-D spatial problems and (iv) 3-D spatial problems.

Researchers, who disagree with the conclusion that simply being male makes one better in SV ability, attributed the differences to a wide range of factors. These factors range from life experiences of females (due to societal expectations) as opposed to males (Halpern, 1992), the more concrete spatial strategies that are used by females in solving spatial tasks (Allen and Hogeland, 1978) and the doubtful validity of the construct (Capland et al, 1985).

Those who strongly supported the notion of a difference in female and male ability gave the degree of brain laterisation as the cause. Males are said to be more laterised than females. A person whose brain is more laterised tended to specialise in verbal processing in one hemisphere and spatial processing in the other. The Cognitive Crowding Theory, Prenatal Hormones, and maturation rates are used to explain this phenomena (Halpern, 1992). The Cognitive Crowding Theory postulates that the existences of verbal and spatial information in the same right hemisphere reduce the neural space for spatial information processing (Levy, 1976).

Although the evidence for ability difference between genders is inconclusive, the fact remains that it could be so and therefore, gender, as a possible confounding variable needs to be controlled. The proportions of gender in the experimental (F = 11, M = 18) and control group (F = 8, M = 20) were approximately similar so gender was not expected to confound the result.

3. 4. Aptitude

Kyllonen, Lohman and Snow (1984) found some indications to show that aptitude affects the choice of strategy in solving a spatial task which in turn affects performance on spatial ability measure. Strategy has been found to be associated with individual difference in spatial ability (Schultz, K. (1991). Therefore, aptitude is a possible source of confounding variable. Aptitude is not however, directly controlled in the study. Nevertheless the polytechnic random placement procedure
(Chapter 1) was expected to control for aptitude it therefore, was unlikely to be a source of invalidity.

4. RELATIONSHIP BETWEEN SPATIAL VISUALISATION ABILITY AND PROBLEM SOLVING SKILLS.

Problems are encountered in everyday life, be it at the work place, at home or in the classrooms, etc. Generally speaking, a problem is "... a situation in which you're trying to reach some goal, and must find a method of getting there." (Chi and Glaser, 1985, p. 229). Problem solving, "...the most important manifestations of human thinking..." (Holyoak, 1990, p. 117) is the process that is involved in order to alleviate the problem.

Beginning as early as the 1920s studies have been carried out to investigate the relationship between SV ability and problem solving. Problems that were studied can be broadly classified into two categories, those that are encountered in teaching and learning and those that are encountered in occupational endeavours.

These studies have shown that SV ability does have an impact on both categories of problems. Some of the findings are reported in the following sub-sections.

4. 1. The impact of SV ability on educational achievements.

Many scientific and technical subjects at secondary and tertiary level require students to perform a variety of spatial tasks in relation to diagrams of 3-D structures.

At lower level skills, students must merely understand the spatial relationships portrayed in these diagrams. In particular, they must understand that these diagrams represent a structure that has depth, as well as width and height. At higher level skills, the students are expected to be able to visualise what the diagram would look like if viewed from a different direction.

The ability to visualise how diagrams of 3-D structures look like after being rotated has been found to be fundamental to the understanding of molecular theory in
chemistry (Tuckey, Selvaratnam and Bradley (1991; Seddon and Shubber, 1985; Seddon and Eniaiyeju and Chia, 1985 and Seddon and Eniaiyeju, 1986).

Spatial ability has also been shown to be related to the learning of organic chemistry. For example, using a two component spatial ability measures (spatial orientation and SV ability), Pribyl and Rodner (1985) investigated the relationships between chemistry and spatial ability among college students of non-science majors and found that:

- subjects in the high spatial ability group scored statistically significantly higher on the chemistry performance compared to students in the low spatial ability group

- subjects in the upper spatial ability group tended to use more drawings (irrespective of being instructed to or not) compared to those in the low spatial ability group

- irrespective of ability group, those who used more drawings tended to have higher scores

Studies on the effects of SV ability on mathematics, however, has not shown consistent results. For example, Turner (1982) found that the ability to transform and compare images (a component of SV ability) is highly correlated to success in integral calculus. Tillotson (1984) on the other hand, found that training on SV skills which improved SV ability and performance on mathematical analytical problem solving did not however, improve performance in mathematics problems that were spatial in nature. Tillotson (1984) attributed the lack of increase in performance to the use of verbal strategies in solving these mathematics problems. However, the lack of increase could also be another indication of the task specific relationship between SV ability and mathematics problem solving.

SV ability has also been found to differentiate individual’s performance on fully utilising a computer-based technology. For example, those with high SV ability are found to be more effective at using a computer aided design applications (Sorby, 1999). It has also been shown in some studies that the effectiveness of using a
computer graphical user interface is related to SV ability (Leitheiser and Munro, (no date).

The use of mental simulations, an element of SV ability which have been shown to be helpful in some domains of physics problem solving is thought to differentiate experts from novices. Experts use qualitative analysis - visualising the physical situation such as imagining the way objects would move or interact with one another - at the initial stage of their problem solving while novices jump straight into abstract representations of the problem (Larkin, 1979). For these problems, SV is thought to provide the insight that would have been overlooked if only the analytical methods in solving problems are considered.

Sorby and Baartmans (1996b) who are engineering educators, propose that the ability to visualise problems is an essential ingredient for students' understanding and is critical to students' success in engineering education. It has also been shown to be particularly important to students' performance in reading and translating engineering drawings (Sorby and Baartmans, 1996a). Even in some cases, where non-spatial strategies would be more appropriate in problem solving, spatial ability is thought to determine the degree to which a problem solver is able to develop and evaluate the non-spatial strategies (Roberts, Gilmore and Wood, 1997).

In summary, SV ability has been shown to be an important aspect of teaching and learning across a range of curriculum areas.

4.2. Impact on occupational performance.

MacFarlane (1964) one of the enduring British researchers is of the view that spatial ability plays an important role in the accomplishment of many occupations such as architects to engineers, neurosurgeon to store managers. This view is supported by Lohman et al. (1987) who argue that the ability to utilise spatial information (having visual-spatial skills) is important in areas such as engineering, architecture, chemistry, the building trades, and air crew selection.
Common to most of the professions mentioned above (engineers, architects and technologists) is the need to design. Design is a process of converting concepts and information into detailed plans and specifications from which a finished product or facility can be manufactured or constructed (Wright, 1994). In other words, an object must first be visualised before it can be created. SV skills are therefore, thought to be essential to the design process (Braukmann, 1993; Pleck, 1991; Wright, 1994; Deno, 1995 and Beakly, Evans and Bowers, 1986).

Working drawings or engineering drawing is the final version of drawings used for the communication of ideas. They are produced by following standardised symbols and conventions and therefore, are used to enable the design and construction of the actual system/object. Accurate interpretations of engineering drawings require SV ability (Baartmans and Sorby, 1996a).

In summary, the literature suggests that SV ability may be essential to many job performances that are mechanical and visual such as design.

5. CONCLUSION

This chapter sets out to increase understanding in SV ability by reviewing the literature on spatial ability and other related literature. It located SV ability as a higher level skill within the spatial ability hierarchy and defined SV ability as the ability to execute multi-step processing of spatial information that demands mental transformations.

This chapter also identifies three variables that may pose a threat to internal and external validity; cognitive development, training and gender, and suggests how the polytechnic placement procedure may have reduced the threats from these variables. Other variables that may confound the results of this study will be discussed in Chapter 5.

SV ability has also been shown to be important to academic success and job performance especially those that involve design tasks. Chapter 3 will continue discussing the role of SV ability in design by focussing on its role in structural design problem solving.
CHAPTER 3


1. INTRODUCTION

Chapters 1 and 2 provided some support for the hypothesis that SV ability is important to the ability to design structures. This chapter and the following chapter will provide further support that link SV ability and structural design. In order to link SV ability to structural design, the structural design skills that demand SV ability will be identified. To identify these skills, task analyses, i.e., procedural task analysis and learning task analysis, on a chosen structural design task were carried out. The procedural task analysis is presented in this chapter followed by the learning task analysis in the next chapter.

The outcomes of the procedural task analysis are a set of structural design procedures - flow charts of design activities (which are composite skills) - that describe the sequence of activities in the structural design process. Nevertheless, some component skills to the identified composite skills that intuitively appear to demand SV ability are also identified.

2. DESIGN: PROBLEMS, PROCESS AND SOLUTIONS

Before getting into the specifics of structural design, the general feature of design, i.e., those concerning its process, problems and solutions will be presented to provide the basic schema for anchoring the forthcoming information.

According to Wright (1994), design is "...a process of converting concepts and information into detailed plans and specification from which a finished product or facility can be manufactured or constructed." (p. 129). Design problems are, therefore, open ended and not well defined in general where the process usually involves finding as well as solving problems. In other words, problems and solutions usually emerge together rather than one following the other (Lawson, 1980 and Zakis,
1997). In other words, once a step of input to design is taken, the designer has to find the problems he/she may have created by this step and try to solve it.

For example, given a problem where it is required to build a crossing for a drain, a designer has to start with a possible solution to the problem even if it is just in the form of a plank across the drain. With this input, new problems associated with choice of size, materials, cost, etc., would emerge. The designer would then add further inputs to the initial proposal, e.g., proposing the materials and plank size. With this new information - through the process of evaluation and refinement - the designer would further refine the initial design.

During the refinement process, new problems may be generated, such as, negative reactions between material and the environmental elements on site, unavailability of the required member size, etc., which requires the formulation of a new solution. In practice, a better definition of the problem is usually obtained through the initial solution. The try-and-adjustment iterations are repeated until the designer feels satisfied that he/she has formulated a satisfactory solution to the problem. In general, there is no one right solution to a design problem, there is only a satisfactory solution. The solution is deemed to be satisfactory when it fulfils the requirements it is designed for.

In summary, design problem solving is an iterative process with more than one path to its solution. Consequently, design problem is always defined through the generation of its solution and more than one solution could be generated from a design problem.

3. A PROCEDURAL TASK ANALYSIS ON THE STRUCTURAL DESIGN PROCESS.

A procedural task analysis "...describes the steps in performing a task..." (Gagné, Briggs and Wager, 1992, p. 147). Before embarking on the procedural task analysis of the structural design process, a brief overview of the structural design process in general will be given. As stated in Chapter 1, structural design is concerned with the design and development of large structures such as bridges, buildings, dams, towers, etc.
It is "...the study of how the various component elements of a building act together to form a supportive structure and transmit forces down to the foundations." (Draycott, 1990, p. 1). The aim of structural designers is to produce a structure that is safe for its users, fulfils its intended purpose during its intended life span and at the same time is economical to construct and maintain (Kong & Evans, 1990).

The structural design process involves complicated and lengthy procedures, which are frequently described as design stages for simplicity. Each design stage consists of a group of design activities. Figure 3.1 shows the stages in the structural design process. It shows that the design stages are not mutually exclusive, i.e., going back and forth between stages is often necessary indicating some reliance on the trial-and-adjustment strategy that is typical of a design process.

![Figure 3.1. The process of civil engineering structural design. (Mac Ginley and Choo, 1990)](image)
Figure 3.2 shows an approximation of the structural design process, which was used for the task analysis. This figure shows the design stages as being mutually exclusive and sequential in nature. Using an approximated design process reduced the complexity of the task analysis by making the analysis of the individual stage feasible.

![Structural design process flowchart](image)

Figure 3.2. A flow chart illustrating an approximation of the structural design process.

Task analyses of the individual design stages will be given in the following sections. For each stage, the design activities, the objective, the expected design outcomes and the composite skills associated with the activities will be identified, always with the intent of linking structural design to SV ability.
3.1 The structural planning stage
The structural planning stage is the first stage of a design process following an identified need of a client. The objective at this stage is to find the one tentative solution that is worthy of further refinement and evaluation.

3.1.1 Activities and outcomes.
The structural planning stage consists of conceptual design and preliminary analysis. Conceptual design involves:

- identifying and assembling constraints and parameters
- generating several solutions to cater to the demands of the previously identified constraints and parameters

The purpose of conceptual design is to generate several solutions, which sets the foundation for choosing the one solution to be adopted. The solutions generated are then compared against each other and evaluated against the demands of the design constraints. Simple structural analysis and cost analysis are also carried out to help in the decision making process. Ultimately, one solution is selected as a possible solution to the initially identified problem. Figure 3.3 shows the flow of activities at the conceptual design stage.

![Figure 3.3. Flow of activities in the structural planning stage](image)

Figure 3.3. Flow of activities in the structural planning stage
The outcome of this stage is a tentative solution, which would be subjected to several cycles of detail analysis and evaluation and refinements.

3.1.2 Necessary skills.

The necessary skills at this stage appear to be (i) the ability to formulate solutions and (ii) the ability to communicate these solutions.

The researcher proposes that the ability to formulate solutions is dependent on SV ability based on the following arguments. According to Fraser (1981), in the attempt to formulate solutions, the structural engineer will search for structures that comply as best as possible with the previously identified constraints, and having a 'feel' for structural behaviour is essential for the success of this search. Fraser (1981) defines structural behaviour as the response of structures to loads or applied deformations which results in "...visual distribution of curvature throughout the structure..." (Fraser 1981, p.20). To have a 'feel' for structural behaviour is to therefore understand the relationships between loads on the structure and the deformation that are produced in the structure (Brohn, 1991).

In other words, having a 'feel' for structural behaviour means having the ability to predict the structural changes occurring in the structure as a result of its responses to loads or applied deformations. Implicit in the understanding of structural behaviour is the ability to mentally manipulate and transform, which is a component of SV ability as defined by McGee (1979). Having the ability to visualise thus appears to be important to the successful solution formulation at the conceptual design stage of structural design.

According to Fraser (1980), the ability to understand structural behaviour is dependent on a clear grasp of several inter-related concepts: structural actions, structural systems, structural shapes, structural materials, structural efficiency and load paths. It seems that, in addition to SV skills, conceptual understanding is also essential to the understanding of structural behaviour. However, according to Greeno (in Battista, 1994), development of conceptual understanding is related to spatial ability which Greeno defines as the ability to construct, manipulate and transform
spatial representations which in fact is SV ability as defined in Chapter 2. The factors just discussed argue for the importance of SV skills to success in conceptual design.

The following sub-sections will elaborate on the above listed concepts and provide further arguments for the inter-relationships between the conceptual understandings of these concepts, structural behaviour, structural design and SV ability.

3.1.3 Structural actions

Structural actions are the internal actions in structural members that are individually known as *axial force, shear force, bending moment* and *torsion*. If a force acts on a member and it causes the member to either shorten or lengthen, the structural action that is induced in the member is known as an axial action. If however, the applied force causes the member to bend, the structural action that is induced in the member is known as a bending action. If on the other hand the applied force causes the member to twist about its longitudinal axis, the induced structural action is identified as a torsion action. Figure 3.4 illustrates the different types of structural actions.

![Figure 3.4. Illustrations on the different types of structural actions.](image)
In general, only one or two of these internal actions are present in any particular structure. Correct identification of the dominant structural action for a particular structure is essential because the structural action determines the structural material and the structural shape (cross-sectional shapes of the members) that best resist the action.

3.1.3.1 Structural materials

Structural materials have properties, which make them suitable as construction materials. Common structural materials are steel, concrete and timber. As stated before, the structural material best suited to a particular structure is determined by the structural action in the structure. Some materials are more suited than others. For example, plain concrete, which is a brittle material, is not suitable for resisting tensile action although it is suitable for resisting compressive action. Steel on the other hand is suitable for resisting both tensile and compressive actions.

Figure 3.5 illustrates the effect of a tensile force on a structure, which is to elongate the structure. A structural member made of ductile material such as steel will lengthen and not immediately break when an attempt is made to pull it apart.

A brittle material such as plain concrete, will not be able to accommodate the necessary elongation and therefore will break. Figure 3.6 illustrates the effect of a compressive action on a structure. It shows that the structure tends to shorten when a compressive force is applied to it.
3.1.3.2 **Structural shapes**

Structural shapes refer to the shape of the cross-section of structural members. Depending on the dominant structural action, some structural shapes are more efficient and appropriate than others. Figure 3.7 illustrates some of the common structural shapes, the associated structural actions and the appropriate materials.

![Structural Shapes Diagram](image)

**Figure 3.7.** Structural shapes and materials that best resist the identified structural actions.

3.1.3.3 **Structural systems**

A structural system consists of either a single member such as a beam or a group of members such as a truss. Some structural systems consist of structural sub-systems. For example, a beam structural system includes sub-systems such as simple beams,
cantilevers and continuous beams although the dominant structural action, which is the flexural action, is common to all.

The column system, which includes, short, slender, tied or a spiralled column is another example of a structural system. Structural systems, structural materials and structural actions are inter-related. This is because normally, a specific type of structural action is dominant for a particular type of structural system, which in turn requires a certain type of structural materials. For example, for a truss system, the dominant structural action is axial action, which could be best resisted by steel, timber, alloys or concrete but definitely not brickwork.

3.1.3.4 Structural efficiency

Structural efficiency relates to the ratio of quantity of material to the load it is resisting. The concept of structural efficiency will be demonstrated with the help of Figure 3.8. In Figure 3.8, beam ‘b’ has an ‘I’ section while beam ‘a’ has a rectangular section. If both beams are supporting equal loads, beam ‘b’ will be deemed to be more efficient than beam ‘a’. This is because there is less material in beam ‘b’ than in beam ‘a’ which makes the ratio of quantity of material to the load the beam is supporting is less for beam ‘b’ making beam ‘b’ relatively more efficient.

The I section used for beam b is suitable because the dominant structural action in beams is bending moment, which means the stress in the beam fibres is not constant across the member section. In fact stress in the beam fibres is highest near the outer surface (top or bottom) and decreases toward the middle section as shown in Figure 3.8. The reduced stress in the mid-section fibre means that some of the materials there could be removed, which typically results in an I-section.
3.1.3.5 Load path

Load path is defined as the route within the structure along which loads flow to the foundations. The foundations are usually the earth but may be water as in a floating crane; air as in aircraft or may be part of another structure. Figure 3.9 illustrates the load paths of loads, which are supported by a truss. The arrows show the paths followed by the loads starting from the applied points to the foundations. This Figure shows that the members of the truss provide the load path by a system of axial actions.
In summary, the understanding of these concepts is necessary in order to develop the 'feel' for structural behaviour, and SV ability intuitively appears to underlie the understanding of these concepts.

The second group of activities at the conceptual design stage is the communication of ideas and designs solutions. SV ability is hypothesised to be essential to the communication of design ideas based on the following argument. To communicate their ideas on spatial arrangements to others, designers produce spatial products, such as sketching and drawings during the design process. It is suggested that these spatial products could not be conceived without some form of prior spatial thoughts such as mental manipulations, transformations, image synthesis, etc., which is the essence of SV skills. In other words, structural designers need to have SV ability in order to formulate and communicate design solutions at the conceptual design stage.

In conclusion, claims for the importance of SV ability to successful conceptual design appears to have some support. The next stage in the structural design process is the structural analysis stage.

3.2 The structural analysis stage.

Structural analysis is part of the refinement and evaluation procedure in structural design. It is a process whereby loads are determined and their distributions through the structure are analysed by applying the principles of structural mechanics. The objective of these activities is to determine the distribution of internal actions in each structural member.

3.2.1 Activities and outcomes

Figure 3.10 illustrates the structural analysis process. The major activity at this stage is mathematical and numerical in nature. The outcomes of this stage will be numerical and graphical representations of internal forces such as sketches of distributions of bending moments, shear forces and stresses.
**3.2.2 Necessary skills**

The structural analysis process relies heavily on mathematical modelling of the behaviour of the real structure. Therefore, although numerical ability appears to be an important element to the success of the structural analysis process, the *ability to relate the physical phenomena to its mathematical model* is equally important if gross errors arising from indiscriminate applications of mathematical models are to be avoided.

For example, the mathematical equation $y = x^2$ is frequently used (with some modifications) to model the deflected shape of a beam (a physical phenomena). This is because when visually modelled using a graph as shown in Figure 3.11, the underlying mathematical structure of this equation depicts (to some extent) the distribution of displacements in a beam under deflection. Therefore, (with some modifications) the deflection of a beam is frequently modelled mathematically by the equation $y = ax^2 + bx + c$. 

---

Figure 3.10. A simplified model of the structural analysis process
This equation is appropriate for a simply supported beam. Therefore if the support conditions are different, additional modifications to the models are made to take into account the effects of the different support conditions.

To use mathematical models in a meaningful way, designers must be able to relate the mathematical models to the physical phenomena the models represent. To achieve this, they must be able to relate the underlying structures of the mathematical models to the physical phenomena. They, therefore, must have the ability to:

- determine the underlying structures of the mathematical models
- visualise the expected physical phenomena
- recognise the similarities between the two, i.e., the underlying structures of the mathematical models and the expected physical phenomena

The role of SV ability here is to bridge the gap between the problem situation (physical and real) and the solution strategy (abstract equations), by avoiding
indiscriminate and meaningless use of equations, as is sometimes the case with problems which are highly analytical and mathematical in nature (Clement, 1981).

In other words, having the ability to visualise the physical phenomena together with the knowledge of the visual model of the mathematical function will create links between the real and physical to the abstract as shown in Figure 3.12.

Figure 3.12. Relationship between design problem solving and SV ability

In conclusion, SV ability is necessary for meaningful structural analysis, because it links between the physical reality and the abstract models of that reality.

The next stage in structural design is the member design stage.

3.3 Member design and the structural detailing stage

Member design involves estimating member sizes, checking and confirming their suitability for the loads at hand. The objective of design at this stage is to produce a specific design for the member concerned (slab, column, beam and wall) which satisfy all the design constraints previously identified.

3.3.1 Activities and outcomes

The member design stage is the stage where all the skills required for conceptual design and structural analysis are again called for. Initially, rules of thumb can be used to estimate member sizes (Viewpoint Publication, 1987). The estimated member sizes will have to be confirmed however, at a later stage. Confirmation of the sizes is necessary to ensure that member sizes previously chosen are adequate in resisting the
effects of the internal actions. These sizes are modified if necessary and a follow up analysis and evaluation would then be carried out. The size needed for each structural member is calculated in relation to the loads it is supposed to carry/resist, its materials and in particular its structural capacity.

The outcome of design at this stage is drawings of the members showing the various cross-sections, the dimensions and the arrangements of the reinforcements (for members using reinforcements such as a reinforced concrete member).

### 3.3.2 Necessary skills

Obtaining the right member proportions is highly dependent on the correct assessment of loads. Loads may be superimposed loads due to such factors as snow, people, equipment, wind action and earthquake or/and dead loads which is the structure’s own weight, referred so because it remains in one position through the entire life of the structure.

Correct assessment of loads on the other hand is dependent on the adequate grasp of **structural behaviour**. Insufficient or faulty understanding could result in poor or even dangerous design. For example, under-reinforcements in some support beams while over reinforcements in others will be the consequence if a two-way slab is perceived as a one way slab. This is because a one-way slab and a two-way slab is different in the way loads are distributed to their support systems as shown in Figure 3.13.

Figure 3.13 shows that loads on a one way slab would tend to be distributed between two supporting beams which are closest together while the loads on a two-way slab would tend to be shared among the four supporting beams. Qualitative analysis, which involves imaginary displacements of slab and imaginary loads flow, is essential to determine how the loads are distributed to the supports which in turn is necessary in order to arrive at the correct assessment of support loads.

Member design is usually followed by detailed design. At the detailed design stage a check is also made to access how the structure will behave under load. Not only the structure must be strong to resist the applied loads without failure, but it must also perform in a manner that is acceptable to the users (serviceability requirement). These
evaluations are to ensure that the amount of deflections, sways, vibrations and cracks are within the tolerable limits.

The design is then detailed to satisfy all the serviceability requirements. SV ability is also important at this stage. For example, in a reinforced concrete design, being able to sketch the deflected shapes of the members would help in the appropriate placement and curtailment of reinforcements.

The final stage in the design process is the structural specification stage.

3.4 Structural specification stage
The structural specification stage is the final stage before the structure is actually constructed. At this stage, documents, drawings and specifications are prepared in detail to ensure that the builder can construct according to the designers' requirements. The working drawings and specification then form the main links between the designer and the contractor.

The ability to prepare, read and interpret drawings (a component of SV ability) is therefore essential to the successful communication of the designers' intent.

3.5 Summary
From the analysis of the design process in general it is shown that the SV ability might be what underlies the ability to predict structural behaviour which is the most essential
skill to a structural engineer. The importance of SV ability was indicated at every stage of the design process.

It was indicated to be essential to the formulations of solutions at the conceptual design stage. It was also indicated to be essential in the preliminary structural analysis stage by aiding the designers in choosing the appropriate mathematical models for analysing their structures. At the detailing stage, SV ability was shown to help in arrangements and curtailments of reinforcements. And, finally, at the structural specification stage, it is necessary to the preparation of the documentation involving drawing.

In summary, the hypothesis that SV ability plays an important role in the successful design of structures is continually supported throughout the analysis of the general design process.

4. TASK ANALYSIS ON THE DESIGN PROCESS OF A REINFORCED CONCRETE COLUMN.

A further task analysis is carried out on the design process of a specific reinforced concrete member, i.e., reinforced concrete column, to ensure that all the relevant structural design skills are identified. The details of this analysis are presented in Appendix 1.

The design process of a reinforced concrete column is chosen for this analysis because of the complexity of its design, which encompasses all the design skills that may require SV ability. Its design complexity is mainly due to the monolithic nature of the reinforced concrete structure. Basically, a reinforced concrete structure is a combinations of structural members such as beams, columns, slabs and walls that are rigidly connected together to form a monolithic frame. Consequently, the structural behaviour of a specific member such as column is influenced by the behaviour of the other members that are connected to it.

The general procedure for designing a column elicited for the task analysis is shown in Figure 3.14. The activities shown in Figure 3.14 are re-represented in Table 3.1 for
simplicity. This table shows that basically, the design of a reinforced concrete column involves two kinds of activities, i.e., the proposing activities, which constitute the initial design stage and evaluation activities, which constitute the rest of the design process.

![Diagram](image)

**Figure 3.14.** The general procedure for designing a reinforced concrete column.

The composite skills of the initial and the evaluation stage are listed in Table 3.1. Some of the necessary component skills - identified through the task analysis (Appendix 1) - are given in the following sections.

### 4.1.1 Initial design

Two composite skills are identified to be necessary for the initial design stage

- *the ability to estimate member size*
- *the ability to estimate reinforcements area*

One of the components to these composite skills is the ability to generate and solve mathematical equations.
Table 3.1. Activities in the design of a reinforced concrete column.

<table>
<thead>
<tr>
<th>Initial design</th>
<th>Step 1</th>
<th>Estimating member size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Step 2</td>
<td>Estimating reinforcement area</td>
</tr>
<tr>
<td>Evaluation and refinement</td>
<td>Step 1</td>
<td>Check that the column is not slender.</td>
</tr>
<tr>
<td></td>
<td>Step 2</td>
<td>Check that the section size and cover comply with the requirements for fire resistance.</td>
</tr>
<tr>
<td></td>
<td>Step 3</td>
<td>Check that cover and concrete comply with requirements for durability.</td>
</tr>
<tr>
<td></td>
<td>Step 4</td>
<td>Calculate axial loads and moments (design loads and moments) according to clause 4.5.3.</td>
</tr>
<tr>
<td></td>
<td>Step 5</td>
<td>Design section and reinforcement</td>
</tr>
</tbody>
</table>

4.1.2 Evaluation and refinements

For the evaluation and refinement stage, five composite skills were identified to be essential (steps 1 - 5).

For Step 1 the following component skills were identified as necessary:

- *the ability to resolve the relationships between axis of rotation, plane of rotations, beams and column dimensions*

- *the ability to the classify the end conditions of a given column*

- *the ability to determine the clear height of a column with respect to bending of the column about a given axis*

The first skill listed is extremely important, as failure to resolve the relationships between the various concepts could at the worst, be disastrous as illustrated in Figure 3.15.
The classification of end conditions affects the computation of clear height, which affects the value of $\beta$. This leads to the wrong assessment of effective height $h_e$, which leads to a short column designed as slender. Additionally, it leads to an increased possibility of failure. Conversely, it leads to an unnecessary expenditure.

Figure 3.15. The cumulating effects of failure to resolve the relationships between axis for rotation, plane of rotations and member dimensions.

The generic spatial skills identified for the execution of Step 1 are:

- the ability to perceive the relationship between axis for rotation and plane of rotation
- the ability to predict what an object would look like if viewed from a different perspective
For Step 2, the skills identified to be necessary are:

- being able to predict what an object would look like from a different perspective
- being able to sketch or do free-hand drawing

For Step 3, the skills identified to be necessary are:

- being able to predict what an object would look like from a different perspective
- being able to sketch or do free-hand drawing

For Step 4, the skills that deemed to be necessary are:

- the ability to identify the common axis of reference between column and beam section when the beam and column is monolithic
- the ability to identify the structural sub-frame (the column and beams to be considered) to be used for moment distribution calculation, i.e., the ability to visualise spatial arrangements in three-dimension

For Step 5, the skills that are deemed to be necessary are:

- the ability to read and interpret drawing and other forms of diagrammatic representations.

5. CONCLUSION

The task analysis in this chapter indicated that SV ability is an essential skill to structural design problem solving, in particular to the understanding of structural behaviour. The specific structural design skills identified to demand SV ability are:

- the ability to classify the end conditions of a given column
- the ability to determine the clear height of a column with respect to bending of the column about a given axis
• the ability to identify the common axis of reference between column and beam section when the beam and column is monolithic

• the ability to perceive the relationship between axis for rotation and plane of rotation.

• the ability to identify the structural sub-frame (the column and beams to be considered) to be used for moment distribution calculation, i.e., the ability to visualise spatial arrangements in three-dimension

There are also generic SV skills being identified, which are:

• the ability to predict what an object would look like if viewed from a different perspective

• being able to sketch or do free-hand drawing

The outcomes from this chapter lend support for investigating the role of SV ability in structural design problem solving and justify the research questions and hypotheses stated in Chapter 5. Additional intellectual skills - including SV skills - that are deemed necessary to the ability to design structures will be identified in the next chapter.
CHAPTER 4

Deriving the Learning Hierarchy for a Task in Structural design: Identification of Enabling Skills.

1. INTRODUCTION

Chapter 3 established the link between SV ability and structural design problem solving when it identifies the composite skills for structural design problem solving that demand SV ability. However, the specific nature (sub-ordinates/super-ordinates) of the relationships between the various skills has not been determined.

This chapter aims to:

(i) identify the enabling skills that are essential to the success of structural design in order to design the structural design instrument

(ii) establish the relationships between the design skills identified in (i) in order to develop the materials for the teaching and learning of SV skills

(iii) identify the spatial skills that are essential to the success of structural design problem solving in order to develop the SV ability research instrument

These aims will be achieved through a learning task analysis of a chosen design objective, which will result in a learning hierarchy of intellectual skills for this particular target objective.

This chapter consists of two sections and a conclusion. The first section discusses the relationships between design practices and design teaching and learning. The second section discusses the development process of a learning hierarchy and its application to the design of a reinforced concrete column. Finally, the conclusion section summarises the skills that are necessary to structural design.
2. STRUC\r\n
As indicated in the previous chapters, structural design is one of the core modules in a civil engineering curriculum. The need to teach design follows the logic that since professional engineers design, students have to be taught how to design (Williamson and Hudspeth, 1982). Design is therefore seen as a vehicle for students to learn new knowledge, to synthesise materials from their engineering courses and to apply the learned analytical skills.

If teaching design is to simulate professional engineering practice, then the goals of teaching design should be to develop those skills, which are inherent in engineers. Wheen (1978) suggested that the aims of teaching design should be:

- to encourage creativity in problem solving (design)
- to impart knowledge of the relevant technology involved in design and design related activities
- to provide the necessary environments for students to apply their analytical or critical skills

The above aims however, describe what are expected of the teachers rather than the learned skills expected of the engineering students. According to Lovell (1966), learning refers to "...a change in behaviour which is more or less permanent in nature, and which results from activity, training or observation." (p. 119). In teaching structural design, the teachers therefore would expect changes in the students' behaviour, which would be the consequence of acquiring the skills that are inherent in structural engineers. Clearly, in order to teach and learn structural design, it has to be described as a set of human skills as opposed to stages (recall Chapter 3).

*By seeing design as a skill we can also quickly start to see how we might assess the quality with which it is carried out, both in terms of its process and the final result; and we shall also start to see the implications for the ways in which people might learn or might be taught the skill, or rather, skills. (Addis 1990, p. 74)*
2.1. Structural design as a set of skills

According to Addis (1990, p.73) successful problem solving in structural design requires the ability to:

- study and analyse (the brief and other data),
- conceive and propose (ideas and possible solutions),
- evaluate (several possible solutions),
- choose (an appropriate solution),
- analyse (likely structural behaviour),
- justify (a chosen design),
- communicate (the design to others)

Obviously, these skills are higher order skills, which are super-ordinates to a myriad of other lower level skills.

Learned human skills, according to Gagné (1985), can be grouped into five categories; intellectual skills, verbal information, cognitive strategies, attitudes and motor skills. Gagné (1985) defines:

- intellectual skills as procedural knowledge, the learned capabilities of 'knowing how' and the capabilities which makes it possible for a person to deal with symbols. An example of an intellectual skill is the ability to do numerical addition or subtraction.

- verbal information as the learned capability to state ideas

- cognitive strategies are "...techniques of thinking, ways of analysing problems, and approaches to the solving of problems...which control the learner's own internal processes..." (Gagné, 1985, p. 48)

- motor skills as the learned capabilities that enable a person to execute "...movements in a number of organized motor acts..." (Gagné, 1985, p. 62).

Examples of motor skills in structural design are: (i) manoeuvring a computer mouse to produce the desired effect on the computer screen when producing a
drawing using a Computer Aided Design package and (ii) putting a mark on paper - where desired - in free-hand sketching to communicate design ideas

- attitudes as "...acquired mental states that influence the choices of personal actions." (Gagné, 1977, p. 63). Examples of attitudes that are conducive to design are: (i) choosing to learn from own and other peoples' experiences by ensuring similar mistakes are not repeated, and past successes are incorporated into the current design where appropriate and (ii) choosing to communicate to and with other specialists - such as architect, contractor and services engineer - when necessary by:

- informing them of the ongoing situation, or any expected changes to be made
- seeking them in matters that require specialist attention

The relationships between the learned capabilities, long-term goals and short-term goals of education are going to be discussed next.

2.2. Long-term goals in education and their specific learning objectives.
A long-term goal of education is essentially a higher level skill, which is made up of a combination of different types of skills (specific learning objectives). The achievement of a long-term goal is therefore dependent on the successful accomplishment of its specific learning objectives. A long-term goal therefore cannot be realised during any specific period of a lesson but can be expected as the outcome of an educational programme. The relationship between a long-term goal and its more specific objectives is illustrated in an instructional curriculum map (ICM) shown in Figure 4.1. Figure 4.1 gives examples of the lower level objectives that are necessary to the accomplishment of the long-term goal. An ICM represents "...the functional relationships among instructional objectives..." which are "...not from the same domains." (Gagné, Briggs and Wager, 1992, p. 159). Therefore an ICM may contain all the five (Gagné, 1985) or three (Bloom, 1956) domains of learned outcomes.
The relationships between the long-term objectives/goals (composite skills) and the short-term objectives (component skills) for the learning of intellectual skills could also be illustrated in a similar manner to the ICM which is recognised as the learning hierarchy of intellectual skills (Gagné, Briggs and Wager, 1992).

![Learning Hierarchy Diagram](image)

**Figure 4.1. Instructional Curriculum Map for structural design.**

### 3. LEARNING HIERARCHY OF INTELLECTUAL SKILLS.

The concept of learning hierarchy was first developed by Gagné in 1962 (cited in White, 1974b). Following that, there has been considerable research on it, particularly in the teaching and learning of mathematics and the sciences (Winkles, 1986; Jones and Russel, 1979; White, 1975; White and Gagné, 1974; White, 1974a; 1974b; Sax, Eilenberg and Klockars, 1972; Merrill, Barton and Wood, 1970; Okey and Gagné, 1970 and Merrill, 1965).

Gagné (1974) defines the learning hierarchy as "...an arrangement of intellectual skill objectives into a pattern which shows pre-requisites relationships among them." (Gagné, 1974, p. 109). It displays the hierarchical relationships between the specific
Learning skills and their more general ones. Figure 4.2 gives an example of a learning hierarchy showing one general objective at the top and several subordinate objectives below it.

This section describes the two aspects of a learning hierarchy; its development and validation process and develops a learning hierarchy for the specific application of teaching and learning in structural design.

3.1. Deriving learning hierarchies for intellectual skills.
A learning hierarchy is derived through an iterative process initiated by the identification of the highest level objective that is known as the 'terminal objective'. Once identified, the terminal objective is written as a behaviourally stated objective, i.e., written in measurable terms, which will provide a means for assessing the student’s mastery.

The question “what must the learner be able to do in order to learn this new element, given only instructions?” (White, 1972a, p. 121) is then asked. The answers to this question will be stated in the form of other behavioural objectives and become the hypothesised subordinates (enabling objectives) to the terminal objective. The same question is asked of each of these subordinate objectives and the process is repeated until such a time that the bottom level skills appear to be simple enough to be performed by the learner population. The hypothesised learning hierarchy is then said to be developed (Jones and Russel, 1979). The hypothesised learning hierarchy is subsequently validated using a specific validation procedure.

3.2. Validation of a learning hierarchy
Validation of a learning hierarchy is essential before it can be used as an effective tool in any teaching and learning exercise. However, the degree of stringency of the validation procedure depends on the purpose of the learning hierarchy. Gagné (in White, 1974b) suggest a model for checking the validity of a hierarchy with a seven steps procedure which was later modified by White (1974b) into a nine-step procedure.
3.3. Development of a learning hierarchy for teaching and learning of structural Design.

This section illustrates and elaborates on the learning hierarchy, which was developed for a specific learning outcome in structural design. This learning hierarchy was developed using the procedure described in Section 3.2. Due to the large number of enabling skills involved, the learning hierarchy had to be developed and presented in parts (Figure 4.2 to Figure 4.8). When combined these sub-learning hierarchies form the learning hierarchy for the chosen target objective.

3.3.1. Identification of the terminal objective

The identified terminal objective concerns the design of a short braced column. A short column is a column that fails as a result of "...material failure by initial yielding of the steel at the tension face or initial crushing of the concrete at the compression face." (Nawy, 1986, p. 199).

The explicit form of the terminal objective is given thus: At the end of the course the students will be able to design a short braced reinforced concrete column supporting an axial load and bending moment given:

(i) the plan and elevations of the building of which the column is a structural member

(ii) the characteristic dead and imposed loads and

(iii) the relevant references and design manuals

Achievement of the target skill will be demonstrated by the ability to

(i) prepare a structural drawing of the column

(ii) document the calculations that were used in the design process and the assumptions and justifications for their design decisions

This particular target skill was chosen for the following reasons:
• the problems that are associated with this skill can have the general characteristics of design problems, i.e., ill-defined and unstructured without being “too unstructured” that developing the learning hierarchy becomes inconceivable

• the achievement of this target skill could be realised within a relatively short time, i.e., several periods of teaching and learning as opposed to a semester length programme

• this target skill encompasses problems that could assess problem solving skills

Gagné, Briggs and Wager (1992) refer to problem solving skill as an intellectual skill that enables the problem solver to develop or synthesise existing rules. If the demand on the problem solver is only to apply given rules, the intellectual skill is referred to as rule learning.

3.3.2. Validation of the learning hierarchy.
The purpose of developing this learning hierarchy was to elicit the relationship (hierarchical and otherwise), between the enabling skills (spatial skills or otherwise). Therefore the rigour of the analysis was not up to the level that is required for producing a detail and accurate inter-relationships between all the possible intellectual skills. Therefore, a three-step validation procedure was deemed sufficient for the purpose. The three-step procedure is as follows with the first two steps embedded in the development procedure.

• defining the terminal objective in behavioural and measurable terms

• asking Gagné’s question “What must the learner be able to do in order to learn this new element, given only instructions?” of the terminal objective and each subordinate (enabling) objective sequentially

• consulting with three subject matter experts, who had had more than four years experience teaching structural design to polytechnic students and incorporating their feedback where found necessary
This procedure encompasses the first three steps of the validation model that was developed by White (1974b).

3.3.3. Elaboration on the learning hierarchy

Figure 4.2 is the learning hierarchy component that was first developed. It shows the target objective, two sub-ordinates and their sub-ordinates. The two immediate subordinate skills are:

(i) the ability to generate an initial design. Sub-ordinates to this skill are the ability to estimate the member size and its reinforcement area.

(ii) the ability to evaluate and refine the initial design, i.e., can judge the appropriateness of the initial design. Sub-ordinates to this skill are the ability to evaluate and refine for the ultimate limit-state and the serviceability limit-state conditions.

![Diagram](attachment:image.png)

**Figure 4.2. Higher level skills required for column design**

By asking Gagné's question of the lowest level skills in Figure 4.2, several subordinate skills are obtained (illustrated in Figure 4.3). Figure 4.3 displays the enabling skills required for generating an initial design, i.e., skills required to enable a learner to
suggest the appropriate column dimensions (breadth x depth) and the necessary reinforcement areas. Learning hierarchy in Figure 4.3 shows that generating an initial design is not a trivial task as tacitly assumed by many teachers (the researcher included), i.e., generating an initial design requires multiple skills.

Figure 4.3. A learning hierarchy for generating an initial design of a short column. (PS, RL, VI and SV represent problem solving, rule learning, verbal information and spatial visualisation)

Taking 'Able to evaluate and refine the initial design' as the terminal objective, Gagné's question was asked and the skills required for the terminal objective are identified and illustrated in Figures 4.4, 4.5 and 4.7. Figure 4.4 displays the enabling
skills required for **judging whether a column is braced** which is an immediate subordinate to the 'able to design and evaluate at the ultimate limit-state' objective. SV skills are shown to be pre-requisites to the ability to judge whether a column is braced or not.

Figure 4.3

Able to evaluate and refine the initial design [PS]

Evaluate and design the element for the ultimate limit-state. [PS]

Ensure that the column satisfy the requirements for a braced column. [PS]

Ensure that the column is short by reference to its slenderness ratio [PS] (Refer to figure 4.5)

Ensure that the column is capable of carrying the design load at ultimate limit state. [PS] (Refer to Figure 4.6 and Figure 4.7).

Can identify a braced column from a structural drawing [RL]

Can identify the appropriate orientation for a bracing to render a given column to be structurally braced in that plane. [Concept, C]

Visualise the response of the structural elements under a set of loading conditions. [SV]

Can interpret drawing [SV]

Figure 4.4. The learning hierarchy for judging whether a column is braced, which is part of the design evaluation at the ultimate limit-state.

Figure 4.5 is another part of the learning hierarchy for evaluation and design at the ultimate limit-state.
Figure 4.4

Ensure that the column is short by reference to its slenderness ratio L/h. [PS]

Determine whether a column is short/or slender. [PS]

Determine the effective height of a column L=Bo given the 2-D representation of the structure. [PS]

Determine the coefficient of effective height for column B [PS]

Determine the clear height L of a column [RL]

Generate a new design for a short column [PS]

Determine the relevant dimensions of beam/slabs and column to be considered [C]

Sketch the relevant structural sub-frame to be considered. [SV]

Manipulate mathematical symbols [RL]

Classify an end condition into condition into condition 1, 2, 3 or 4 [PS]

Determine the elevation to be considered. [SV]

Do free-hand sketch [SV]

Identify the plane of bending for a given axis for bending or vice versa. [C]

Retrieve information from tables [RL]

Visualise the structural response to a set of loading conditions. [SV]

Construct a 3-D from 2D representations [SV]

Can reason spatially [SV]

Figure 4.5. The learning hierarchy for ensuring a column is short.

Figure 4.5 shows that the enabling skills required for ensuring a column is short are spatial skills, which are:

- the ability to do free-hand sketching
- the ability to predict structural behaviour
- the ability to predict what an object look like from a different perspective
• the ability to construct a 3-D representation from its 2-D representations

Figure 4.6 displays the enabling skills required for ensuring a column is capable of carrying the applied loads at the ultimate limit-state.

Figure 4.6. The learning hierarchy for evaluating and ensuring that a column is capable of supporting the design loads at the ultimate limit-state.

Again the enabling skills consist of a set of SV skills:

• the ability to do free-hand sketching
• the ability to predict structural behaviour
• the ability to read and interpret drawings
• the ability to read and interpret charts and graphs
Figure 4.7 displays the enabling skills for calculating the design loads.

The three spatial skills that are shown to be necessary to the ability to calculate design loads are:

- the ability to predict structural behaviour
- the ability to do free-hand sketching
- the ability to see spatial relationships between various spatial and structural mechanics concepts, i.e., axis and planes of rotations and bending moments
Figure 4.8 shows the enabling skills required for ensuring a column is safe at the serviceability limit-state. Here, two spatial skills are shown to be necessary:

- the ability to predict structural behaviour
- the ability to read and interpret drawings

3.3.4. Summary on the learning hierarchies.

The main purpose of developing the learning hierarchy was to determine the intellectual skills including SV skills that are required in structural design problem solving. Figure 4.2 to Figure 4.8 combined, form the learning hierarchy for designing a short braced column that supports an axial load and a bending moment. In this hierarchy, SV skills are found to be pre-requisites to the stated learning objective.
3.4. Expected learning outcomes

Integrating the findings from Chapters 2, 3 and 4, the following learning outcomes - written in their explicit forms - are generated for the purpose of the study.

At the end of the treatment, the learner shall be able to:

- mentally construct a 3-D representation from a given set 2-D representations demonstrating the ability by choosing the correct 3-D representations from a set of alternatives for a given 2-D representation of a 3-D structure (see Figure 4.3)

- sketch a 3-D representation of a structure based on the multiple 2-D views of the same structure demonstrating the ability by sketching an isometric drawing from the orthographic projections (see Figure 4.5)

- relate axes to planes, demonstrating the ability by choosing the correct plane from a set of drawings given the axis (see Figure 4.5 and Figure 4.7)

- determine the effective heights of the column for the two principle planes of bending demonstrating the ability by computing the value of the effective height for a given column bent about a given axis (see Figure 4.5)

- determine the clear height of a column for a given plane of bending demonstrating the ability by computing the free height for a given column (see Figure 4.5)

- classify the condition of the end of a column into condition 1, 2, 3 or 4 depending on the relative dimension of depth of column and depth of beam in the plane under consideration, demonstrating the ability by giving the correct classification for a column, given the dimensions of the column and the adjoining members (see Figure 4.5)

- classify a given column into an internal, an external or a corner column, demonstrating the ability by following the procedure in the given code of Practice (see Figure 4.6)
• predict the behaviour of structure under a given loading conditions, demonstrating the ability by sketching the deflected shapes of beam and columns under loads (see Figures 4.3, 4.4, 4.5, 4.7 and 4.8)

• determine the magnitude of axial load going to the column from the associated beams demonstrating the ability by computing the axial load supported by a given column (see Figure 4.7)

• determine the load arrangement which produces critical loading conditions for maximum moment and axial load associated with bending in a given plane demonstrating the ability by sketching the sub-frame to be used for the load analysis (see Figure 4.7)

• determine the second moment of area of the individual members (beams and columns) in a given plane which frames into the column at the joint under consideration demonstrating the ability by calculating the value of the second moment of area of a given member (see Figure 4.7)

3.4.1. Skills to be included in the treatment for SV ability.

Looking at the summary of skills identified in Chapters 3 and 4, it is observed that the number of design skills that demand SV ability and the necessary SV skills are many. It is therefore not possible to include all of them in the treatment for the study. Therefore, only a few of the skills will be included. The skills chosen are those that appear repeatedly in the outcome of several objectives/skills analysis and those that could be taught in a short period that is allocated for the study. The structural design skills that appear to require SV ability to be included are the ability to:

1. Predict the behaviour of structure under a given set of loading conditions, demonstrating the ability by sketching the deflected shapes of the structure, the distributions of its internal forces and its support reactions.

2. Mentally construct a 3-D representation by synthesis transformation demonstrating the ability by sketching/choosing the isometric drawing given the orthographic projections of the same structure.
3. Mentally decompose a 3-D structure into its component views demonstrating the ability by sketching/choosing the appropriate multiple orthographic views of a given isometric view.

4. Predict what an object would look like from a different perspective demonstrating the ability by identifying the correct response from a set of alternatives.

4. CONCLUSION

A learning analysis was carried out in this chapter for designing a short reinforced concrete column carrying axial load and bending moment. The learning hierarchy for this target objective was derived producing a set of skills that are pre-requisites to the target objective. SV skill was identified as one of the pre-requisites of the target objective.

This outcome of the learning analysis in this chapter will be useful to the development of:

• the learning materials for the teaching and learning of SV skills, (to be discussed in Chapter 5)

• the development of the SV ability and the structural design instruments (to be discussed in Chapters 6 and 8)

The next chapter, Chapter 5 will discuss the research methodologies that were adopted for the study.
CHAPTER 5

Research Methodology

1. INTRODUCTION

This chapter describes the research methods and materials that were used in the study. As stated in Chapter 1, the study consisted of four mini-studies:

- Mini-study 1 which investigated the effects of teaching and learning of SV skills on SV ability
- Mini-study 2 which investigated the relationship between attitude towards sketching and drawing (S&D) and SV ability
- Mini-study 3 which investigated the effects of teaching and learning of SV skills on structural design problems solving
- Mini-study 4 which investigated the effects of teaching and learning of SV skills on structural theory problem solving.

This chapter will deal with the methods and materials pertaining to each mini-study in turn. However, a description of the research population will be given first, as it was common to all mini-studies.

2. RESEARCH POPULATION

The immediate population, to which the findings of this study were to be generalised, was the civil engineering diploma students - who were in their final semester of study - from Malaysian polytechnics. Polytechnic students as opposed to university students were chosen for two reasons:

- The common administrative system of the polytechnics, which provided conditions that were conducive to the successful implementation of the study
- The lower ability of the polytechnic students who would benefit more from innovative teaching and learning interventions
2.1 Common administrative system for all polytechnics

The common administrative body, the Department of Technical Education (DTE) of the Malaysian Ministry of Education was responsible for all matters pertaining to the polytechnics such as the curriculum, students' enrolments and developments of teaching and learning facilities.

As a consequence of the shared administrative system the following conditions were found to be common to all the polytechnics:

- students' enrolment procedure, which resulted in groups of students in different polytechnics being similar to one another in the relevant traits (e.g., gender proportions, academic performance, age, racial compositions, etc.)

- curriculum guidelines for teaching and learning

- lecturers' teaching competence

- teaching and learning facilities (laboratory, classrooms, etc)

Similarities in the relevant traits between groups of students from different polytechnics, which were essential to the external validity of the study, were the consequence of the random placement method used by the DTE when enrolling the students. Under this method, all successful candidates had an equal chance of being placed in any one of the eight Malaysian polytechnics. Consequently, all groups of students in the enrolling semesters (Semester 1 and Semester 5) at all polytechnics were likely to be equivalent with respect to their academic abilities, age, racial and gender compositions. This condition ensured higher chances of achieving equivalence between samples when the purposive sampling method for the research subjects was used six months later (semester six students were students who had successfully undergone the six months semester five course).

Although differences arising from experiences unique to the individual polytechnic were expected between groups of semester six students in separate polytechnics, these differences were not anticipated to be significant due to the influential impact of the other common factors that were shared between polytechnics.
The common curriculum guidelines (unlike universities) ensured homogeneity in academic experiences and would reduce chances of inter-polytechnic disparities in academic performance. In addition to that, the curriculum, which was developed cooperatively by representatives from all polytechnics (shared between polytechnics) would encourage better implementation of the curriculum.

Adequate teaching competence among the lectures would further reduce variations in performances among students of different polytechnics. However, teaching style, teachers’ characteristic that has been claimed to affect learning, was not controlled in the study. Teaching styles refers to “...a person’s pervasive instructional qualities that persist even though situational conditions may change.” (Spoon and Shell, 1998, p. 42) while leaning styles refers to “... the attitudes and behaviours that determine an individual’s preferred way of learning.” (Honey and Mumford, 1992, p. 1). Presmeg (in Bishop, 1989) found that non-alignment in teaching and learning styles affects the learning of mathematics in some groups of secondary schools students. However, the students in the present study are older and matured students who according to Halpin and Peterson (1986) would not be affected greatly by non-alignment in teaching and learning styles as older students are able to accommodate their learning styles to “...the less-than-desirable instructional procedures.” (Halpin and Peterson 1986, p. 973) of the teachers.

Finally, the common educational facilities together with the common curriculum and the adequate lecturers’ competence provided similar quality of learning experiences for groups of students from different polytechnics and would therefore, reduce threats to external validity arising from variations in learning experiences.

2.2 Lower academic ability in polytechnic students.

In general, the academic ability of the polytechnic students was lower than their university counter-parts. This assumption was based on the entry requirements for courses in polytechnics, which were lower compared, to entry requirements for similar courses in universities. Due to the generally higher regard for universities, it was natural for those school leavers intending to go for further studies to consider polytechnics as an alternative only to be considered after universities. This conclusion was based on casual observation throughout the researcher’s 15 years
experience as a polytechnic lecturer. It is thus felt that the lower ability polytechnic population will benefit relatively more from the teaching intervention compared to the university population.

2.3 Summary

In summary, the diploma students in Malaysian polytechnics were identified as the immediate population for the study. Having them as the immediate population was advantageous as it was relatively more likely to get representative samples from polytechnic - a consequence of the shared administrative system - than from university populations. Having samples that are representative of the population is essential for external validity, i.e., generalisation to population (Black, 1999). The potential benefit of the study was also identified to be more for the polytechnic population than for the university populations.

3. MINI-STUDY 1: THE EFFECTS OF TEACHING AND LEARNING OF SV SKILLS ON SV ABILITY

The purpose of this mini-study was to investigate whether teaching and learning of SV skills using specific learning materials (treatment) will influence SV ability in civil engineering subjects from Malaysian polytechnics. Also of interest were whether:

• there is a difference in the SV ability gains between males and females engineering students

• teaching and learning SV skills affected males and females engineering students differently

3.1 Research questions and hypotheses.

The main research question formulated for this study was:

Is there a difference in the SV ability gain scores between the group that receives teaching and learning of SV skills (experimental group) and the group that did not (control group)?
The two additional research questions were:

a) Is there a difference in the SV ability gain scores between males and females irrespective of treatments?

b) Is there a difference in the SV ability gain scores between males and females across treatments?

One main hypothesis and three null-hypotheses guided the study. The hypotheses was:

*The gain scores of the subjects who are taught SV skills employing object manipulations, S&D (the experimental group) will not be significantly different compared to those who are not (control group) regardless of gender.*

The three null hypotheses were:

a) There will be no statistically significant difference between males and females in their SV ability mean gain scores as measured by the Spatial Visualisation Ability Test Instrument (SVATI) irrespective of treatments.

b) There will be no statistically significant difference between the experimental and the control group in their mean gain scores on the SVATI irrespective of gender.

c) There will be no statistically significant interactions between gender and treatments.

### 3.2 Research variables

The terminology, *dependent* and *independent variable* will be used consistently throughout this thesis irrespective of the research designs they are associated with (experimental or ex post facto). This is for convenience of use and application of statistical tests, rather than suggesting causal relationships.

The dependent variable in this mini-study was *the gain score on the SVATI*, i.e., the difference between the post-test score and the pre-test score. The data collected for this variable was classified as interval data since the difference between scores of the
same interval size represents equal magnitude and the zero score has no specific meaning.

The independent variables were gender (male and female) and types of learning programme (taught SV skills and not taught). The variables for both groups of data were classified as nominal data, as no ranking was implied and the involved individuals or events could either belong to or not belong to the specified category.

3.3 The treatment
The purpose of the treatment (the teaching and learning of SV skills) was to improve the SV ability of the selected subjects, with the long-term intent of improving their ability to solve structural design problems. The time allocated for the teaching and learning of SV skills was three two-hour sessions with 30 minutes allocation towards the understanding of structural behaviour.

The following SV ability components had been identified (in Chapter 3 and Chapter 4) as being essential to problem solving in structural design. They were the ability to:

- mentally construct the 3-D representations of 3-D structures based on the 2-D representations of the same structure, which was to be inferred from the ability to read and translate engineering drawing
- determine what an object would look like if seen from a different direction, which was to be inferred from the ability to identify 3-D representations from given perspectives
- predict the transformation of objects that were subjected to specific constraints, which was to be inferred from the ability to sketch the deflection of structural members under a given set of loading and support conditions

The SV skills learning materials were designed to be relevant to the teaching and learning of structural design and were delivered as part of the normal structural design module. The SV activities included model building using construction cubes and free-hand drawing. These activities were provided over a one-week period.
The model building activities were included in the treatment because it provided the concrete experiences that help prepared the learners for dealing with more abstract concepts (Ben-Chaim, 1997). This is especially important for those subjects who may not yet reach the formal operational stage of thinking. According to a study by Killian (1979), only approximately 25% of college students are at the formal operational stage of thinking. Although a study by Lawson and Blake (1976) found a slightly higher proportion of formal thinkers, (57% to 65%), the proportion who has not reached formal operational level is still substantial, and need to be taken into consideration in the design of the teaching materials.

The free hand sketching and drawing activities on the other hand was included because of its importance to communication in general (Simpson, 1992), and to the visualisation of space in particular. Drawing in general, complements verbal communication. For example, a frequently encountered statement during a design class; *the depth of the beam is larger than the depth of the column in the plane of bending* is quite hard to grasp for some learners when it is not complemented with a diagram. There are several concepts that the learners have to contend with in this case, namely, the concepts of *depth of beam, depth of column* and *plane of bending* and there are also the issues of relationships between these concepts. Through the researcher's personal experience as a lecturer, she often found that ideas/information are better assimilated when presented as labelled drawings, either alone or in addition to the text description than if the information has been simply presented text-description.

Free hand drawing in particular is thought to be helpful to learners by reducing the burden on the working memory during problem solving. It is helpful to learners by making their abstract ideas concrete and making their assumptions explicit to themselves and to others. For example, sketching of the visual responses of structures in structural design communicates a person's abstract understanding of structural behaviours (Brohn, 1990 and Fraser, 1981).

In brief, sketching is a communication tool as well as a problem solving tool (Anning, 1997) and its importance to design thinking is beginning to be recognised.
as indicated by studies that attempt to relate sketching and cognition (Yi-Luen Do and Gross, 1999 and Macfadzean and Cross, 1999).

The visualisation activities given in the treatment were not ‘practices’ for solving either the SVATI items or the Structural Design Instrument (SDI) items. Nevertheless, some similarities exist between the tasks in the treatment and the tasks in the SVATI and the SDI items (see Appendix 3 and Appendix 6).

3.3.1 Examples of SV activities.

SV activities in the treatment were designed to produce (i) learning of SV skills for general applications and (ii) learning of SV skills for specific structural design applications. The same teaching strategy was employed for activities in both applications, i.e., from the concrete to the abstract, such as from object manipulations to sketching and drawing from observation and imagination. Sketching and drawing are terms used to include making detailed or rough representations of observed or imaginary objects using pen or pencil. Examples of the SV activities are given below and the full teaching and learning activities are given in Appendix 2.

3.3.2 SV activities for general applications.

Three target objectives were identified for the lesson. The subjects would be able to:

a) draw the perspectives of an object given the elevations

b) draw the elevations of an object given the perspectives

c) recognise an object given its elevations

Students were given a set of building blocks to be used as aids in visualisation. Activities were sequenced in such a way as to help subjects to progress from being very dependent on the concrete aids (building blocks) to being less dependent and finally to be able to deal with less concrete ideas. In summary, the learning materials were designed to provide the subjects with the learning experiences that progressed from the concrete to the abstract as described next page.
3.3.2.1 *Description of SV activities*

Stage 1: Subjects constructed buildings according to the given plans and sketched the perspectives from a given angle. They were specifically asked to use the building they construct to help them see what the perspective look like.

Stage 2: Subjects constructed buildings according to plan and sketched the elevations. They could manipulate the constructed building to help them obtain the elevations.

Stage 3: Subjects were given the elevation drawing and they were asked to draw the perspectives. They could still use the blocks if they wished but they were becoming less and less dependent on them.

Stage 4: Students were given a floor plan of a building and asked to sketch the perspectives and the elevations. They were expected to achieve this without the help of the building blocks.

These activities, which had been modified for the purpose of the study, were adapted from Izard (1990), Baartmans and Sorby (1996a, 1996b), Saads and Edwards (1997), Ben-Chaim, Lappan and Houang (1988) and Lappan, Phillips and Winter, (1984).

3.3.3 *SV activities for structural design applications.*

Three target objectives were identified for the lesson. At the end of the lesson the subjects would be able to:-

a) Determine the deflected shape of a beam under different support conditions and loading conditions by sketching the deflected shape of a given hypothetical beam problem.

b) Determine a simple support effect, a pinned support effect and a fixed support effect on the given beam by sketching the shape of the beam in the vicinity of the supports.

c) Determine when to use simple support and when to use pin support in a design of a continuous beam by giving a verbal response to a hypothetical beam design problem.
Beam models constructed from flexible materials (Howard, 1998) and sketching and drawing of structural diagrams (Brohn, 1990 and Brohn and Cowan, 1977) were two of the teaching and learning aids in this treatment.

3.3.3.1 Description of the activities

Stage 1: The researcher (the instructor) demonstrated to the students:

- the different support conditions, simply supported, fixed and pinned
- the deflected shapes of a beam as a result of applied loads and the different support conditions

Stage 2: The subjects manipulated the model and try to model the resultant beam as a result of a prescribed conditions, e.g., a continuous beam of three equal spans with only one span loaded and sketches.

Stage 3: Subjects predicted beam responses to a given set of applied loads and support conditions and demonstrated their ability by sketching the deflected shapes of the beam which was later verified using the beam model.

Stage 4: Subjects solved problems on structural behaviour of beams.

3.4 Research Design

A pre and post-test quasi-experimental design method - using two intact classes of students as the control and experimental group - was adopted for this study. This design provided ecological validity by keeping the subjects in their natural setting and learning environment, which would have been impossible if the experimental design with a random sampling method had been used. However, despite the purposive sampling method, sample representativeness and control of extraneous variables were made possible as a consequence of the placement procedure used by the DTE that randomly placed students into polytechnics (see section 2.1).

The design structure (time and sequence of events in the study) is shown on the following page.
(\(RA_a\)) \(\rightarrow\) \(O_{a1}\) \(\rightarrow\) \(X_a\) \(\rightarrow\) \(O_{a2}\)

(\(RA_o\)) \(\rightarrow\) \(O_{o1}\) \(\rightarrow\) \(X_o\) \(\rightarrow\) \(O_{o2}\)

\(Y_a = O_{a2} - O_{a1}\)  \(Y_o = O_{o2} - O_{o1}\)

\(Y_a\) is compared to \(Y_o\)

The variable maps for the study is shown in Figure 5.1. This Figure shows all the variables identified to be relevant to the study, the sequence of events as well as the structure of the study. It is an elaboration of the research structure shown above.

The ovals include the potential extraneous variables that must be controlled to ensure internal and external validity. Control of these variables will be explained in the forthcoming sections.

The design incorporates two equivalent groups (as explained before) ensuring there is comparison across groups when one group serves as the control. As the study occurred over the same time interval for the treatment and the control groups, in addition to them being equivalent groups, any public event over this period (e.g., T.V programme, etc.) was not expected to affect the two groups differentially. As they were equivalent for the relevant traits, differential regression towards the mean was also not anticipated between the groups.

Maturation was not thought to be a source of confounding because the subjects who were adult learners were not likely to change in maturation within the one-week duration of the study. The brief period of the study also eliminates confounding from decreasing sample quality associated with a long period of study. Samples' instability was avoided, as the samples were captive audiences.
Figure 5.1. The Variable map for the Quasi-experimental design study on the effect of teaching and learning of SV skills on SV ability. It shows the proposed independent variables (boxes), the operational definition of the dependent variable (box with rounded corners), the dependent variable (heavy box with rounded corners) and identified extraneous variables (ovals)
Differential interaction with the independent variable treatment was desired and expected. However, the design did not control for the possibility that a change in attitudes toward SV skills, (making them work harder to improve themselves) was causing the improvement in SV ability in the treatment group. In summary, the design ensured external validity and some internal validity.

3.5 Research subjects and sampling methods.
The research subjects were intact classes of civil engineering students from two Malaysian polytechnics, Ungku Omar Polytechnic (UOP) and Port Dickson Polytechnic (PDP) who were in their final semester. The experimental group (the group that was taught SV skills) was an intact class of 29 students from UOP while the control group was an intact class of 28 students from PDP. These two groups were treated as equivalent groups with justifications (recall section 2). Table 5.1 gives the descriptive statistics of the groups. The reasons for choosing these two groups as the samples will be duly explained.

Table 5.1. Descriptive statistics for the groups under the SV ability study.

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of subjects</th>
<th>Mean Age</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental (UOP)</td>
<td>29</td>
<td>22.5</td>
<td>11</td>
<td>18</td>
</tr>
<tr>
<td>Control (PPD)</td>
<td>28</td>
<td>23.0</td>
<td>8</td>
<td>20</td>
</tr>
</tbody>
</table>

As the UOP was the only polytechnic that has two classes of civil engineering diploma students and mistakenly believing that the two groups would be equivalent, the initial plan for the study was to use the two classes from the UOP as research subjects. However, on reaching the location, it was discovered that the two classes were highly unlikely to be equivalent because of the streaming procedure - illustrated in Figure 5.2 - practised in the UOP.

As what is clearly shown in Figure 5.2, the two diploma classes in the UOP could not be equivalent because these two classes consisted of students from different diploma programmes. One class consisted of those students who enrolled through the integrated diploma programme (IDP) and the special diploma programme.
Polytechnic certificate holders from the Integrated Diploma-Programme.

Three and a half year diploma programme
Candidates have 'O' levels, direct from schools.
[Class 1]

One year diploma programme
Candidates have polytechnic certificates.
[Class 2]

Equivalent diplomas

Figure 5.2. Streaming of candidates in the diploma programme in UOP.

As explained earlier in Chapter 1 section 7.1, the three diploma programmes (DP, IDP, SDP) have different entry requirements. Consequently, the students of the combined (IDP and SDP) semester six class were more heterogeneous than the students of the DP semester six class in terms of age, entry qualifications and experience. The students in the DP were younger, possess higher academic qualifications at the time of entry but had only a maximum of six month's working experience. While those from the combined class were relatively older, may have lower academic qualifications at the time of entry (IDP) but had more than six months of working experience (recall Chapter 1). The SDP students especially were very heterogeneous in nature. Being former polytechnic students who had had at least three years working experience, they were therefore, older in age, had more experience in the related fields, and were most likely to be motivated and to have positive attitudes towards learning. The streaming procedure practised in UOP thus created two non-comparable classes of students in UOP.

Why choose the final semester-(semester six) students? First of all this study is part of a larger study which involves looking into the effect of SV ability on two other inter-related modules, structural design and structural theory. The
structural design module was only taught as a separate module (on its own) in the semester five and the semester six. Therefore, the choice was between the semester five or the semester six groups. The semester six students were the better choice because they had adjusted to the life in the polytechnics. The semester five students on the other hand were newly registered students with the exception of the students who enrolled through the diploma programme. The semester five was in effect the first semester in the particular polytechnic for those in the special diploma programme and possibly for those in the integrated programme. They were therefore, still in the adjustment period (being in new polytechnic, faced with new lecturers, making new friends, etc.) and variables associated with these adjustments could confound the outcome of the study.

Maturation effect has been shown to be one of the confounding variables in past studies. For example, Hill and Obenauf (1979) found that maturation effect rather than treatment was responsible for the improvement in SV ability of the first semester teacher trainees they investigated. Blake and Nordland (1978) in another study of first semester trainee teachers also found some indication that maturation effect was confounding the result of their study. They argued that the daily demands of decision making for these first time away-from-home students might be responsible for their leap in maturation over the one semester period.

Although the SV study in the polytechnic case was for a period of two weeks only and maturation effect was highly unlikely, but the efforts involved in adjusting to a new place might turn into confounding variables. It was therefore, decided that the semester six students and not the semester five students were the most appropriate choice of samples for the study.

The researcher chose the mixed semester six class as the treatment group. Doing so was advantageous to the study for any group from the remaining polytechnics would then become a potential control group. Choosing the DP class would not have been suitable because this group was unique and not comparable to other semester six classes in other polytechnics. The other eight polytechnics had only one class of diploma students, which were ‘mixed’ classes. Choosing the UOP mixed class was expected to enhance external and internal validity.
Although any classes from the remaining polytechnic could have been chosen as the experimental group, the UOP group was chosen as experimental group because of the past connection between the researcher and the institution which ensured co-operation from all concerned. Assistance was obtained from the teaching and administrative staff to smoothen out implementation problems, such as the scheduling of lessons and test administrations.

After choosing the UOP group as the experimental group, any group of semester six from the remaining polytechnics became potential control group. However, choosing the PDP group provided several advantages:

- PDP was the nearest polytechnic to the Department of Technical Education the location at which the researcher was based during her study stay in Malaysia
- the researcher had good previous working experience with some of the staff at the PDP civil engineering department which ensured co-operation and assistance when required

*Why use intact classes?* Using intact classes of students as research subjects was justified in this case as random selection and assignment could add extraneous variables to the study. Furthermore, in view of the random placement procedure adopted by the Department of Technical Education (the responsible body for polytechnic enrolments) it would seem that each polytechnic would end up with equivalent groups of students anyway, except for the special case in UOP previously explained.

In summary, the research subjects were two equivalent classes of civil engineering students from two Malaysian polytechnics UOP and PDP who were in their final semester. The experimental group was an intact class of students from UOP \((n = 29)\) while the control group was an intact class from PDP \((n = 28)\). Table 5.1 gives the descriptive statistics of the groups.

3.6 Instrument

The Spatial Visualisation Ability Test Instrument (SVATI), which is given in Appendix 3, had been specifically developed for the study. The development
process of the SVATI is given in Chapter 6. The SVATI has a reliability of 0.70 (Chapter 9).

3.7 Data analysis

Both descriptive and inferential statistics were used for the analysis of data in this study. A two-tailed, two-way ANOVA procedure was used for the inferential statistics. The two-way ANOVA was favoured as it permitted simultaneous testing of differences, between and within groups. A two-tailed as opposed to a one-tailed test was chosen because no assumption was made on the direction of the results. However, if the direction of the result were such that the treatment group was most likely to do better, a one-tailed test would have been more appropriate. The use of this parametric test was justified after ensuring that the assumptions underlying the parametric methods (such as normality of population distributions, homogeneity of variance between groups, etc.) were satisfied.

4. MINI-STUDY 2: THE RELATIONSHIPS BETWEEN ATTITUDE TOWARDS SKETCHING AND DRAWING AND SV ABILITY.

Attitude towards sketching and drawing (S&D) was hypothesised to be related to SV ability and learning in general. The hypothesised relationship between attitudes and learning is supported both by theories on learning, findings from casual observations (through the researcher's 15 experience as a lecturer) of classroom interactions and information gathered from informal discussions with polytechnic lecturers.

The behaviourist model of human behaviour suggests that human behaviour is tied to not only the cognitive (intellectual) and psychomotor (manual dexterity, etc.) but also to the affective factor, i.e., one's beliefs, feelings, attitudes, etc. (Gagné, 1977, Coleman, 1971). Casual observations on classroom interactions by UOP teaching staff also support the assumption that 'students feelings towards a subject matter was a pre-disposing factor to successful learning in that subject area'. However, to this day, no formal effort has ever been made to measure the validity of this assumption.
Since S&D is an important tool to the visualisation of space, it was thus felt that an investigation into the relationship between attitudes towards S&D and SV ability should be made a part of this study. An indication of the relative strength of the civil engineering subjects’ attitude towards S&D were obtained by comparing their attitude with a group that is recognised to appreciate S&D, i.e., a group of polytechnic architecture students.

4.1 Research questions and hypotheses

Three research questions were formulated for the study:

a) Do civil engineering subjects have a less positive attitude towards drawing and sketching compared to architecture students?

b) For the civil engineering group only, is there a relationship between attitudes towards drawing and sketching and spatial visualisation ability?

c) For the civil engineering group only, is there any relationship between the instrument components?

4.1.1 Difference in attitudes towards S&D between the civil engineering group and the architecture group

For the differences in attitudes between the engineering group and the architecture group, the following hypotheses were formulated.

a) There will be a statistically significant difference between the means of the civil engineering and the architecture group on the View of the professional role of S&D as measured by the relevant component of the Attitude Questionnaire.

b) There will be a statistically significant difference between the means of the civil engineering and the architecture group on the Values of the personal usage of S&D as measured by the relevant component of the Attitude Questionnaire.

c) There will be a statistically significant difference between the means of the civil engineering and the architecture group on the Tendency to use S&D as measured by the relevant component of the Attitude Questionnaire.

The following null hypotheses were generated for the above hypotheses:
a) There will be no statistically significant difference between the means of the civil engineering and the architecture group on the *View of the professional role of S&D* as measured by the relevant component of the Attitude Questionnaire.

b) There will be no statistically significant difference between the means of the civil engineering and the architecture group on the *Values of the personal usage of S&D* as measured by the relevant component of the Attitude Questionnaire.

c) There will be no statistically significant difference between the means of the civil engineering and the architecture group on the *Tendency to use S&D* as measured by the relevant component of the Attitude Questionnaire.

### 4.1.2 Correlation between attitude components

The following three hypotheses were formulated for the correlation between the instrument components:

a) There will be a statistically significant correlation between the score on the *View of the professional role* and the *Value of the personal usage of S&D*

b) There will be a statistically significant correlation between the score on the *View of the professional role* and the *Tendency to use S&D*

c) There will be a statistically significant correlation between the score on the *Value of the personal usage* and the *Tendency to use S&D*

The hypothesised relationship between the attitude components is visually represented in Figure 5.3.

The following null hypotheses were generated for the correlation between components.

a) There will not be a statistically significant correlation between the score on the *View of the professional role* and the *Value of personal usage of S&D*

b) There will not be a statistically significant correlation between the score on the *View of professional role* and the *Tendency to use S&D*
c) There will not be a statistically significant correlation between the score on the Value of personal usage and the Tendency to use S&D

Figure 5.3. The model for the hypothesised relationships between the components of the attitude towards S&D.

4.1.3 Relationship between attitude towards S&D and SV ability.

Four hypotheses were formulated for testing the relationships between attitudes and SV ability.

a) There will be a statistically significant correlation between the View of professional role of S&D and the pre-test score of the SVATI.

b) There will be a statistically significant correlation between the Value of personal usage of S&D and the pre-test score of the SVATI.

c) There will be a statistically significant correlation between the Tendency to use S&D and the pre-test score of the SVATI.

Figure 5.4 illustrates these hypotheses graphically.
Figure 5.4. The hypothesised model for the relationships between attitudes and SV ability.

The following null hypotheses are for the correlation between the attitude components and SV ability.

a) There will be no statistically significant correlation between the View of professional role of S&D score and the SVATI score.

b) There will be no statistically significant correlation between the Value of personal usage of S&D score and the SVATI score.

c) There will be no statistically significant correlation between the Tendency to use S&D score and the SVATI score.

4.2 Research variables

For the investigation into the difference in attitudes towards S&D, the attribute variables were groups of students, i.e., civil engineering students and architecture students (ordinal data) and the active variable was the score on the attitude questionnaire.

For the investigation into the relationship between attitudes towards S&D and SV ability, the attribute variables were attitudes (interval data) and the active variables were scores on the spatial visualisation ability instrument (interval variable). Data collected for both variables were interval data.
4.3 Research Design

The Post-test/Observation only, with a control group (ex-post facto) design was adopted for the study into the difference in attitudes between the civil engineering group (following the civil engineering programme) and the architecture group (following the architecture programme). The research design is shown below.

\[ (PS) \rightarrow X_a \rightarrow O_a \]
\[ (PS) \rightarrow X_o \rightarrow O_o \]

\[ Y_a = O_a \quad Y_o = O_o \quad Y_a \text{ is compared to } Y_o \]

The variable map for the study is shown in Figure 5.5. Both groups were representative of their respective populations (polytechnic architecture students and polytechnic civil engineering students), which was a consequence of the polytechnic selection and placement procedures (recall 2.1). Both groups had equivalent proportion of males to female so non-equivalent gender distribution would not be a source of confounding variables.

The engineering subjects were on average 1½ years older than the architecture sample but this factor by itself was not thought to affect attitudes towards in general both groups were matured students (above 20 years old). However, the number of years in the polytechnic for the architecture group is less than the engineering group because the architecture group was a group of students who were in the final semester of the Certificate programme.
Figure 5.5. Variable map for the ex-post facto study of the comparison between attitude towards S&D of the architecture subjects and civil engineering subjects.
Nevertheless, the lower number of years in the polytechnic would not be a source for invalidity because the architecture subjects had been polytechnics students for at least 1½ years, which means that they polytechnic environment was not new to them.

The effects of time on the maturation of subjects, sample stability and regression towards the mean were also not sources of confounding variables since the observation was only made once.

4.4 Research subjects.
The civil engineering subjects were those described in Section 3.5 and the sample size was the combined subjects of the control and the experimental group \( (n = 57) \). The architecture subjects were 19 architecture students who were following the final semester of the Architecture certificate programme from UOP and PDP.

The proportions of males to females are roughly 7:3 for both groups. The mean age of the architecture sample was 21 years while the mean age of the civil engineering sample was 22½ years. The average age of the architecture sample was therefore, 1½ years less than the engineering sample. The architecture sample also had 1½ years less of polytechnic education (a certificate course is a 2-year programme while a diploma course is a 3½-year programme). The architecture sample in general has only had six months working experience while the diploma sample (definitely those enrolled in the SDP) had had more than six months working experience.

Nevertheless, being in their final semester as well as having gone through six month’s work experience, the architecture sample were matured enough in their attitudes towards S&D and taking them as a group that had extreme positive attitudes towards S&D was justified. It was therefore, not necessary to have diploma architecture students as sample.

However, the higher maturity in combination with the longer working experiences of the engineering subjects was expected to reduce the gap in attitudes towards S&D between the engineering and the architecture groups. The longer working experience which usually involved drawings in some way (drafting or interpreting
drawings) might induce a more positive attitude towards S&D in the engineering subjects. In other words, the attitude difference between the architecture sample and the engineering sample would have been larger if the engineering sample had had no extra working experience.

4.5 The relationships between attitudes towards S&D and SV ability

One group observed was used to investigate the relationship between attitudes and SV ability. The research design is shown in Figure 5.6. Two observations were taken from the same sample and the observation was later correlated.

![Figure 5.6. The correlational research design for the study on relationships between attitudes towards S&D and SV ability.](image)

In a study such as this, the most likely source of extraneous variable was a non-representative sample. However, in this study a non-representative sample was not thought to be a source of extraneous variables as the civil engineering group was representative of the population, a consequence of the polytechnic selection and placement procedure (recall Section 2.1). Effects of time on maturation, etc. and regression towards the mean were also not sources of extraneous variables as the observation was only made once. The most likely source of any confounding would be instruments with low reliability and validity.

The research subjects were identical to the subjects in the SV ability study (recall Section 3.5)
4.6 Attitude instrument
The instrument was an attitude questionnaire specifically developed for the study. The development of the instrument is given in Chapter 7. The evaluation of the instrument is given in Chapter 10.

4.7 Data analysis
The data was analysed using a PEARSON function and two-tailed t-test of significance on EXCEL worksheet (version 7 of Windows 95) after Black (1999). The methods and results of the data analyses are given in Chapter 12.

5. MINI-STUDY 3: THE EFFECTS OF TEACHING AND LEARNING OF SV SKILLS ON CIVIL ENGINEERING PROBLEM SOLVING (STRUCTURAL DESIGN)
In the traditional polytechnic design class, design was taught from the analytic to the visual, i.e., teaching and learning of multitudes of analytical techniques precede the creative part of design. According to Williamson and Hudspeth, (1982), design should be taught from the visual to the analytic. In this study the experimental group was exposed first – be it for only one week - to the visual and spatial aspect of design (the learning and teaching of SV skills) before they were subjected to the numerical-analytical aspects of structural design. It was expected that the skills learned from the teaching and learning of SV skills would be transferred to structural design problem solving and would be reflected in a higher structural design performance (SDI mean score) in the treatment group. Teaching and learning of SV skills were expected to improve structural design problem solving as:

- SD problems share a common feature with SV problems, i.e., they both deal with processing of spatial information although, SD problems require knowledge specific spatial skills while SV problems require generic spatial skills.
- the SD problems that are in the SDI have been specifically designed to demand SV skills.
Figure 5.7 illustrates the proposed relationships between SV ability and the ability to solve SD problems, which leads to the research questions and hypotheses.

Figure 5.7. Proposed relationships between spatial visualisation ability and structural design problem solving.

5.1 Research questions and hypotheses
Two research questions have been formulated for this study which were:

a) Is there a relationship between SV ability and problem solving in structural design?

b) Do teaching SV skills employing object manipulations, sketching and drawing enhance performance in problem solving in structural design?

Two hypotheses were formulated, i.e., for the relationship between SV ability and structural design and for the difference in performance on structural design problems between the control and the treatment group.
The hypothesis for the relationship is:

*There will be a statistically significant correlation between SV ability as measured by the SVATI and structural design problem solving skills as measured by the Structural Design Instrument (SDI).*

The hypothesis for the difference is:

*There will be a statistically significant difference between the mean score of the treatment group and the control group as measured by the SDI.*

The null hypotheses formulated were:

a) There will be no statistically significant correlation between SV ability as measured by the SVATI and structural design problem solving as measured by the SDI.

b) There will be no statistically significant difference between the means of the treatment group and the control group on structural design problem solving as measured by the SDI.

5.2 Variables

The dependent variable in this study was the *post-test score on the SDI*. The data were interval data. The independent variable was *teaching* and *not teaching* SV skills and the data gathered were nominal data.

5.3 Research Design

A quasi-experimental design of Post-Test/observation with a control group after Black (1999) was adopted for the study. The structure (time and sequence of events) is shown Figure 5.8. The research design is shown in Figure 5.9. This design is highly dependent on the sampling technique used if the result is to support causality.
Figure 5.8. The time and sequence of the events in the study

Two equivalent groups (equivalence achieved through the polytechnic selection and placement procedure, recall Section 2 and section 3.5) were used which means 'no comparison across groups' was unlikely to be a source of extraneous variable.

The post-tests were administered at the same point in time during their academic session, i.e., after they have finished their syllabus and were waiting to sit for their final examinations. Therefore, differential maturation effect was not expected between the control and the treatment group.

The post-tests were however, administered at a six-month interval. Therefore, although there was no unparalleled event over the two semesters, unidentified factors could still be a source of invalidity. There was however, no changes over policy or regulations to differentially affect the samples. Regression towards the mean was not expected to be a source of extraneous variable because only a single measure was taken.

The samples were quite stable because they were a captive audience. However, three of the subjects in the treatment group dropped out of the polytechnic due to failing a polytechnic test, which was non-related to the study. Losing the three subjects would not affect the validity of the study since the number was very low and its cause was unrelated to the study.
Figure 5.9. The variable map for the Quasi-experimental design study on effects of teaching SV skills on structural design.
5.4 Population and samples
The population was the same as described in Chapter 5 (section 2). The samples were two consecutive groups of semester six students from Ungku Omar polytechnic. The control group was the semester six of the Dec. 1997 - May 1998 \((n = 77)\) session while the experimental group was the semester six of the Jun. 1998 - Nov. 1998 session \((n = 61)\). The potential for the time difference to be a source of invalidity was discussed earlier in Section 5.3.

5.5 Research instrument
The measuring instrument, the SDI, was specifically designed for the study. The design and development of this instrument is given in Chapter 8. The evaluation of this instrument and some evidence for its reliability and validity is given in Chapter 10.

5.6 Data analysis (Statistical validity)
A two-tailed \(t\)-test using Excel worksheet (after Black, 1999) was used for the data analysis. The \(t\)-test was justified on the evidence of homogeneity of variance and normality of the underlying distributions. The methods and results of the analyses are given in Chapter 13.

6. MINI-STUDY 4: THE EFFECTS OF TEACHING AND LEARNING OF SV SKILLS ON CIVIL ENGINEERING PROBLEM SOLVING (STRUCTURAL THEORY)
It was expected that the skills learned from the teaching and learning of the SV skills would be transferred to problem solving in structural theory and would be manifested by a higher mean score for the treatment group on the structural theory examination paper. This expectation is based on the following argument.

Structural theory problems are characterised by the applications of mathematical methods to problems of structures. The ability to solve mathematics problems has been shown to be related to SV ability and because of the shared characteristics between mathematics and structural problems, it was therefore, expected that the ability to solve structural theory problems would be related to SV ability too. In addition to that, the problems of structures require dealing with and processing of
spatial information which is part of SV ability. It was therefore, logical to expect a relationship to exist between structural theory and SV ability.

Figure 5.10 illustrates the hypothesised relationships between the four concepts, (mathematics problems, SV ability, spatial information processing and structural theory problems) which led to the research questions and hypotheses.

Two research question were formulated for this enquiry:

a) Is there a relationship between SV ability and examination performance on structural theory problems?

b) Does teaching and learning of SV skills employing object manipulations, sketching and drawing enhance examination performance on structural theory problems?
Two hypotheses were generated for the research questions. The hypothesis generated for the relationships between spatial visualisation ability and performance on structural theory problems was:

*There will be a statistically significant correlation between SV ability as measured by the SVATI and performance on solving structural theory problems as measured by the Structural Theory examination paper.*

The hypothesis generated for the effects of teaching and learning of SV skills was:

*There will be a statistically significant difference between the mean score of the treatment group compared to the control group on the performance in solving structural theory problems as measured by the Structural theory examination paper.*

Two null-hypotheses were formulated corresponding to the above hypotheses:

a) There will be no statistically significant correlation between SV ability as measured by the SVATI and structural theory as measured by the Structural theory examination paper.

b) There will be no statistically significant difference between the mean score of the treatment group compared to the control group on the performance in solving structural theory problems as measured by the Structural theory examination paper.

6.1 Variables

The dependent variable in this study was the post-test score on the ST examination paper, which was interval data, and the independent/manipulated variable was *teaching/not teaching spatial visualisation skills*, which was nominal data.

6.2 Research Design

A quasi-experimental design of Post-Test/observation with a control group was adopted for the study. The structure (time and sequence of events) is shown in
Figure 5.11. This design is highly dependent on the sampling technique used if the result is to support for causality. The design for this study is shown in Figure 5.12. The design used two equivalent groups (recall section 2 and 3.5) which was likely to eliminate the 'no comparison across groups' as a source of extraneous variable.

\[
\begin{align*}
\text{RS}_a & \quad \rightarrow \quad X_1 \quad \rightarrow \quad O_a \\
\text{RS}_0 & \quad \rightarrow \quad X_0 \quad \rightarrow \quad O_0 \\
Y_a &= O_a \quad \quad Y_0 = O_0
\end{align*}
\]

Figure 5.11. The time and sequence of events in the study

The post-tests were given after a six-month interval but there were no unparalleled events such as changes over policy or regulations over the two semesters to differentially affect the samples. However, unidentified factors could still be a source of invalidity.

Differential maturation effect was not expected between the control and the treatment group since the post-tests were administered at the same point in time during their academic session. Regression towards the mean was not a source of invalidity because only a single measure was taken.

Sample instability was not a source of invalidity because the samples were a captive audience. However, three treatment subjects were lost from the study due to failing on a non-related polytechnic test. Losing these subjects would not affect the validity of the finding since the number was very low and their leaving was due to something other than the treatment.
Figure 5.12. The variable map for the Quasi-experimental design study on the effects of teaching SV skills on performance on the structural theory problems.
6.3 Population and samples
The population to which the results were to be generalised was as described in section Chapter 5 (section 2). The samples were two consecutive groups in semester six from Ungku Omar polytechnic. The control group was the group from the Dec. 1997 - May 1998 session ($n = 79$) and the experimental group was the group from the Jun. 1998 - Nov. 1998 session ($n = 66$). The potential for the time difference to be source of invalidity was discussed earlier in Section 5.3.

6.4 Research instrument
The test instruments were not specifically designed for the study. They were two structural theory examination papers from the two semesters concerned which were the Dec. 1997 - May 1998 session and the June 1998 - Nov. 1998 session respectively. The description of this instrument is given in Chapter 8 and its evaluation is given in Chapter 10.

6.5 Data analysis (statistical validity)
A two-tailed Wilcoxon Mann-Whitney was used instead of the $t$-test for testing the difference, as one of the assumptions —normality of distribution— was not met. The data was analysed using EXCEL worksheet after Black (1999). The methods and results of analysis are given in Chapter 14.

7. CONCLUSION
This chapter has described the research methods and materials used in the study. The study employed four research designs;

- the two groups pre-test/post test Quasi-experimental design, for studying the effect of teaching and learning of SV skills on SV ability
- the Post-test/Observation only Quasi experimental design, for studying the effect of SV skills on problem solving in civil engineering (structural design and structural theory problem solving)
• the Post-test/Observation with a control ex-post facto design, for studying the difference in attitudes towards sketching and drawing between the civil engineering and an architecture groups.

• the correlational ex-post facto design, for studying the relationship between SV skills and problem solving in civil engineering.

The chapter has also identified and discussed the control of some of the factors that may affect the validity of the findings. In the forthcoming chapters, further aspects of the study are going to be dealt with.

In Chapter 6, the development of the research Instrument for mini-study 1, the SVATI will be discussed followed by the research instrument for mini-study 2, the Attitude questionnaire in Chapter 7. In Chapter 8, development of the instrument for mini-study 3, the SDI and the instrument for mini-study 4, the ST paper will be discussed.

Chapter 9 will report on the evaluation of the research instrument 1, the SVATI followed by Chapter 10 on the evaluation of the remaining instruments. Chapters 11, 12, 13 and 14, will deal with the Data analysis for the four mini-studies in turn and the final chapter, Chapter 15 will be on the conclusion and the implications of the study.
CHAPTER 6

Instrument Development for Mini-study 1: Spatial Visualisation Ability Test Instrument (SVATI).

1. INTRODUCTION

This chapter describes the development process of the Spatial Visualisation Ability Test Instrument (SVATI). The SVATI (Appendix 3) is a paper and pencil test, which has been specifically designed and developed to meet the measurement objectives of the study. The SVATI was used twice in the study; serving as a pre-test, administered before the treatment, and as a post-test, administered after the treatment.

This chapter consists of three sections and a summary. The first section discusses the rationale behind the new instrument. The second section describes the procedures used to develop the SVATI including the measures that were taken for ensuring instrument reliability and validity.

The third section discloses the practical problems that were encountered during the development process of the SVATI.

2. RATIONALE FOR DESIGNING A NEW SV ABILITY INSTRUMENT

Using a specifically designed instrument as opposed to a commercially acquired one was prompted by the findings following a literature search and personal communications with instrument designers and spatial ability researchers (Ben-Chaim and Lappan, 1986; Embretson, 1997b and Larson, 1998). The findings were:

- studies that used different definition of SV ability were sometimes using identical SV measure

- studies that used identical definition of SV ability sometimes differed in their SV measures

- commercially available instruments were costly
As a consequence, the researcher (a novice in psychological measurement) found it very difficult to decide on a suitable instrument from among the available ones. Concerned for instrument reliability and validity and the high cost in acquiring a commercially available instrument motivated the researcher to design a new, SV ability test instrument for the study.

Some of the paper and pencil spatial ability instruments examined were a Pattern Folding Test (Embretson, 1997a; 1996; 1994), the Vandenberg Mental Rotation Test (Vandenberg and Kuse, 1978; Shiina, Saito and Suzuki, 1994; Shiina, Suzuki and Tsutsumi, 1994; Shiina, Saito and Suzuki, 1996) and a Mental Cutting Test (Makino et al., 1992; Suzuki et al., 1992; Saito, Makino et al., 1994, 1996 and Saito, Shiina et al. 1994, 1996)

2.1 Rationale for the paper and pencil test instrument

A paper and pencil test was chosen instead of the alternative, a computer-administered test for the following reasons:

- a paper and pencil test - such as listed in the previous section - has been successfully used and found to be satisfactory in measuring spatial ability in previous studies

- a paper and pencil test was less costly to develop because it did not involve high expenses associated with costly purchases of computer hardware or software

- a paper and pencil test posed fewer difficulties to administer in the polytechnic because it was not constrained by the limited computer facilities of the polytechnics (the location study). Furthermore, using a paper and pencil test as opposed to a computer-administered test also avoided any complications associated with software and hardware incompatibility.

3. DEVELOPMENT PROCESS OF THE SVATI

The SVATI was developed in three stages within a four-month period, during which time it underwent several design-and-evaluation iterations, beginning with the
baseline version (the trial instrument) followed by the prototype SVATI and finally the working version SVATI. Figure 6.1 illustrates the stages of the SVATI development process.

![SVATI Development Process Diagram]

Figure 6.1. The three-stage development process of the SVATI.

3.1 Developing the Baseline version SVATI

The objective of an instrument design in general, is to develop an instrument that would consistently measure the same thing (has reliability) and would measure what it was supposed to measure (has validity). Reliability and validity of the SVATI instrument rests upon choosing the appropriate spatial tasks and providing the appropriate stimuli of the type of tasks, i.e., the skills demanded by the spatial tasks have to correspond to the skills necessary to SV ability. Consequently, the definition of the construct is critical to the choice of spatial tasks.

The following problem solving activities were undertaken in order to achieve the above objectives.

- defining the SV ability constructs
- deciding on the spatial tasks
- evaluating the items/instrument

3.1.1 Defining the SV ability constructs

The task of defining SV ability was undertaken in Chapter 2. In Chapter 2, SV ability was defined as the ability to execute multi-step processing that necessitates object manipulate in imagination. Manipulation of objects in imagination involves:
• rotation of a visually depicted object; (e.g., rotation in the picture plane of a 2-D or a 3-D representation)

• folding and unfolding a 2-D representation of a 3-D object to form a 3-D representation of the same object (e.g., building a cube from a flat unfolded pattern of that cube)

• synthesising the multiple 2-D views of a 3-D object to form a 3-D representation of the same object (e.g., from orthographic projections to isometric representation)

The above definition was supported by the results from the cognitive analysis in Chapter 4, which identified the following skills as being essential to successful problem solving in structural design.

• the ability to construct a 3-D representation of a structure from the 2-D representations of the same structure (e.g., constructing an isometric drawing from a set of orthographic drawings)

• the ability to understand structural behaviour or generically stated as: the ability to predict the transformation of an object under prescribed conditions (e.g., accurately predicting the view of an object under a given transformation)

3.1.2 Deciding on the spatial tasks

Deciding on the spatial tasks involved:

i. choosing a spatial task that has the potential to measure the identified spatial skills

ii. postulating the strategy that would be used to solve the chosen task

iii. comparing the postulated strategy to the construct of SV ability

iv. confirming/rejecting the choice and if a choice was rejected a new task was chosen and steps (i) to (iv) were repeated

Two types of spatial tasks were chosen for the baseline version SVATI: (i) Cube construction tasks and (ii) Engineering drawing tasks. These tasks were chosen
because their problem solutions required the ability to execute multi-step processing and the ability to execute the mental rotation process (SV ability) as explained in the forthcoming sections.

3.1.2.1 Cube construction tasks

The Cube construction tasks were based on items that were used in SV ability studies by Baartmans and Sorby (1996b) and Embretson (1994). A typical task would require a test-taker to identify the cube (from a set of cubes) which could be constructed from a given flat pattern of six square faces. Figure 6.2 shows a typical example of a Cube construction item.

Figure 6.2. A cube construction item showing the stem (on the left) and the four alternative responses.

According to Shepard and Cooper (1982), Cube construction tasks are mental rotation tasks in essence but with two differences. Each rotation in the paper folding task is “a) a rigid rotation of only one piece of the entire object relative to the rest, rather than a rotation as a rigid whole and b) is just one in a sequence of such operations that had to be completed before the required response could be made.” (Shepard and Cooper, 1982, p. 189). The Cube construction tasks therefore require mental transformation and steps by steps processing which qualify them as an indicator of SV ability. To be more specific, the ability to perform this task was taken as an indication of the ability to construct a 3-D representation of an object from its 2-D dimensional representation by mentally executing the transformation process of
folding-and-unfolding. The postulated solving strategy for the Cube construction items (Appendix 3) is based on the strategy proposed by Embretson (1994).

3.1.2.2 Engineering Drawing items

The Engineering drawing items were adapted from exercises found in publications by Baartmans and Sorby (1996b), Giesecke et al., (1998) and Lappan, Phillips and Winter (1984). The Engineering drawing items measure two types of transformations:

- **Type 1:** measures the ability to decompose - decomposing a 3-D representation of an object into its 2-D components (isometric view into its orthographic views).

- **Type 2:** measures the ability to synthesise - constructing a 3-D representation of an object from its 2-D representations (interpreting orthographic views);

Inclusion of the Engineering drawing items were justified in three ways:

- Engineering drawing is an established tool for visualisation of 3-D spaces in engineering (Ferguson, 1993)

- the subjects were engineering students and the ability to read and interpret engineering drawings had been the traditional measure of SV ability amongst engineering students

- the ability to translate engineering drawings is related to spatial ability (McGee, 1979)

- there is the need for more studies investigating the contribution of engineering drawing skill to SV ability

Figure 6.3 shows an example of Engineering drawing item of Type 1.
The postulated solving strategies which was adapted from Giesecke et al. (1998), for items of Type 1 and 2 is given in Table 6.1.

Table 6.1. Solving strategies for the Engineering drawing items

<table>
<thead>
<tr>
<th></th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
</table>
| i | Identify the surfaces, front (F), top (T) and right (R) surfaces from the isometric view (referring to the stem) | Attach the views to form flat pattern as shown [T]
|   |                                                                                              | [F]    |
|   |                                                                                              | [R]    |
| ii| Note the shape of these surfaces by visualising them if viewed at right angle                  | Fold the pattern to join T to R to form a 3-D shape or rotate the unattached square faces to attach them to each other |
| iii| Allocate broken lines for hidden surfaces                                                    | Retain shape in mind and compare the constructed 3-D to the alternatives |
| iv| Arrange the resultant shapes in the standard form                                             | Identify the right alternative from the set of alternatives |
| v | Identify the right alternative from the set of alternatives                                   | Give a response (by putting a (\(\checkmark\)) at the appropriate alternative |
| vi| Give a response (by putting a (\(\checkmark\)) at the appropriate alternative)                |        |

In summary, the Cube construction items and the engineering drawing items measure similar but not identical skills (see Appendix 3).
3.2 Evaluating the Baseline version SVATI

The baseline version SVATI was evaluated to:

a) detect defects in the trial items such as:

- items without a correct answer or more than one correct answer - ensuring that each item in the future version has an answer and only one correct answer

- inefficient distracters - ensuring that the distracters are as plausible as the correct alternative in future version

- items that do not discriminate - ensuring that items do discriminate in future version

- extremes in difficulty - ensuring that items are not too easy or too difficult in future items

b) determine the adequacy of the length of instrument and to suggest an appropriate number of items for the coming SVATI version

c) judge the suitability of the test presentation and to suggest improvements for future version

A series of informal exchanges of ideas between the researcher and several people who were SV experts and a trial of the instrument on a representative sample were carried out to achieve the above objectives.

3.2.1 Trial of the Baseline version SVATI

In this study, the baseline version SVATI was administered to a group of 20 final semester first year civil engineering students in the University of Surrey. They were chosen because they shared the relevant characteristics - academic domain and academic level - with the subjects in the actual study who were final semester civil engineering diploma students in Malaysian polytechnics. The Malaysian subjects were
assumed to be equivalent to the University subjects because previous diploma holders had been admitted direct to the second year of the British University programme.

The trial test was successfully conducted during a course on Design project with the assistance of a civil engineering lecturer (Howard, 1998). The subjects were informed that the test, which they were about to take, was part of a study into Design teaching and learning. They were also assured that their performance on the given test would not affect their grades in any way.

The trial group consisted of 17 males (85%) and three females (15%), a male to female proportion which was similar to the study samples (intact classes of Malaysian polytechnic civil engineering students).

The trial subjects were given seven minutes to complete the test. Immediately prior to the test, the subjects were given an overview of the test structure and its specific objectives. To improve homogeneity of solving strategies, the subjects were instructed on the solving strategy for the Cube construction tasks in Section I. The solving strategy for the Engineering drawing tasks in Section II was not given because the tasks were familiar to the subjects. Opportunities for queries were given and the trial was administered only after no further query was forthcoming.

The trial test was later followed by interviews involving three randomly selected subjects, to determine how they arrived at their answers (to confirm, reject or modify the solution strategy postulated earlier). Therefore two types of data, quantitative and qualitative were collected. The quantitative data were obtained through the test instrument and the qualitative data through the interviews. Excel Version 6 was used to analyse the quantitative data.

3.2.1.1 Data analysis on the trial of the instrument

Although the baseline SVATI consisted of 12 items, only 11 items were included in the analysis. This was because the one item - third item in Section II - did not have a correct answer. The baseline SVATI was therefore effectively reduced to five Cube construction items in Section I, and six Engineering drawing items in Section II.
Figure 6.4 displays the distribution of scores on the baseline version of the SVATI. The distribution is negatively skewed, i.e., skewed to the left indicating that there might be a ceiling effect, that is, the items were too easy and therefore majority of subjects were getting the correct answers.

![Figure 6.4. Distribution of scores on the Baseline version SVATI (n = 20).](image)

Having items that were easy could be contributing to this outcome. An item analysis was later carried out to yield more detail information on the items. This was presented in the item analysis section, section 3.2.1.3.

Figure 6.5 shows the distribution of scores on Sections II and I. The range of scores is slightly larger for the second section than the first section. For ease of comparison these scores have been converted to be scores out of ten.

Descriptive statistics of the trial scores are given in Table 6.2. The mean score of the Engineering drawing items was found to be smaller, $\bar{x} = 68\%$, than the mean for the Cube construction items, $\bar{x} = 74\%$. 
It was also observed that the standard deviations for the two sets of scores were different, although the number of items in both Sections II and I were approximately equal (five and six). The second section had a larger standard deviation ($s = 1.74$) compared to the first section ($s = 1.22$) indicating the possibility that items in Section II were covering a wider range of skills compared to items in Section I. Consequently, the variance for Section II was more than twice that of Section I (3.04 as compared to 1.48). Variance, which is the square of standard deviation, affects the reliability of the test scores, which will be explained in the next section.

Table 6.2. Descriptive statistics for the scores on the Baseline SVATI.

<table>
<thead>
<tr>
<th></th>
<th>Overall Instrument (N = 11)</th>
<th>Section I (N = 5)</th>
<th>Section II (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>7.8 (70.9%)</td>
<td>3.7 (74%)</td>
<td>4.10 (68%)</td>
</tr>
<tr>
<td>$s$</td>
<td>1.60</td>
<td>1.22</td>
<td>1.74</td>
</tr>
<tr>
<td>$s^2$</td>
<td>2.57</td>
<td>1.48</td>
<td>3.04</td>
</tr>
</tbody>
</table>

3.2.1.2 Reliability estimates of the trial scores

Table 6.3 displays the reliability coefficients ($r_{xx}$) for the baseline SVATI. These coefficients indicate the internal consistencies of the instruments and were estimated
using the Kuder-Richardson 20 (KR20) formula. The KR20 was used instead of the Cronbach alpha formula as the items had been dichotomously scored.

Table 6.3. Reliability estimates (based on KR20) for the baseline SVATI

<table>
<thead>
<tr>
<th>Section</th>
<th>Items N</th>
<th>rxx based on KR20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section I</td>
<td>5</td>
<td>0.42</td>
</tr>
<tr>
<td>Section II</td>
<td>6</td>
<td>0.72</td>
</tr>
<tr>
<td>Overall test</td>
<td>11</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Table 6.3 shows that the reliability estimates were acceptable except that of Section I where the reliability was deemed to be on the low side. According to Fraenkel and Wallen (1990), for research purposes, a reliability estimate of at least 0.7 is favourable. Davis (in Dyer 1979), however, argue that a reliability estimate of 0.5 might still be acceptable for a group size of between 25 to 50 as it is normally found in educational research. Therefore, although the required reliability for an instrument is not a fixed value, \( r_{xx} = 0.42 \) for Section I was clearly unacceptable and therefore needed to be enhanced.

The intended purpose of the SVATI was to detect the difference between two groups (if it existed). Therefore, having as high a reliability as possible was essential because an instrument with a low reliability would inhibit finding a significant difference even when it exists (Black, 1999). Having a highly reliable instrument is also necessary to lend confidence to a no-significance outcome. If the instrument is highly reliable, an outcome, which is not statistically significant, is likely to be non-significant indeed rather than the consequence of the inability of the instrument to detect the difference. In brief, high reliability is essential to remove the threat to internal validity pose by low instrument reliability (Black, 1999).

Thus improving the reliability of Section I was necessary if scores on Section I were to be used in making inferences. To prescribe remedial steps for enhancing the instrument reliability, efforts to identify reasons for the poor reliability were made.
According to Black (1999), low reliability could be due to:

- a low number of items
- a small range of ability amongst the subjects that results in low standard deviation
- a large number of items with high difficulty index and/or individual items/questions with low discrimination index or low item total correlation, indicating a possible intrinsic weakness in the items

The low reliability of Section I could not be solely explained by the low number of items because Section II, which had an equally low number of items, had a much higher reliability. The higher reliability of Section II was, however, expected because the subjects were familiar with the Section II items which were Engineering drawing items. As a consequence, the solving strategy used by subjects for items in Section II may also be more homogeneous than the solving strategy used for the Section I items. Item analysis on the items was carried out to determine possible causes of the low reliability.

3.2.1.3 Items Analysis on the Baseline version SVATI

Item analysis is an analytical tool used to identify suspect items but not to explain why they are so (Black, 1999) and further analysis is required to identify the possible underlying causes for the poor items.

Table 6.4 and Table 6.5 display the results of the item analysis on the Cube construction items and the Engineering drawing items respectively. These tables provide information on the trend of responses given by the test-takers and the statistical properties of the individual items. Column 1 shows the item number and the correct response corresponding to it. Column 2 shows the number of correct responses by the high achievers (first row) and the low achievers (second row) for each item. This column gives the first indication of any 'defect' that an item may have. For example, an item which is found to be equally or more attractive to the low achievers would be considered as 'suspect items' and warrant further investigation.
Data from this column would later be used to compute the discrimination index (Disc. D) and the difficulty index (Diff. P) shown in column 9 and column 10 respectively.

Columns 3 to 6 show the number of responses to the given alternatives (correct response and distracters). These columns enable an instrument designer to identify inefficient or defective distracters. A distracter is considered to be inefficient if it is not chosen by any low achiever. A distracter is also considered inefficient if the high achievers respond more frequently to it than the low achievers.

Column 8 serves as a 'check' while columns 9 to 11 gives the statistical properties of each item: its Disc. D; its Diff. P and its item total correlation, ITC. Disc. D indicates the tendency of an item to discriminate between the high and the low achievers (Black, 1999). Diff P indicates the difficulty level of an item, i.e., an indication of how many are getting it right. An ITC on the other hand indicates how consistent an item is with the instrument as a whole. These properties are inter-related but for the SVATI, the ITC would be the most appropriate indication of an item's quality since internal consistency is the ultimate aim of the instrument.

Table 6.4. Results of the item analysis on the Cube construction items

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>Omit</th>
<th>Total</th>
<th>Disc. D</th>
<th>Diff. P</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-D</td>
<td>9</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>10</td>
<td>0.40</td>
<td>0.70</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-B</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.10</td>
<td>0.85</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-D</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0.40</td>
<td>0.80</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-A</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.60</td>
<td>0.70</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-C</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.30</td>
<td>0.65</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.4 and 6.5 show that items in Section II have consistently higher ITC compared to items in Section I indicating that they are consistently measuring the
same thing (strategy/skills/knowledge, etc.). The ITC values range from 0.42 to 0.82 for Section II and 0.19 to 0.75 for Section I. In fact, one item in section I has extremely low ITC of 0.19. On close examination of the item, it was found that only two processes were necessary to confirm the correct answer: (i) a 90° rotation in-the-picture plane process and (ii) a comparison process. According to the previously defined criteria (Chapter 2), this item would be considered an easy item because of the simple process (rotation in-the-picture plane) and the low number of processes required for its problem solution.

Table 6.5. Results of the item analysis on the Engineering drawing items

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>SA</th>
<th>EB</th>
<th>SC</th>
<th>SD</th>
<th>Onit</th>
<th>Total</th>
<th>SDisc</th>
<th>Diff</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-C</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.40</td>
<td>0.80</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-D</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>10</td>
<td>0.50</td>
<td>0.45</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-B</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.10</td>
<td>0.95</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9-D</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>1</td>
<td>10</td>
<td>0.70</td>
<td>0.55</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-C</td>
<td>9</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.70</td>
<td>0.55</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11-B</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0.50</td>
<td>0.75</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The higher consistency of the Section II items were expected, as these items were Engineering drawing items. Being one of the taught modules in the engineering programme, subjects' solving strategies were more likely to be similar to one another, more likely to be similar to the postulated solving strategy and less likely to involve guessing.

In summary, compared to items in Section I, items in Section II were found to be:
- more difficult and covering a larger range of difficulty level
- having higher ITC values
Therefore, to improve the reliability of the instruments:

- the measurement error had to be reduced (e.g., reduce guessing)
- the range of skills covered needed to be increased (items should cover from the easiest to the most difficult)
- the ITC values had to be increased (items should be consistently measuring what the overall instrument is measuring) for Item 2, Item 3 and Item 8
- the number of items needed to be increased

3.2.1.4 Validity of the Baseline version SVATI

The validity of the measuring instrument has a direct bearing on the score of the test. If a test is not measuring what it is supposed to measure (not valid) the test score would not be a legitimate indicator of the subject in the said ability.

Establishing the validity of an instrument therefore is essential in any study. This is true whether an instrument is specifically developed for the study or derived from other sources. The validity of an instrument has to be established in advance before the instrument is put to use.

The forms of validity relevant to this instrument were construct validity, empirical validity and concurrent validity.

3.2.1.5 Construct Validity of the Baseline version SVATI

Construct validity concerns the consistency between the definition of a construct and what an instrument is measuring. For the baseline SVATI, construct validity was established by ensuring agreements between the essential characteristics in the strategy used by subjects and a strategy postulated by the test designer. In other words, the tasks in the SVATI were designed to demand the strategy defined by the constructs. Table 6.6 shows the SV ability constructs and their operational definitions.

Evidence collected for establishing the instrument validity was derived from interviews. However, subjects were only required to report on their strategy for the Cube construction items as these items were novel to the students and therefore non-
homogeneity of strategy (a combination of formal and informal strategy) was more likely.

Table 6.6. Table of SV ability component skills and operational definitions.

<table>
<thead>
<tr>
<th>SV ability</th>
<th>Constructs</th>
<th>Operational definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>The ability to perform complex multi-step processing of spatial information where the ability to mentally transform (manipulate, rotate, twist, or invert) pictorially presented visual stimuli is an important criterion.</td>
<td>• The ability to execute multi-step processing of spatial information</td>
<td>• given a perspective of an object, identify the isometric under rotated condition.</td>
</tr>
<tr>
<td></td>
<td>• The ability to execute mental transformations of rotation, decomposition and synthesis</td>
<td>• given an isometric, identify the orthographic drawings.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• given the orthographic drawings, identify the isometric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• given a flat pattern of six square faces, choose a cube - from an array of cubes - that may be constructed from it</td>
</tr>
</tbody>
</table>

A formal strategy was the one suggested to the subjects as illustrated in Appendix 3 and an informal strategy was the one developed by the students themselves. Subjects were expected to adopt the formal strategy for solving the items in Section II because engineering drawing was one of the taught modules in their Engineering programme.

The result of the interview on Section I revealed that besides the postulated folding strategy, subjects also had an alternative strategy. The alternative strategy utilised was *mental rotation in-the-picture plane*. The strategy can be described as follows:

i. Choose a cube

ii. Choose two surfaces on the stem and match their orientations to the corresponding surfaces on the chosen cube. Match the orientation of the stem object to the cube (or vice versa) by rotating the object as we are rotating a real object in the physical world.

iii. Identify a third surface on the stem object that corresponds to the third surface on the cube.
iv. Mentally detach the third surface on the stem object, rotate it in the picture plane and reattach it to one of the two previously chosen surfaces in step (ii) to form an imaginary stem object.

v. Compare the imaginary stem object to the chosen cube.

vi. If the 'imaginary stem pattern' corresponds to the chosen cube, the chosen cube is the correct alternative. If not, the subject goes to the next cube and repeats process until a solution is confirmed.

The spatial tasks were therefore reduced to problems of visualisation in two dimensions, which is easier than a 3-D visualisation problem (Lohman et al., 1987). It was interesting therefore to find that the low ability subjects interviewed claimed to have favoured the in-the-picture plane rotation strategy. However, more data is required before any claim could be made on the relationship between ability and strategy because there were only two subjects of low SV ability and two of high SV ability who were interviewed.

Subjects interviewed also reported that they found that items were more difficult as the distances between the surfaces to be attached increased. This was taken as an indication of an increase in the number of rotations or an increase in the number of foldings required, which supported the postulated solution strategy. Subjects also reported to attach two surfaces that were lying on the same axis were easier than to do so for two surfaces that were lying on separate axes (Figure 6.6).

It could be that, mis-aligned surfaces induced more additional information than needs to be maintained in memory. However, this is only a speculation on the part of the researcher although the need for maintaining a stable representation in memory is one of the requirements of spatial ability (Lohman et al., 1987).
Easy
Surfaces lying on the same axis (aligned)

Difficult
Two surfaces lying on separate axis (mis-aligned)

Figure 6.6. An easy item with aligned surfaces and a relatively difficult item with mis-aligned surfaces.

Although mental rotation in the picture plane was used instead of the folding-unfolding strategy, the tasks did require multi-step processing and the execution of mental rotation, which correspond to the constructs of SV ability. In summary, the Cube construction items had construct validity because mental rotation and multi-step processing is involved in the solution strategy.

3.2.1.6 Empirical validity of the Baseline version SVATI

The Cube construction items were expected to be correlated to the Engineering drawing items and empirical validity is said to be established if a positive correlation is found between the two tasks. Using Pearson correlation, a positive correlation of moderate dimensions \( r = +0.48 \) was found between the scores on the two tasks. This correlation is statistically significant at the 5% level \( (r_{crit} = 0.44, df = 18 \text{ and } n = 20) \) indicating that the correlation is unlikely to be a consequence of a chance event. The coefficient of determination \( (r^2 \times 100) \) was estimated as 0.23 indicating that 23% of factors accounting for variability are common to both tasks. The relationship between the scores on the two tasks is illustrated in a scatter diagram in Figure 6.7.

3.2.1.7 Concurrent validity of the Baseline version SVATI

Concurrent validity relates to the strength of correlation between an instrument and another valid instrument used for measuring the same construct. No concurrent validity was established for the baseline SVATI. However a concurrent validity was established for the working version SVATI using the Vandenberg Mental Rotation
Task (1971), to be reported in Chapter 7, on the implementation and evaluation of the SVATI instrument.

In summary, it was concluded that the Cube construction items and the engineering drawing items meet the criteria of the SV tasks, however, the baseline SVATI needs to be improved to reduce threat to internal validity.

![Scatter diagram illustrating the relationship between the scores on the Cube construction items and the Engineering drawing items (r = 0.48, p < 0.05, r² = 0.23).](image)

**Figure 6.7.** Scatter diagram illustrating the relationship between the scores on the Cube construction items and the Engineering drawing items ($r = 0.48$, $p < 0.05$, $r^2 = 0.23$).

### 3.3 Measures taken to improve instruments’ reliability and validity

The following measures were undertaken to improve the quality of the instrument.

- introduce more complex items for Section I and II, i.e., design more items that demand larger number of mental processes, for example, by increasing the distances between surfaces to be “connected/attached”, etc.
• introduce items that demand whole object rotation to increase the loading on 3-D mental rotation strategy in the instrument, to be placed in Section III

3.4 Development and evaluation of the Prototype version SVATI

Based on the above recommendations the prototype version SVATI was developed with the following specifications:

• ten items on cube construction for Section I, 15 items on engineering drawing for Section II and 10 items on mental rotation of pictorially presented objects (to be described in the next section) for Section III, making a total of 35 items

• 20 minutes duration was allocated for the test. This duration was decided on since it permitted test administration during the normal classroom session - which was 45 minutes per session - while providing some allowances for any unforeseen circumstances. The time allocated was also deemed adequate for the study subjects, considering that the trial subjects took less than 10 minutes to complete the baseline SVATI that consisted of 12 items

• SV ability would be taken as the total score on the SVATI

The mental rotation items, being newly introduced spatial tasks, will be described in the next section.

3.4.1 Mental rotation items

The mental rotation items were pictorial representations of 3-D objects. The skill demanded of the test-taker was the ability to see the object from a different perspective.

According to Shepard and Cooper (1982), the strategy used to solve mental rotation items depends on the stimuli. They argue that, only well learned, familiar objects encourage holistic, integrated internal representation and therefore holistic mental rotation, i.e., the whole object is rotated in the same way as were a real object in the physical world. Less familiar objects or incompletely integrated visual objects (where the look of the overall object cannot be easily imagined) on the other hand, may
encourage a more schematic representation (object broken down into meaningful parts that relate to each other rather than perceived as holistic) and piece by piece processing. Shepard and Cooper (1982) also suggest that some ‘mental rotation tasks’ are not solved holistically but solved by a discrimination strategy which may be due to some superficial cues peculiar to those stimuli (and therefore do not make use of mental rotation). The above arguments of Shepard and Cooper (1982) were noted, and steps were taken to design items that would be solved holistically. Figure 6.8 shows a typical mental rotation item.

![Figure 6.8. An example of a Mental rotation item](image)

The strategy postulated for the mental rotation items was:

i. focus on the stem object
ii. choose an alternative (could start with the first alternative)
iii. mentally rotate the stem or the alternative and match the stem object to the cube
iv. if the two objects match, respond as correct, if not repeat the above steps for the next alternative

### 3.5 Evaluation of the Prototype version SVATI

Aware of the importance of evaluations and second opinions, the researcher sought the help of three colleagues who were deemed to have a high SV ability (based on their professions): a web-page designer, an architecture lecturer and a science lecturer
to double-check the researcher’s efforts. The objectives for the instrument evaluation were:

- to determine the quality of the presentation / layout of the test paper
- to identify and overcome any previously overlooked errors
- to confirm the solution strategy was still spatial strategy, which is indicated by subjects’ reports of transformations such as rotation, folding, etc.
- to identify alternative strategies if any
- to ensure that there were no glaring mistakes in the distracters which might alert the test-takers to the possible answers by a process of elimination
- to ensure that there was a correct answer and that there was only one correct answer for each item

3.5.1 Outcomes of the evaluation

The evaluation yielded the following outcomes:

i. All items taken from the trial instrument were acceptable (five from Section I, and four from Section II). Two items from Section II that were originally Items 6 and 7 in the trial instrument were dropped because their format was different to the rest of the Engineering drawing items.

ii. Two Cube construction items were found to have faulty distracters: the distracters of one item were too glaringly incorrect, and another item was found to have two correct answers. Faulty distracters need to be eliminated because it may reduce the reliability and validity of the instrument.

iii. Six Engineering drawing items were problematic ranging from faulty (obviously “wrong”) distracters to non-availability of correct answers.

i. Six mental rotation items had faulty items whereby the distracters were impossible objects, which if left uncorrected, would threatened the validity of
the test. This is because subjects could get the correct response through a process of structural comparisons followed by elimination rather than a process of mental rotation.

After several revisions and further modifications the working version SVATI as used in the polytechnic - was accomplished. The working version SVATI had 10 items in Section I, 11 items in Section II and eight items in Section III. The list of changes undergone by the SVATI from the baseline version to the working version is summarised in Table 6.7.

3.6 Production of the Working version SVATI.

The instrument was designed and drafted using Microsoft Office and Turbo CAD 3.0. An original version of the instrument was printed on A4 paper using an ink-jet printer and 100 copies were produced from the original. The test was printed using the facilities at the department of Technical Education in Malaysia. One week was taken for the instrument production, which included requesting permissions from the respective authorities, negotiating a suitable timetable for the loans of equipment, purchasing materials, etc.

Table 6.7. Summary of the development stages of the SVATI

<table>
<thead>
<tr>
<th>Section</th>
<th>SVATI (baseline version)</th>
<th>Changes</th>
<th>SVATI prototype</th>
<th>Changes</th>
<th>SVATI (Working version)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>5 items</td>
<td>Dropped = 0 items</td>
<td>Available = 10 items</td>
<td>Modify = 3 items</td>
<td>N = 10 items</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remained = 5 items</td>
<td>Faulty = 3 items</td>
<td>Remained = 10 items</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added = 5 items</td>
<td>New total = 10 items</td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>7 items</td>
<td>Dropped = 3 items</td>
<td>Available = 15 items</td>
<td>Dropped = 4 items</td>
<td>N = 11 items</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remained = 4 items</td>
<td>Faulty = 7 items</td>
<td>Modify = 3 items</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added = 11 items</td>
<td>New total = 15 items</td>
<td>Remained 11 items</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>0 items</td>
<td>Added = 10 items</td>
<td>Available = 10 items</td>
<td>Dropped 2 items</td>
<td>N = 8 items</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Faulty = 6</td>
<td>Faulty = 6</td>
<td>Modify = 4 items</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Remained = 8 items</td>
<td></td>
</tr>
</tbody>
</table>
3.7 Practical problems encountered in the process of the instrument design.

The initial objective of the SVATI design was to develop a three-section instrument with an equal number of items in each section. However, this objective had to be replaced with a more achievable one due to difficulties encountered along the way. The difficulties encountered were mainly associated with time constraints and software constraints. These constraints led to the reduction in the number of items from 35 in the prototype version to 29 in the working version SVATI.

The six items from the prototype SVATI had to be discarded due to major defects. Amending the defects or redesigning new items were not feasible due to a combination of time and the software, which was not fully functioning at the 3-D level which was unfortunately not realised until too late. The difficulty with the software was especially trying when used to design the mental rotation items. This was also the main reason why there were fewer Mental rotation items compared to the others. To put this into perspective, the time between the pilot study and the actual study was only one month apart. The pilot study took up one week which left the researcher with three weeks for the following activities:

- designing the additional items (stems and alternatives)
- drafting these items using the problematic software
- evaluating the newly designed items and making the necessary modifications
- translating the SVATI into Malay
- negotiating access to printing facilities, etc.

With tremendous efforts, the final version was successfully completed one day before the commencing date of the actual study.

Thus, the original target of developing a three section instrument with equal number of items in each section had to be abandoned and replace by a more feasible and achievable target of a three-section instrument with as many items in each section as possible.
4. CONCLUSION

This chapter has described the development process of the SVATI, the research instrument for mini-study 1. The SVATI started as a 12-item instrument (the baseline version), which consisted of two types of spatial tasks: Cube construction tasks and Engineering drawing tasks. The baseline version underwent several evaluation-and-refinement iterations that included a trial on a group of civil engineering subjects from the University of Surrey, to develop into the prototype version SVATI. The prototype consisted of 35 items on Cube construction, Engineering drawing, and Mental rotation items. All items were - choose one out of four alternatives - multiple-choice items. The multiple choice items format permitted the assessment of relatively complex spatial skills within the specified test duration. Similar items were grouped within one section to encourage a more homogeneous solving strategy, which should enhance the score reliability.

The working version SVATI was accomplished upon evaluation and refinement of the prototype SVATI. The working version was thus a 29-item instrument of similar format to the prototype. The achieved quality of the SVATI in the actual study will be discussed in Chapter 9.

The next chapter, Chapter 7, will describe the development process of the second research instrument, the Attitude Questionnaire which is the instrument for mini-study 2.
CHAPTER 7

Instrument Development for Mini-study 2: The Attitude Questionnaire

1. INTRODUCTION

This chapter describes the development process of the research instrument for mini-study 2 - the Attitude Questionnaire (Appendix 4). The Attitude Questionnaire is a three-section, 32-item instrument that is scored on a five point Likert Scale. The aim of the Questionnaire was to determine the strength of the attitude towards sketching and drawing (S&D) of the civil engineering subjects in the study.

2. DEVELOPMENT PROCESS OF THE ATTITUDE QUESTIONNAIRE

The development process of this Questionnaire involves:

- Determining the contents of the Attitude Questionnaire
- Deciding on the format of the Questionnaire
- Writing the attitude statements
- Evaluating the Attitude Questionnaire

2.1 Determining the content of the attitude questionnaire

Attitude is a social construct, which is not observable but can only be inferred from other human responses. The content of the Attitude Questionnaire was based on the tri-componential viewpoints. According to one of the proponents of this viewpoint Oppenheim (1966), an attitude is “...a state of readiness, a tendency to act or react in a certain manner when confronted with a certain stimuli. Thus the individual’s attitudes are present but dormant most of the time; and only become expressed...when the objects of the attitude is perceived.” (Oppenheim, 1966, p. 105-106).
The tri-componential viewpoint holds that attitude is a single entity and the three components thoughts, feelings and behaviour are what constitute an attitude (Oppenheim, 1992).

The cognitive component consists of ideas and beliefs of the attitude holder about the attitude object. For example:

'Sketching and drawing is for draftsman.'

The affective component consists of feelings and emotions of an attitude holder towards the attitude object. For example:

'I like drawing'

The behavioural component consists of an attitude holder's action tendencies towards the attitude object. For example:

'I use sketching and drawing to communicate'

According to this viewpoint, attitudes are reinforced by beliefs (cognitive component), often attract strong feelings (emotional component) which will lead to a particular form of behaviour (the action tendency component) (Oppenheim, 1992). Figure 7.1 illustrates the viewpoints of the tri-componential proponents. In this Figure, the three aspects are shown to be essential to the concept of attitude.

Figure 7.1. The tri-componential viewpoint on attitude (Oskamp, 1991).
Therefore, according to this viewpoint, in order for an attitude measure to be valid, it has to include all the three attitude aspects (Oppenheim, 1992 and Sudman and Bradburn, 1982).

However, there are those who question the validity of the tri-componential viewpoint. They argued that, although this viewpoint appears to be conceptually clear, there is lack of empirical evidence to support it (Oskamp, 1991). According to Oskamp (1991), the moderately strong relationships, i.e., $r \approx +0.5$ between the three components that were found in most studies do not appear to support the tri-componential viewpoint. Oskamp (1991) also questioned the usefulness of this viewpoint. Therefore, although the tri-componential viewpoint underlies the questionnaire design, the competing argument, which is the separate entities viewpoint, was also kept in view and will be briefly explained.

The separate entities viewpoint holds that the three components (which are proposed by the proponent of the tri-componential viewpoints) are separate entities which may or may not be related, depending on the particular situation (Oskamp, 1991). Figure 7.2 illustrates the relationships between these components. It shows the three aspects as being separate entities, which may be related depending on the situation. Ajzen and Fishbein (1980) who support this viewpoint, suggest that the term attitude should be solely reserved for the affective dimension that indicates individual’s negative or positive evaluation towards an attitude object and defined attitude as "...a person's evaluation of any psychological object..." (Ajzen and Fishbein, 1980, p. 26-27)

Figure 7.2 The separate entities viewpoints (Oskamp, 1991).
The separate entities viewpoint had some implications on how the instrument was to be treated in the study (Chapter 10).

2.2 Deciding on the format of the questionnaire

The Questionnaire was designed as two equivalent halves to enhance its reliability. This means that for every attitude statement, there is a second statement, which had been worded differently, but nevertheless carrying the same message. The attitude statements with their matching seconds are given in Appendix 5.

2.3 Response format

The Likert Technique was chosen as a measurement method because it is relatively easier to construct and has been shown to have a statistically high degree of validity and reliability (Thomas, 1978). A set of attitude statements was presented to which the subjects expressed their agreement or disagreement on a five-point scale. Each agreement or disagreement was given a numerical value from one to five. Therefore, a total numerical value can be calculated from the responses concerned.

The subjects' ratings were not however, always scored corresponding to the number on the rating scale. For example, a response in box 1 for Item 1 is given a five point score while a response in the corresponding box for Item 14 is given a one point score. This is because in Item 1, a response to box 1 indicates favourable disposition towards S&D while an identical response in Item 14 indicates the reverse (recall Appendix 4). This method of scoring has been adopted to reduce occurrences of respondents automatically responding without reading the attitude statements.

2.4 Length of the questionnaire

The Questionnaire was designed to have 32 items in total. A combination of the time available for implementation, the required data and the cost and efforts in questionnaire preparation and production determined the questionnaire length.
2.5 Questionnaire presentation and layout

The Questionnaire presentation and layout was chosen so that it was easy for the subjects to follow which would invite completion and reduce errors.

2.6 Writing the attitude statements

According to the tri-componential viewpoint, in the measurement of attitude, the emphasis is not only on measuring the right attitude but also on the inclusion of all the components. For the present attitude measure, the three indicators (components) that were identified to be relevant to the attitude towards S&D are:

- View of the professional role of S&D which corresponds to the cognitive aspect of attitude
- Value of the personal usage of S&D which corresponds to the affective aspect of attitude
- Tendency to use S&D which corresponds to the behavioural tendency aspect of attitude

The three indicators were chosen because it was hypothesised that having a positive view of the professional role of S&D is related to personal value in S&D and action tendency towards S&D. For example, if the subjects view S&D as being important to their future career, it might encourage them to develop their skills in S&D (increased tendency to use S&D) and in the process might discover that S&D may have some personal value.

Ideally, there should have been equal numbers of statements for each construct but statements for one construct (the Tendency to use S&D) were found very challenging to write. Finally, 12 statements were written for each of the first two constructs and only eight statements were written for the last constructs.

2.7 Evaluation of the attitude instrument

A trial study on an equivalent sample, which is essential in achieving a reliable instrument, was not carried out because the instrument was not developed in sufficient time to enable it to be administered to an equivalent trial group in
Malaysia. However, the instrument had been tried on a group of former polytechnic engineering students. Based on the results of this trial and the evaluation by three polytechnic lecturers (Jafni, 1998; Md Salleh, 1998 and Wan Izni, 1998), the attitude statements were revised several times before being accepted in the instrument. A pilot study could not be carried out in the U.K. due to language obstacles and cultural differences.

3. CONCLUSION

This chapter has described the development process of the Attitude Questionnaire, which measures the attitude towards sketching and drawing. The tri-componential viewpoint provided the basis for the questionnaire content. The Likert Technique was the method used to measure the attitude concerned where the subjects were requested to rate a set of attitude statements on a five-point scale. The overall content coverage was discussed with colleagues from Ungku Omar polytechnic to ensure content validity. Evidence for the reliability and validity of this instrument based on data from the actual study will be discussed in Chapter 10.

The development process of the remaining research instruments - the Structural Design Instrument (SDI) for Mini-study 3 and the Structural Theory Examination paper (ST Paper) for Mini-study 4 - are going to be described next in Chapter 8.
CHAPTER 8


1. INTRODUCTION

Chapters 6 and 7 described the development process of the SVATI (the research instrument for mini-study 1) and the Attitude Questionnaire (the instrument for mini-study 2) respectively. This chapter will describe the development process of the remaining research instruments; the Structural Design Instrument (SDI), the research instrument for mini-study 3 (Appendix 6) and the Structural Theory Examination Papers (ST Paper), the research instruments for mini-study 4 (Appendix 8 and Appendix 9).

2. RESEARCH INSTRUMENT FOR MINI-STUDY 3: THE SDI

The SDI is a paper-and-pencil, norm-referenced achievement test instrument designed specifically for the study. Its purpose was to measure structural design problem solving skills that demand SV ability among civil engineering students in Malaysian polytechnics. To cover the range of intellectual skills demanded by problem solving, items in the SDI were designed to cover four of the cognitive categories from the Bloom's Taxonomy of Cognitive domain (Bloom, 1956): knowledge, application, analysis and evaluation category. Examples of SDI items that represent each of these categories are given in Table 8.1.

Table 8.1. Bloom's cognitive categories and the SDI items that represent them.

<table>
<thead>
<tr>
<th>Levels and category according to Bloom (1956)</th>
<th>SDI item (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 &amp; 2 – Knowledge and comprehension</td>
<td>1</td>
</tr>
<tr>
<td>Level 3 – Application</td>
<td>11</td>
</tr>
<tr>
<td>Level 4 – Analysis</td>
<td>14</td>
</tr>
<tr>
<td>Level 6 – Evaluation</td>
<td>18</td>
</tr>
</tbody>
</table>
The SDI consisted of 18 questions in the Malay language. However, some questions were multi-parts and each part was treated as an item, which explained the number of items being 24.

2.1 Classification of items

Classification of an item to a category is based on the solution steps and strategy required for solving it. For example, Item 1 is categorised as a level 1 item because it can be solved easily by recalling previously learned information and attaching meaning to it. In contrast, Item 16 is classified as an analysis problem because the solving strategy would require breaking the problem into parts and solving each part individually for the overall solution to be obtained. Table 8.2 shows the solution steps for Item 16.

Table 8.2. Steps executed to solve Item 16 (Appendix 6) with the related abilities.

<table>
<thead>
<tr>
<th>Steps to be executed</th>
<th>Skills associated with the steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Identify beam BE from drawing</td>
<td>- Visualise 'load flow' from structural member to support.</td>
</tr>
<tr>
<td>- Identify members supported by beam</td>
<td>- Read and translate drawing plan</td>
</tr>
<tr>
<td>- Classify slab into one way</td>
<td>- Execute an algorithm for classification of slab</td>
</tr>
<tr>
<td>- Classify slab into one way</td>
<td>- Divide integers</td>
</tr>
<tr>
<td>- Classify slab into one way</td>
<td>- Choose an appropriate classification based on the comparison between a calculated value and a given value.</td>
</tr>
<tr>
<td>- Visualise loads on slab to be supported by supports (beam BE)</td>
<td>- Identify load path</td>
</tr>
<tr>
<td>- Calculate dead load due to slab</td>
<td>- Execute qualitative reasoning</td>
</tr>
<tr>
<td>- Calculate imposed load on slab to be supported by beam</td>
<td>- Can calculate area</td>
</tr>
<tr>
<td>- Convert total load/beam to load/m run on the beam (uniformly distributed load on beam/m run)</td>
<td>- Calculate load in kN given load /m² and the area over which the load is distributed.</td>
</tr>
<tr>
<td></td>
<td>- Calculate load in kN given density in kN/m³ and volume in m³</td>
</tr>
<tr>
<td></td>
<td>- Can calculate volume</td>
</tr>
<tr>
<td></td>
<td>- Can calculate mass</td>
</tr>
<tr>
<td></td>
<td>- Can compute the relationship between a physical property and the units representing it e.g. Unit for volume is m³ which means (length)³.</td>
</tr>
</tbody>
</table>
Therefore, the subjects must be able to identify the parts making the problem, identify the solution steps and their algorithm before a solution could be obtained.

Although quite complicated, Item 16 cannot however, be classified as an evaluation item because judging against specified criteria is not part of the solution process.

2.2 Choice of language

The Malay language was used in the SDI instrument because the research subjects who were Malaysian were more proficient in Malay and the use of English in the SDI could confound the results. However, English was used at the initial stage of the instrument development because it was:

- the language of the experts consulted by the researcher
- the language of most reference books that were available to the researcher

The initial use of English was also essential to facilitate a planned trial, which was to involve a group of civil engineering students from the University of Surrey. This planned trial did not, however, take place due to time constraints.

2.3 Development of the SDI

Designing the items for the SDI was not an easy task mainly because there was no information available on the subject's structural design test-performance in a classroom setting. Assessments of students were usually based on project work (take home exercises) and did not include test or examinations. Students' work was therefore, most likely to be the product of teamwork rather than an individual's effort. As such, these projects/take-home assignments rarely reflect (if any) individual's competence. Consequently, there was no information on what the students could individually achieve within a specified period in a classroom setting. This led to the design of a lengthy and highly inappropriate trial instrument (Appendix 7) that was piloted in Malaysia.

2.3.1 The trial SDI

The trial SDI consisted of eight problems on reinforced concrete (the most extensively covered topics in the subjects' curriculum), which were at the analysis and evaluation
level of the cognitive domain. The items were similar to those problems that were sometimes given to the subjects during their tutorial class. The trial SDI was in English and was to be answered within 45 minutes. All the necessary information was provided on the test paper itself and the trial subjects did not have to search for information or data from other sources.

2.3.2 Evaluation of the trial instrument

The trial SDI was administered to a group of six former polytechnic students who were following a diploma programme in a Malaysian University. The instrument was administered individually to the subjects by a colleague (Jaafar, 1998) who was herself a structural design lecturer in UOP.

The findings from this trial indicated that the instrument was extremely difficult for the subjects. According to Jaafar (1998), a few subjects were observed to be making some attempts but after failing to actually begin, they subsequently gave up. Others appeared to be giving up without even trying. When these subjects were asked to comment, their responses were unanimous, 'the questions were too difficult'.

The fact that they could not solve the problems successfully was not as worrying as the fact that they did not even attempt the questions. Clearly, the researcher had grossly overestimated the capability and the motivation of the subjects.

Jaafar, (1998) suggested that the subjects might have judged the items to be beyond their capability (therefore, not worth trying) based on the complexity of the drawings, the wordiness of the problems and the lengthy responses that were expected from them. Therefore, in order to progress with the instrument, the major difficulty identified was how to encourage the subjects to respond to the items. Jaafar (1998) proposed reducing the appearance of complexity would be one way of encouraging responses, which could be achieved by:

• reducing wordiness and the number of complex drawings
• using easy response format such as, tick the right answer or circle the right answer
employing multiple choice items instead of essay type of items to assess analysis and the higher order intellectual skills

2.4 Redesigning the trial instrument into the working version SDI
Following the extremely unfavourable outcomes of the trial study, only two of the original items were retained, and redesigned before being included in the SDI. New items at varying cognitive emphasis were designed and a more systematic approach to instrument design was adopted that included specific measures for ensuring instrument validity and reliability after Black (1999).

2.4.1 Ensuring instrument reliability
Instrument reliability is concerned with its consistency and stability in its measurements. Large measurement errors would greatly reduce instrument reliability. In designing the SDI measures were taken to control the following sources of errors:

• translation error

• ambiguity in the test items

• inconsistency in Test administration

2.4.1.1 Avoiding translation error
Translation error could be a source of measurement error for the SDI as the SDI was translated from English into Malay. To reduce incidences of inappropriate translations, an experienced structural design lecturer who was proficient in both English and Malay (Jaafar, 1998) was asked to evaluate the working version SDI. Her feedback was noted and the necessary changes were made to the SDI.

2.4.1.2 Resolving ambiguity in the SDI items
The researcher realised that even with extremely careful translation efforts, ambiguities in the Malay version could still arise. The researcher therefore, decided that any ambiguity in the working version SDI was to be resolved by referring to the English version SDI. Thus, before the English version SDI was printed in its final
form, a final effort at eliminating all ambiguities and errors from the items was carried out by the researcher with the help of a measurement expert (Black, 1998).

2.4.1.3 Ensuring consistency in Test administration.
The SDI was administered to two groups of subjects at a six-month interval. Consistency in the administration procedure was extremely important because any inconsistency between the two administration procedures might affect the internal validity of the study. Therefore, the researcher personally briefed the test administrator on the planned administration procedure.

Failures by students to follow the proper test instruction could also lead to an unreliable set of test scores for a particular test administration. For example, the items in the instrument were distributed over two sections according to difficulty levels. It was essential therefore, for subjects to attempt and give their response to both sections for the score to be a valid indicator of their ability. To ensure that the subjects had the opportunity to attempt both sections, (maximising the chances of all items being attempted), the administrator was instructed to ask the students after the first 25 minutes (the time allocated for the first section) and to continue to the second section.

2.4.2 Ensuring instrument validity
Validity concerns the relationship between what an instrument is claimed to be measuring and what it actually measures. Thus, validity is a very essential characteristic of an instrument.

The SDI was supposed to measure problem-solving skills in a specific knowledge domain (structural design) and therefore, a non-representative content mainly posed threats to validity. In other words, if the structural design knowledge domain were not adequately represented in the instrument, the test-scores would not be a valid indicator of problem solving skills in structural design. Therefore, striving for content validity was the major concern in the instrument design.
In order to be a valid instrument, the items in the SDI instrument must be

- be representative of the subject matter content and the cognitive emphasis identified previously

- demand the SV skills identified in Chapter 3 and Chapter 4

2.4.2.1 Ensuring content validity

Ideally an achievement test instrument should be designed to measure all the content and skills relevant to the knowledge domain being assessed. Unfortunately to do so in practice, using one paper and pencil classroom test was quite impossible. Therefore, only a sample of possible content and skills, which were of immediate interest to the study was included in the test instrument.

Content validity was established by having a representative content. To achieve a representative content a table of specifications was developed. The table of specification serves two purposes, i.e., as:

- a tool in achieving validity at the instrument design stage

- an evidence of content validity at the evaluation stage

Developing a table of specifications was a systematic way of Appropriating skills and content to the SDI instrument. It entailed making decisions on the topics and the cognitive levels to be tested and the weightage for them.

The appropriate topics to be included in the instrument were determined by analysing the semester 6 and semester 5 structural design syllabus. A topic was deemed appropriate if its content could be used to design items to test problem solving skills identified through the task analysis in chapter 3 and the learning hierarchies in Chapter 4.

Analysis of the syllabus revealed that it consisted of three main topics:

- The philosophy of the limit state design method
- Reinforced concrete design
• Pre-stressed concrete design

The philosophy of the limit state design methods covers the concept of design in general such as how the design procedure was conceived, how load was defined, why a safety factor was introduced, the role played by statistics, etc.

The next two topics, reinforced concrete design and pre-stressed concrete design focus on the design procedures of structural members. Designing a structural member was one of the design activities identified in Chapter 3. Member design is a process whereby the ultimate outcome is a design of a structural member such as a column, a beam or a slab (which a building is composed of) rather than an overall solution to a building or a bridge.

The content of the syllabus therefore, dictated that only those tasks relevant to member design were to be set for the test. It might be proposed that limiting the problems to tasks related to member design is not representative of problem solving in structural design. Fortunately, this is not the case because the methodology of design (what is involved here), which is appropriate to an overall structure, is also applicable to a member design, be it at a micro level.

It was decided that only materials related to reinforced concrete member design would be covered. No items were set on pre-stressed concrete. This is because the items set on reinforced concrete alone were sufficient to test the identified spatial visualisation skills.

Thus, only the skills required in the design of reinforced concrete structural members were assessed. In addition to that, the structural design tasks prescribed were to demand the two composites of SV skills identified earlier:

• the ability to predict visual structural changes under given loading conditions

• the ability to perceive the relationship between the reference system - axis for rotations, planes of rotations and bending moments
Table 8.3 shows the first level of analysis in designing the table of specifications for the structural design instrument. Design skills identified in Chapters 3 and 4 are used to develop this table.

Table 8.3. The first level of analysis in designing a table of specifications for a cognitive test on structural design instrument covering beam slab and column.

<table>
<thead>
<tr>
<th>Content</th>
<th>Knowledge</th>
<th>Comprehension</th>
<th>Application</th>
<th>Analysis</th>
<th>Synthesis</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load assessment on beam</td>
<td></td>
<td></td>
<td></td>
<td>XX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation and design</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural behaviour</td>
<td></td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COLUMN</td>
<td></td>
<td></td>
<td></td>
<td>XXX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axis of rotation</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projection</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planes of bending</td>
<td></td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective height</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural behaviour</td>
<td></td>
<td>X</td>
<td>XXX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLAB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Evaluation and design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: An 'X' indicates one question.

Table 8.3 shows the content (three main topics in the semester six syllabus), which were identified to be relevant to the study and the number of items associated with each topic and cognitive emphasis.

2.4.3 Evaluating the SDI prior to the study

Overall evaluation of the instrument by a polytechnic lecturer was necessary because the researcher, who designed the SDI, had no current knowledge of the polytechnic students. The items were designed in the U.K by the researcher with the assistance from two subject matter experts (Howard, 1998 and Parkes, 1998), who were
teaching structural design and structural analysis to civil engineering students in the University of Surrey.

The polytechnic lecturer (Jaafar, 1998) was requested to evaluate the finished instrument on the:

- difficulty level of the items in the instrument and if they were appropriate for the polytechnic students. Ensuring items were of acceptable standards and level of difficulty was very important because an inappropriate level of item difficulty could have adverse effects on instrument reliability and validity.

- fairness of content, i.e., whether the content is a true reflection of the emphasis given in the polytechnic curriculum.

- adequacy of information, i.e., is the information given sufficient or is more information required.

- layout of the test, i.e., could it be improved to reduce examination fear and confusion in the subjects.

Finally, another aspect of the items that needed to be considered was the question of plausibility, i.e., is the question posed by the item believable to the subjects? In addition to the lecturers' evaluation, the viewpoints of a professional structural engineer were also sought to ensure that the questions posed were indeed encountered in practice. This 'plausibility factor' was important because the subjects in the study had design and construction-related experience (industrial training) prior to the study. Therefore, a question that was invalid in practice (does not happen as described in real life) would confuse them.

3. RESEARCH INSTRUMENT FOR MINI-STUDY 4: THE STRUCTURAL THEORY EXAMINATION PAPER (ST PAPER)

The research instruments for mini study 4 (ST Paper) were two structural theory examination papers (Appendix 8 and Appendix 9) from two consecutive semesters. The ST Paper measures the ability to analyse structural problems and to apply
mathematical techniques in solving structural problems. The ST Papers consisted of Section A and Section B. Section A had six items and Section B had three items. Both sections had items that were at the analysis level of the cognitive domain. However, the items in Section B were longer, more difficult and carried more marks compared to items in Section A. Test-takers were required to answer four items from Section A and two items from Section B.

The structural theory lecturers in UOP drew items for the ST Papers from the UOP item bank. Only items that complied with the item specifications were used in the ST Papers. Table 8.4 shows the specifications for each item. The specifications and the items were collaboratively designed by a group of subject matter experts, who were lecturers from the various polytechnics. The use of the specifications improved equivalence between the two ST Papers. The researcher did not, however, have any control over the design of the ST Papers.

Each polytechnic had its own item bank with identical sets of items in each of them and ST Papers in each polytechnic were set by their own lecturers. However, the same procedures that were followed in UOP were also followed in each polytechnic. Consequently, although the individually set ST Papers were not identical they were equivalent to each other. In brief, ST Papers from the different polytechnics might not be identical but they were equivalent with respect to their content and cognitive emphasis.

4. CONCLUSION

This chapter described the design and development process of the SDI - the instrument for mini-study 3 and the ST Paper - the instrument for mini-study 4. The SDI was specifically designed for the study. Its content was limited to the semester six structural design curriculum. The SDI consisted of 18 multi-part questions, which totalled into 24 items. The SDI items were designed to measure the intellectual skills of the following cognitive emphasis:

- the knowledge of spatial concepts pertaining to structural design
- the ability to apply knowledge and concepts pertaining to understanding of structural behaviour
- the ability to analyse and evaluate given reinforced concrete designs

Table 8.4. Item specifications for the items in the ST Paper. (Students answered Four questions from Section A and Two questions from Section B)

<table>
<thead>
<tr>
<th>Item</th>
<th>Marks</th>
<th>Topic and objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Section A</strong></td>
</tr>
</tbody>
</table>
| 1    | 15    | Topic: Moment distribution and indeterminate beam  
Objectives: to assess the ability to determine internal forces (bending moments and shear forces) of a loaded beam using moment distribution method where support settlement is a given condition. |
| 2    | 15    | Topic: Moment distribution and Portal frame  
to assess the ability to determine internal forces (bending moments) of a loaded frame using the method of moment distribution. |
| 3    | 15    | Topic: Internal forces of Truss structures  
to assess the ability to solve problems of nodes displacements and internal forces related to trusses. |
| 4    | 15    | Topic: Influence lines and beam problem  
to assess the ability to solve problems of influence lines for internal forces (bending moments, shear forces, support reactions etc.) |
| 5    | 15    | Topic: Influence lines and pin-jointed structures  
to assess the ability to solve problems of influence lines for internal forces that are predominantly axial in nature. |
| 6    | 15    | Topic: Buckling problem of a Compression member  
To assess the ability to solve problems related to structural buckling. |
|      |       | **Section B (the problem requires lengthier solution steps compared to section A)** |
| 1    | 20    | Topic: Displacement and applied loads in Truss structures  
to assess the ability to solve problems internal forces and node displacements. |
| 2    | 20    | Topic: Influence line problems and simple beam  
to assess the ability solve qualitatively and quantitatively the problems of influence lines. |
| 3    | 20    | Topics: Influence line problems and truss structures  
to assess the ability to qualitatively and quantitatively the problems of influence lines |
The heterogeneity of the instrument as a consequence of the different cognitive emphasis and item types might have some bearing on the instrument reliability, which will be discussed in the second evaluation chapter, Chapter 10.

In contrast to the SDI, the ST Papers were not designed for the purpose of the study. They were designed as examination papers and the researcher had no control over any part of the design. The two ST Papers were not identical but equivalent with respect to their content and cognitive emphasis for measures had been taken by the responsible committee to ensure that they were so. Subjects were required to answer four items from Section A and two items from Section B, with a consequence that not all subjects were answering identical set of six items. This had some bearing on the reliability and validity of the instrument, which will be discussed in Chapter 10 - the second evaluation chapter.

The next chapter (Chapter 9), which is the first evaluation chapter, will present the evaluation of the first research instrument, the SVATI.
1. INTRODUCTION

This is the first of two chapters on instrument evaluation. The evaluation of the Spatial Visualisation Ability Instrument (SVATI) will be dealt with in this chapter and the evaluation of the others (the Attitude Questionnaire, the SDI and the ST paper) will be dealt with in the following chapter (Chapter 10).

The SVATI was the instrument used to measure SV ability in mini-study 1. The design and development process of the SVATI was dealt with in Chapter 6. During the development process, specific measures had been taken to ensure instrument reliability and validity. Evidence for the reliability and validity of this instrument based on data from the actual study is presented in this chapter.

2. RELIABILITY OF THE SVATI

The appropriate form of reliability for the instrument is the internal consistency of reliability since the reliability is estimated based on a single sitting on the instrument. A high internal consistency estimate would indicate items that are consistently measuring the same thing, while a low estimate would indicate the reverse (Black, 1999).

2.1 Coefficients of reliability

The coefficient of reliability ($r_{xx}$) for the SVATI was calculated using the KR20 formula as the items were dichotomously scored. The reliability calculation was based on 28 items - instead of 29 items as was the total - because one item, i.e., Item 23 had to be discarded for it had no correct answer, although it had two near correct answers. For all purposes, the SVATI will be treated as a 28-item instrument from now onwards.

Reliability coefficients were calculated for the overall SVATI, as well as for the individual sections of the SVATI. Table 9.1 shows the reliability coefficients for the overall SVATI and its components. The reliability coefficients are 0.70 for the overall...
SVATI, 0.55 for Section I, 0.43 for Section II and 0.53 for Section III. Although the overall SVATI has an acceptable reliability, the individual sections of the SVATI are deemed to be of low reliability.

Table 9.1. Reliability coefficients for the SVATI estimated using KR20 formula.

<table>
<thead>
<tr>
<th></th>
<th>Number of Items (N)</th>
<th>Reliability estimates (rxx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVATI</td>
<td>28</td>
<td>0.70</td>
</tr>
<tr>
<td>SVATI part I (Cube construction items)</td>
<td>10</td>
<td>0.55</td>
</tr>
<tr>
<td>SVATI part II (Engineering drawing items)</td>
<td>11</td>
<td>0.43</td>
</tr>
<tr>
<td>SVATI part III (Mental rotation items)</td>
<td>7</td>
<td>0.53</td>
</tr>
</tbody>
</table>

2.2 Possible reasons for the low reliability of the SVATI

There are several possible reasons for the low reliability of the SVATI. Any single factor or in combinations such as, a low number of items, a high error of measurement or a less than ideal representative sample could be contributing to the low reliability. The impact of the various factors on the reliability is discussed in the following sub-sections.

2.2.1 A low number of items

In general, the number of items in each of the sections of the SVATI is low. Increasing the number of similar items is expected to improve the reliability of the SVATI. The projected reliability of an instrument associated with an increase in item number could be calculated using the Spearman-Brown prophecy formula (Black, 1999). Using the Spearman-Brown prophecy formula, the projected reliability of the instruments are found to be above 0.70 - as displayed in Table 9.2 - if the number of items were to be increased to 28.
Table 9.2. Predicted $r_{xx}$ ($r_{xx}'$) for $N = 28$, based on the Spearman-Brown Prophecy formula.

<table>
<thead>
<tr>
<th>Original N</th>
<th>Original $r_{xx}$</th>
<th>$K$ for increased $N$ to 28</th>
<th>$r_{xx}'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>0.70</td>
<td>1.00</td>
<td>0.70</td>
</tr>
<tr>
<td>10</td>
<td>0.55</td>
<td>2.80</td>
<td>0.74</td>
</tr>
<tr>
<td>11</td>
<td>0.41</td>
<td>2.55</td>
<td>0.72</td>
</tr>
<tr>
<td>7</td>
<td>0.50</td>
<td>4.00</td>
<td>0.80</td>
</tr>
</tbody>
</table>

The Spearman Brown prophecy formula is given by Equation 9.1:

$$r_{xx}' = \frac{K r_{xx}}{1 + (K - 1)r}$$  \hspace{1cm} \text{Equation 9.1}

2.2.2 

A less than ideal representative sample

An instrument that is designed based on a sample that is less than the ideal representative of the target sample would not achieve a high reliability when used on the target sample. The sample employed for the trial of the instrument was not a good representative sample of the target sample as indicated by the distinctions in a) their score reliability coefficients and b) the item total correlation (ITC) of the items administered to the two groups (the trial and the study sample).

Table 9.3 displays the reliability coefficients for the baseline version SVATI and the working version SVATI.

Table 9.3. Reliability for the working version SVATI and the baseline version SVATI

<table>
<thead>
<tr>
<th>SVATI</th>
<th>Reliability coefficients based on the actual study (n = 57)</th>
<th>Reliability coefficients based on the trial of the instrument (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section I</td>
<td>0.55 (10 items)</td>
<td>0.43 (5 items)</td>
</tr>
<tr>
<td>Section II</td>
<td>0.43 (11 items)</td>
<td>0.72 (6 items)</td>
</tr>
<tr>
<td>Section III</td>
<td>0.53 (7 items)</td>
<td>Not available</td>
</tr>
<tr>
<td>Overall</td>
<td>0.70 (28 items)</td>
<td>0.74 (11 items)</td>
</tr>
</tbody>
</table>
Table 9.3 shows that the reliability of the baseline version - which was based on the Surrey's sample - is higher than the reliability of the working version SVATI, which was based on the polytechnic samples indicating the non-representativeness of the trial sample. A clearer indication of the non-representativeness of the trial sample is seen in the lower ITC of the working SVATI, when a sub-set of nine items (common to the trial and the study) was compared as shown in Table 9.4.

In general, the ITC obtained from the trial group is higher than those obtained from the study group indicating that these items were more consistent for the trial group than the study groups.

Table 9.4. The ITC for the sub-set of nine items that were common to the baseline version and the working version SVATI.

<table>
<thead>
<tr>
<th>Item</th>
<th>ITC for the baseline SVATI</th>
<th>ITC for the working version SVATI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subjects: University of Surrey students</td>
<td>Subjects: Malaysian polytechnic students</td>
</tr>
<tr>
<td>1</td>
<td>0.40</td>
<td>0.58</td>
</tr>
<tr>
<td>2</td>
<td>0.33</td>
<td>0.09</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
<td>0.42</td>
</tr>
<tr>
<td>4</td>
<td>0.74</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>0.41</td>
<td>0.43</td>
</tr>
<tr>
<td>6</td>
<td>0.54</td>
<td>0.32</td>
</tr>
<tr>
<td>7</td>
<td>0.60</td>
<td>0.30</td>
</tr>
<tr>
<td>8</td>
<td>0.45</td>
<td>0.24</td>
</tr>
<tr>
<td>9</td>
<td>0.76</td>
<td>0.45</td>
</tr>
<tr>
<td>Reliability (r_{xx})</td>
<td>0.61</td>
<td>0.27</td>
</tr>
</tbody>
</table>

In fact, the items were so inconsistent for the study groups that their score reliability is only 0.27 in contrast to 0.61 for the trial group.

In summary, contrasts in the ITC and the reliability estimates indicate that the trial group was not a good representative of the study group. The lack of representativeness could be due to cultural and educational differences since the trial subjects were not Malaysian and had not undergone any Malaysian engineering education programme.
2.2.3 *A high error of measurements*

High error of measurements might also be contributing to the low instrument reliability. Increasing the ITC, i.e., by improving any weak items, can reduce the high error of measurements.

2.3 *Items analysis*

An item analysis was carried out to determine weak items that may be contributing to the less than satisfactory reliability of the SVATI. The item analysis yields information on the properties of the individual items. It gives some indication of a defect in an item. The results of the analysis are shown in Appendices 10, 11, 12, and 13.

Appendix 10 displays the items properties, i.e., Discrimination index (Disc. D), difficulty index (Diff. P) and ITC, when these items were grouped into a single instrument (overall SVATI). Appendices 11, 12, 13 display the items properties when the items were grouped and analysed as three separate instruments. Comparison between the tables in these appendices show that items analysed as part of the overall instrument have different statistical properties, to the corresponding items analysed as part of the individual sections. This is expected because the items in the individual section of the SVATI are more homogeneous than the items in the overall SVATI.

Items with ITC less than 0.3 are considered to be weak items because they are not consistent with the instrument as a whole. The following items are considered weak items because of their low item total correlations (see Appendices 2, 3 and 4).

Section I: Item 2
Section 2: Item 13, Item 16 and Item 19
Section 3: none

To seek possible reasons for the weak items, further qualitative analyses were carried out. Analysis of these items is carried out in turn in the following sub-sections.
2.3.1 Cube Construction item: Item 2

Figure 9.1 displays Item 2, which is a Cube construction item. The Figure shows that the alternatives are identically oriented and the three faces on the cube correspond to three surfaces on the stem, which are within close proximity. The low ITC could therefore, be a consequence of an item that is too easy. Having identically oriented alternatives may have reduced the solution steps that are necessary for solving the item, which reduces the difficulty of the item. Table 9.5 which displays the distribution of responses on the item shows that 56 out of 57 subjects, i.e., almost everybody gave the correct response to the item, a clear indication of an easy item:

![Figure 9.1. Item 2 on Cube Construction](image)

The identically oriented alternatives may render the item easy because it might have induced a practice effect on the test-takers as they move from one alternative to the other, which makes it easier for them to identify the correct or incorrect responses. Furthermore, it appears that having a cube that is apparently being constructed from three flat surfaces that are within close proximity to each other eliminated the necessity for any folding action from the solution strategy. The non-functioning distracters on the other hand are merely the consequence of the two above-mentioned factors.

In brief, the item is weak because it requires very few steps in its solution strategy. It could be improved by having alternatives that are not identically oriented and having cubes that are not apparently being constructed from three surfaces that are in close proximity to each other.
Table 9.5. Distribution of responses by the high achievers (second row) and the low achievers (third row)

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>O</th>
<th>Total</th>
<th>Disc. D</th>
<th>Diff. P</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-B</td>
<td>29</td>
<td>0</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>29</td>
<td>0.06</td>
<td>0.98</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>0</td>
<td>27</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Engineering Drawing items: Item 13

Figure 9.2 shows Item 13, which is an item on engineering drawing. On the left, there is an isometric drawing of a 3-D object and on the right, there are four sets of orthographic drawings where one represents the isometric drawing on the left.

![Diagrams of engineering drawing items](image)

Stem  
Alt. A  
Alt. B  
Alt. C  
Alt. D

Figure 9.2. Item 13 on Engineering drawing.

The low ITC could be due to a combination of inefficient distracters and an easy item. Table 9.6 displays the distribution of responses on this item. It shows that two distracters are not functioning effectively, i.e., Alt. B appears to be equally attractive to the high and the low achievers and Alt. D seems to attract more of the high than the low achievers. It appears that only Alt. A is functioning effectively, i.e., only the low achievers are attracted to it.

Table 9.6. Distribution of responses to Item 13

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>O</th>
<th>Total</th>
<th>Disc. D</th>
<th>Diff. P</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-C</td>
<td>20</td>
<td>0</td>
<td>1</td>
<td>20</td>
<td>8</td>
<td>0</td>
<td>29</td>
<td>0.25</td>
<td>0.67</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>3</td>
<td>1</td>
<td>18</td>
<td>6</td>
<td>0</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Item 13 could also be considered as an easy item because of the alignment of the surfaces in the isometric drawing that are either parallel or perpendicular to each other. Such an alignment makes translation from the isometric to the orthographic drawing or vice versa relatively easy.

2.3.3 Engineering Drawing item: Item 16
Figure 9.3 shows Item 16, which is also an engineering drawing item. The low ITC may be caused by an extremely easy item as indicated by the extremely high Diff. P in Table 9.7.

![Plan View, Front View, Right View](image)

Figure 9.3. Item 16 on Engineering drawing

The item may be easy because a process of elimination / discrimination strategy instead of SV might have been used to solve this item. In this item, all the lines in the orthographic views are either perpendicular or parallel to each other, which eliminates any possibility of a sloping or non-rectangular surface in the isometric. However, sloping surfaces or triangular surfaces are present in all alternatives except one and a subject could arrive at the right answer by a process of elimination which was a consequent of poorly designed distracters. Since discrimination strategy is not an SV strategy, it explains the low ITC of the item.

Table 9.7 displays the responses of the subjects on Item 16, which confirm the poor-designed-distracter hypothesis. In this table, three alternatives appear to be ineffective, i.e., Alt. A and C are not chosen by the low achievers while Alt. D is chosen by both low and high achievers with equal frequency.
Table 9.7. Distribution of responses to Item 16

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>O</th>
<th>Total</th>
<th>Disc-D</th>
<th>Diff-P</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-B</td>
<td></td>
<td>28</td>
<td>0</td>
<td>28</td>
<td>0</td>
<td>1</td>
<td>29</td>
<td>0.06</td>
<td>0.96</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27</td>
<td>0</td>
<td>27</td>
<td>0</td>
<td>1</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Item 16 also has one 'impossible shape' (Dror, 1997) as an alternative - Alt. D - which could be easily eliminated from a potential correct answer and further reduce the difficulty of the item. Surprisingly, there are still subjects who chose alternative D, probably a consequence of a guessing strategy.

2.3.4 Engineering Drawing item: Item 19

Figure 9.4 shows Item 19, on an engineering drawing task. The low ITC for this item may be due to an easy item as indicated by the high Diff. P given in Table 9.8.

![Figure 9.4. Item 19 on Engineering Drawing](image)

Table 9.8 shows the responses of subjects on this item.

Table 9.8. Distribution of responses for Item 19

<table>
<thead>
<tr>
<th>Quest</th>
<th>Correct</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>O</th>
<th>Total</th>
<th>Disc-D</th>
<th>Diff-P</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>19-B</td>
<td></td>
<td>27</td>
<td>0</td>
<td>27</td>
<td>1</td>
<td>0</td>
<td>29</td>
<td>0.25</td>
<td>0.86</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>2</td>
<td>22</td>
<td>2</td>
<td>0</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9.8 shows that the item is discriminating positively and in general, the distracters appear to be functioning except for alternative D where none of the low achievers chose it. Alternative D could be improved by adding more invisible surfaces to it.

2.3.5 Mental Rotation Item
None of the Mental rotation items has ITC less than 0.3. The low reliability therefore, could be simply due to the low number of items.

2.3.6 Summary
The low reliability of the instruments was mainly due to a combination of low ITC and the small number of items. The low ITC could be the consequence of items that were too easy.

The task for the Cube construction item could be made more complex by avoiding identically oriented alternatives and by not employing stem surfaces that are in close proximity for the design of the alternatives.

The task for the Engineering item could be made more complex by increasing the number of surfaces, inducing the necessity for visualising hidden parts and mental reorientation of figures in space (Kramer, 1995).

The low ITC could also be due to usage of discrimination strategy by subjects. According to Dror (1997), eliminating the use of impossible shapes - shapes that cannot possibly exist physically in reality - as distracters could reduce discrimination strategy.

3. THE VALIDITY OF THE SVATI
Two forms of validity were appropriate for the SVATI, i.e., construct validity and concurrent validity. Rigorous efforts had been employed throughout the developmental stage of the instrument in order to achieve a highly valid instrument. For example, types of item used had been chosen not only because they had been successfully employed in previous studies but also because they had been shown to
demand the spatial skill identified as contributing to SV ability (recall Chapter 2). Evidence for the respective forms of validity are presented next.

3.1 Construct validity

The following factors are taken as evidences supporting some construct validity.

- The spatial tasks in the SVATI were based on spatial tasks that have been established to posses construct validity (Chapter 6, Section 3.1.2.1, 3.1.2.2 and 3.4.1)

- There was concurrence between strategies reportedly used by subjects and the strategy postulated for the tasks (Chapter 6, Section 3.2.1.5)

- There was statistically significant correlation between the different components of the SVATI as shown in Table 9.9 indicating some shared variances among the tasks.

Table 9.9. Correlation coefficients between groups of items.

<table>
<thead>
<tr>
<th></th>
<th>Engineering drawing items</th>
<th>Mental rotations items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube construction items</td>
<td>0.35* (r² = 12%)</td>
<td>0.48* (r² = 23%)</td>
</tr>
<tr>
<td>Engineering drawing</td>
<td></td>
<td>0.27* (r² = 7%)</td>
</tr>
<tr>
<td>items</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05

3.2 Concurrent validity study

Concurrent validity was established between the SVATI and the criterion instrument, the Mental Rotation Test (MRT) designed by Vandenberg (1971), which was a widely used instrument for measuring SV ability. Permission to use the MRT was provided by (Huckfeldt, 1999) from Colorado University (former workplace of Vandenberg) through e-mail communication.

The MRT is a test devised to measure mental rotation ability as an indicator of SV ability. The Shepard and Metzler (1971) figures were used in the MRT. The validity of the instrument as a measure of mental rotation has been advocated by Shepard and
Metzler (1971) and Vandenbarg and Kuse (1978) and corroborated in studies by Shiina et al. (1990). The MRT, which consisted of 20 items was designed as a split-half instrument. The items were highly homogeneous as reflected by the reliability estimate obtained in previous studies by Vandenbarg and Kuse, (1978). A copy of the instrument is given in the Appendix 14.

The concurrent validity study was carried out on a sample of eight subjects whose SVATI scores ranged from the lowest, with a score of 10 to the highest, with a score of 23. Table 9.10 shows the data for the eight subjects on the SVATI and the MRT. The internal consistency for the MRT scores in this study was found to be 0.94 (highly reliable set of scores) based on the Split-half reliability formula.

Table 9.10. The MRT scores and the corresponding SVATI scores for the eight subjects in the concurrent validity study.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>MRT score</th>
<th>SVATI score</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>S2</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>S3</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>S4</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>S5</td>
<td>34</td>
<td>21</td>
</tr>
<tr>
<td>S6</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td>S7</td>
<td>36</td>
<td>23</td>
</tr>
<tr>
<td>S8</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Mean</td>
<td>26</td>
<td>19.13</td>
</tr>
</tbody>
</table>

The correlation between the MRT and the SVATI was 0.74, which is considered a high correlation (Cohen and Holliday, 1979). The correlation coefficient indicates the extent to which the two variables are related. A positive correlation indicates a similar trend of change in the two corresponding variables, i.e., an increase in one variable would follow an increase in the other variable and a negative correlation indicates the reverse, i.e., when one variable goes up the other goes down. A high positive correlation coefficient indicates closer associations between the two variables.
The $r^2$, which in this case is 55%, indicates the percentage of the shared variances between the two instruments.

Figure 9.5 illustrates the relationship between the MRT and the SVATI scores. Keeping in mind that there are not many data points, a linear trend is indicated in the relationship between the MRT and the SVATI.

![Scatter diagram illustrating the relationship between the working version SVATI and the MRT (r = 0.74, $p < 0.05$, $r^2 = 0.55$, n = 8)](image)

**Figure 9.5.** Scatter diagram illustrating the relationship between the working version SVATI and the MRT ($r = 0.74$, $p < 0.05$, $r^2 = 0.55$, $n = 8$)

### 3.3 Summary

In summary, evidence for validity was found in:

- the high concurrent validity coefficient obtained between the SVATI instrument and the MRT, another commonly used instrument for measuring SV ability
- the similarity between the strategy used by the subjects as reported by them in the interviews (Chapter 6) at the end of the trial test and the strategies postulated for solving the items
4. RECOMMENDATIONS FOR IMPROVING THE RELIABILITY AND VALIDITY

Reasons attributed to low reliability are a low number of items and items of low ITC. The effect of the low ITC on reliability was very clear in Section II where more than 36% of the items have ITC less than 0.3 and the reliability was only 0.43. It was found that the low ITC was mainly caused by items that were too easy. Increasing the complexity of the tasks and improving the distracters in items with low ITC are recommended in order to improve their ITC which in turn would improve reliability.

Reducing the instances of and the impact of guessing is also recommended in order to improve instrument reliability. Reducing the impact of guessing would reduce measurement errors and consequently increase the reliability of the measurement.

Instances of guessing could be reduced by penalising wrong answers, such as giving a negative score for wrong answers. The consequence are, there may be many negative scores or many unanswered items. The impact of guessing on the other hand could be reduced by introducing a fifth alternative, which gives a subject additional choice. The fifth alternative will effectively reduce the chance score from 25% to 20%.

Piloting all items is also recommended in order to improve the reliability of the SVATI. The ideal practice is to have a larger number of items (as many items as possible) in the baseline SVATI, eliminate unsuitable items upon evaluation and retain only those items that have the desired properties. As explained in Chapter 6, only 11 items out of the 28 items of the SVATI had been piloted. Ensuring all items have been piloted would not only improve the instrument reliability but also reduce workload towards the end of the instrument development.

Improving the validity of the instrument is also recommended in order to improve its reliability. The validity of the instrument could be improved by ensuring a high consistency between the postulated strategy for the items and the strategy used by subjects. This could be achieved by gathering more data on the solution strategies that are used by subjects, which could be utilised in the evaluation and refinements of the items.
5. CONCLUSION

In summary, the SVATI as a whole is sufficiently reliable and valid but inferences made based on the individual sections need to be taken with caution. Several steps could be taken to improve the reliability of the instruments especially that of the individual sections. The findings suggest that there is need for a larger number of items and also the need for more complex items. There is also a suggestion on how to improve the impact of the pilot study on reliability. Finally, it is also recommended that a more extensive qualitative investigation into the strategy used by subjects is necessary to designing better future instrument.

The next chapter will be dealing with the evaluation of research instruments 2, 3, and 4, i.e., the Attitude Questionnaire, the Structural Design Instrument (SDI) and the Structural theory examination paper (ST paper).
CHAPTER 10
Instruments Evaluations: Part II

1. INTRODUCTION

The previous chapter (Chapter 9) reports on the evaluation process and outcomes of the SVATI, which is the research instrument for mini-study 1. This chapter will report in turn, on the evaluation process and outcomes for the remaining research instruments providing evidence for reliability and validity, namely:

- *The Attitude Questionnaire*: Research instrument for mini-study 2
- *The Structural Design Instrument (SDI)*: Research instrument for mini-study 3:
- *The Structural Theory examination paper (ST paper)*: Research instrument for mini-study 4:

2. ATTITUDE QUESTIONNAIRE: RESEARCH INSTRUMENT FOR MINI-STUDY 2

The Attitude Questionnaire (Appendix 4) is a three-section, 32-item instrument that is scored on a five point Likert scale. It was designed to measure a person's attitudes towards sketching and drawing (S&D). Following the tri-componential viewpoints, three constructs; the *View of the professional role of S&D*, the *Values of personal usage of S&D* and the *Tendency to use S&D* were initially hypothesised to be the components of the attitude towards S&D (recall Chapter 7). The correlations between these constructs were however, only moderately strong as shown in Table 10.1 (although statically significant) for the constructs to be treated as aspects of a single entity. The correlations need to be very strong if the constructs are to be treated as aspects of single entity (Oskamp, 1991). The result that indicates the construct as being separate entities is entirely consistent with the separate entity viewpoint (Oskamp, 1991).
Table 10.1. Pearson product moment correlations (r) between the Questionnaire components based on data from the actual study (n = 76).

<table>
<thead>
<tr>
<th></th>
<th>Value of personal usage of S&amp;D</th>
<th>Tendency to use S&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>View of the professional role of S&amp;D</td>
<td>0.29*</td>
<td>0.58*</td>
</tr>
<tr>
<td>Value of personal usage of S&amp;D</td>
<td></td>
<td>0.39*</td>
</tr>
</tbody>
</table>

\( df = 74, r_{critical} = 0.26 \)

*P < 0.05

Scatter diagrams in Figure 10.1, Figure 10.2, and Figure 10.3 illustrate visually the relationships between these constructs. These scatter diagrams are based on the combined civil engineering and the architecture scores, n = 76.

![Figure 10.1. Scatter diagram illustrating the relationship between the View of the professional role and the Value of the personal usage of S&D (r = 0.29, p < 0.05, n = 76)\]
Figure 10.2. Scatter diagram illustrating the relationship between the Value of the personal usage and the Tendency to use S&D ($r = 0.39$, $p < 0.05$, $n = 76$).

Figure 10.3. Scatter diagram illustrating the relationship between the View of the professional role and the Tendency to use S&D ($r = 0.58$, $p < 0.05$, $n = 76$).
2.1 Reliability of the instruments

Table 10.2 displays the Split-half reliability coefficients ($r_{sh}$) for the instruments, which is based on data from the actual study. The Split-half estimates were appropriate since the instruments had been designed as two equivalent halves. The reliability of the instruments are fairly acceptable although higher reliability coefficients for the Value of Personal Usage of S&D and the Tendency to Use S&D which are 0.66 and 0.68 respectively would be desirable.

The required reliability for any research instrument is not a fixed value. For example, Thomas, (1978) suggests that a reliability of at least +0.8 is needed for an attitude instrument to be a reliable measure of attitude, while Davis, (in Dyer, 1979) judged that a lower reliability of +0.70 may still acceptable.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>No. of Items</th>
<th>$r_{sh}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>View of professional role of S&amp;D</td>
<td>12</td>
<td>0.80</td>
</tr>
<tr>
<td>Value of personal usage of S&amp;D</td>
<td>12</td>
<td>0.66</td>
</tr>
<tr>
<td>Tendency to use S&amp;D</td>
<td>8</td>
<td>0.68</td>
</tr>
</tbody>
</table>

2.1.1 Item Analysis

An item analysis was carried out to identify weak items and to suggest possible explanations for them. Weak items were identified by their low ITC. The ITC for the items in the individual component are displayed in Table 10.3 and the summary of the item analysis is given in the following sections.

2.1.1.1 Views of the professional role of S&D.

There is only one item in the Views of the professional role of S&D section that has an ITC lower than 0.3. The reason for the low ITC could be due to the conflicting messages that were embedded in the item statement.
The item statement, "Creative thinking and not logical thinking is required to interpret engineering drawing" is found to be a combination of two statements, i.e.:

- creative thinking is required to interpret engineering drawing
- logical thinking is not required to interpret engineering drawing

As a consequence, conflict over the statements might have occurred. For example, some respondents might agree with the first message but disagree with the second or vice versa, which meant that their responses might either represent the first or second statement.

Table 10.3. Item total correlations for the items in the corresponding components of the Questionnaire.

<table>
<thead>
<tr>
<th>View of professional role of S&amp;D ($r_{xx} = 0.80$)</th>
<th>Value of personal usage of S&amp;D ($r_{xx} = 0.66$)</th>
<th>Tendency to use S&amp;D ($r_{xx} = 0.68$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>ITC</td>
<td>Item</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>3</td>
<td>0.51</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0.28</td>
<td>26</td>
</tr>
<tr>
<td>12</td>
<td>0.52</td>
<td>32</td>
</tr>
<tr>
<td>8</td>
<td>0.34</td>
<td>30</td>
</tr>
<tr>
<td>22</td>
<td>0.49</td>
<td>31</td>
</tr>
<tr>
<td>11</td>
<td>0.54</td>
<td>25</td>
</tr>
<tr>
<td>7</td>
<td>0.48</td>
<td>21</td>
</tr>
<tr>
<td>13</td>
<td>0.42</td>
<td>29</td>
</tr>
<tr>
<td>14</td>
<td>0.67</td>
<td>16</td>
</tr>
<tr>
<td>18</td>
<td>0.52</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>0.55</td>
<td>24</td>
</tr>
<tr>
<td>23</td>
<td>0.41</td>
<td>20</td>
</tr>
</tbody>
</table>
Rewriting the item into a statement with a single idea that is consistent with the overall instrument would improve its ITC, and consequently the instrument reliability.

2.1.1.2 Value of personal usage of S&D.

Three items in the Value of personal usage of S&D section were found to have ITC of less than 0.3, Item 30, Item 29 and Item 24. The low ITC of Item 30, "My skills in reading and interpreting drawing is sufficient for project supervision" might be due to the item statement which was not an indicator of personal value (as the other items were) but an indicator of something else such as self-confidence.

Item 29, "I need to improve my skills in sketching, reading and translating drawing" may also be suffering from the same problem as Item 30, although its ITC (0.29) is not as low as that of Item 30.

The low ITC of Item 24, "Higher marks should be given for preparation of detail drawings as compared to orthographic drawings", may be because the statement is not an indicator of personal value of S&D but an indicator of a person's personal preferences for the different types of drawings.

2.1.1.3 Tendency to use S&D.

None of the items in this component has an ITC that is lower than 0.30. The lowest ITC is 0.35 (one item) and the ITC for the rest of the items are generally high (0.42 to 0.67). Consequently, the reliability of this component is higher than the reliability of the Value of personal usage of S&D component, which has higher number of items. Nevertheless, since the items in this instrument are so few, the effect of low ITC may be more detrimental to the reliability of the instrument than if there are more items. For this instrument, Items 2, 17 and 28, have relatively low ITC compared to the rest of the items.

Item 2 "I do not use sketches to answer questions in tests or examination unless instructed to." is stated in the negative, which might have inspired defensive
reaction in some respondents. Furthermore, the statement has a conditional clause, which may be difficult for those who are verbally challenged to fully comprehend. A combination of the two could have caused inconsistency in responses.

Item 17 "In examination, I use sketches and diagrams to help me solve problems." does appear to belong to its allocated group of items. However, the statement could have caused some difficulties to some subjects. For example, these subjects might have used sketches in examination for a different reason, such as; to make it appear as though some thought has been given to answering a given problem, to fill up a would be otherwise blank space, etc. For these subjects, the statement is partially correct and might have caused difficulty especially for those with poor verbal ability. A simple I use sketches and diagrams in examinations might have been a better attitude statement.

Item 28 "Free hand sketching should be taught to students in my field." does not appear to be consistent with the overall theme of this instrument, which measures the tendency to use S&D. This statement appears to measure the degree of importance placed on S&D and may be consistent with either what the Professional role of S&D or the Personal usage of S&D are measuring.

In summary, some items have low ITC indicating intrinsic weaknesses. Improvement in ITC could be achieved by rewriting them in the positive phrases and ensuring that each statement only carries a single message.

2.2 Validity of the instrument
The Attitude Questionnaire was designed to be a valid measure of the attitude towards S&D based on the theory of the tri-componential viewpoints. A valid content coverage for the questionnaire was achieved through discussions with colleagues who were architecture and civil engineering lecturers from UOP (recall Chapter 7). The instrument's validity was also indicated by the high positive score of the architecture group - a group that is well known to appreciate S&D - on this instrument (reported in Chapter 12).
However, the possibility that the instrument components were not inter-related as suggested by Ajzen and Fishbein (1980) was also considered. The correlation coefficients between the components were calculated and found to be modest as shown in Table 10.4. Although all correlations are found to be positive and statistically significant at the 5% level of significance, the shared variances are small as indicated by the small \( r^2 \) values. Due to the modest correlations, the components were therefore, treated as separate entities. The Attitude Questionnaire was therefore, taken as valid measures of three constructs instead of one. Inferences was later made based on the individual components, and not on the instrument as a whole.

Table 10.4. Pearson product moment correlations (\( r \)), and Index of determination (\( r^2 \)) among components of the Attitude Questionnaire.

<table>
<thead>
<tr>
<th>Views of the professional role of S&amp;D</th>
<th>Value of personal usage of S&amp;D</th>
<th>Tendency to use S&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.29 ( (r^2= 0.08) )</td>
<td>0.58 ( (r^2= 0.34) )</td>
</tr>
<tr>
<td>Value of personal usage of S&amp;D</td>
<td></td>
<td>0.39 ( (r^2= 0.15) )</td>
</tr>
</tbody>
</table>

2.3 Summary
The results of the evaluation indicated that the Attitude Questionnaire was in fact three instruments, measuring:

- The View of the professional role of S&D
- The Value of personal usage of S&D
- The Tendency to use S&D

These instruments were found to be fairly reliable although an increase in the reliability coefficients for component II and III was desirable. In hindsight, an increase in the reliability coefficients could have been achieved if the following steps had been taken:

- administering the trial instrument to an equivalent sample
• improving the items with low ITC (those that are less than 0.3 or considerably less than the rest of the items in a particular instrument, such as Items 6, 30, 24, 29 and 28)

• repeating the steps until a satisfactory item total correlation is obtained

• increasing the number of items to at least 20 (Thomas, 1978)

Therefore, for future attitude measure, adding the above steps to the current procedure is recommended in order to achieve an instrument of a high reliability and validity.

3. RESEARCH INSTRUMENT FOR MINI-STUDY 3: STRUCTURAL DESIGN INSTRUMENT (SDI)

The SDI, (recall Appendix 6), is an achievement test instrument that consists of 18 questions. However, some questions have several parts, each of which was treated as individual items for the reliability analysis, which made the total number of items for the analysis to be 24. The SDI consisted of 13 select-type (subjects select the answer from a set of alternatives) items and 11 supply-type (subjects supply the answers) items.

3.1 Reliability of the instrument

The internal consistency is the most relevant form of reliability for the SDI. It is a measure of the relative degree to which the responses to an individual item correlate to the total score (Black, 1999). The items in the SDI are not scored dichotomously, therefore, the Cronbach’s alpha formula instead of the KR20 formula was used to compute the reliability estimate.

The reliability was estimated to be 0.73, which was considered to be acceptable according to Yu (1998). The reliability was based on the scores of the treatment group \( n = 66 \) and the distribution of these scores is displayed in Figure 10.4. Although the instrument is considered to be fairly reliable, a higher reliability could have been achieved. To determine the causes for the less than excellent reliability, an item analysis was carried out.
3.1.1 Item analysis

The item analysis yields information on the properties of the individual items. It gives some indication of a defect in an item. Table 10.5 shows the ITC for the items in the SDI. It shows that more than 50% of the SDI items have values that are less than 0.5 when they were analysed as one single instrument. This indicates that more than 50% of the items were not consistent with the total scores, meaning that some of those with high scores do badly on these items, while some of those with low score do well. There are several possibilities for the low ITC such as, poor wording, poor teaching, students absent when topic is taught or questions were not answered. Poor wording could not be the cause of the low ITC because, measures have been taken to ensure that they are clear and unambiguous (recall Chapter 8).

Students being absent when topics were taught could not be totally ruled out from the possibilities. However, the students have been exposed to the topics on several occasions, over a lengthy period of instructions, from semester 4 to semester 6 so none of the students could say that they have not been sufficiently exposed to the topics. Nonetheless, poor teaching of the topics could be a source of poor ITC. Unsuitable teaching method namely lecturing, may be the cause of low ITC for Items, 1, 4, 5, 6, 7, 14, 15 and 16 that demand conceptual understandings in
reaching their solutions. Unanswered questions are also a source of low ITC especially for Items 18(ii).

Table 10.5. Distributions of the ITC for the SDI items

<table>
<thead>
<tr>
<th>Item</th>
<th>ITC</th>
<th>Items</th>
<th>ITC</th>
<th>Items</th>
<th>ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.13</td>
<td>9</td>
<td>0.12</td>
<td>13</td>
<td>0.54</td>
</tr>
<tr>
<td>2</td>
<td>0.33</td>
<td>10</td>
<td>0.18</td>
<td>14</td>
<td>0.19</td>
</tr>
<tr>
<td>3</td>
<td>0.23</td>
<td>11a</td>
<td>0.83</td>
<td>15</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>0.01</td>
<td>11b</td>
<td>0.67</td>
<td>16</td>
<td>0.06</td>
</tr>
<tr>
<td>5</td>
<td>-0.12</td>
<td>11c</td>
<td>0.79</td>
<td>17(i)</td>
<td>0.64</td>
</tr>
<tr>
<td>6</td>
<td>0.18</td>
<td>12a</td>
<td>0.25</td>
<td>17(ii)</td>
<td>0.27</td>
</tr>
<tr>
<td>7</td>
<td>-0.09</td>
<td>12b</td>
<td>0.41</td>
<td>18(i)</td>
<td>0.59</td>
</tr>
<tr>
<td>8</td>
<td>0.36</td>
<td>12c</td>
<td>0.24</td>
<td>18(ii)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Based on the Bloom’s Taxonomy (Bloom, 1956), the SDI has 10 items at the concept level, 6 items at the application level and 8 items at the analysis and above level.

The less than excellent reliability could also be due to the heterogeneity of the SDI items. According to Ebel (1965), homogeneous tests tend to be more reliable than heterogeneous tests. The SDI was, however, not homogeneous because it not only contains supply-type and selection type items, it also contains several types of selection-type-items, such as, tick one from two alternatives, tick one from five alternatives and tick as many right answers as possible from a set of alternatives.

3.2 Validity of the instrument
The relevant form of validity for the SDI was content validity. Evidence for content validity could be found in the procedures used to design the SDI, which were:

- the use of a specifically developed Table of Specifications that formed the basis for the test content (Chapter 8, Section)
• the adoption of the various measures outlined in Chapter 8, (Section 3.2)

• the incorporation of the recommendations from various subject matter experts involved throughout the design stage

Evidence for some concurrent validity was also found in the correlation between the SDI and the SVATI ($r = 0.48$, $r^2 = 0.23$) which was significant at the 5% significance level (Chapter 13).

3.3 Summary
The SDI was found to be reasonably reliable as indicated by the reliability coefficient, $r_{xx} = 0.73$. It was also considered to possess content validity, the consequence of the measures taken during its developmental stage and some concurrent validity as indicated by the statistically significant correlation between the SDI and the SVATI ($r = 0.47$, $p < 0.5$).

4. RESEARCH INSTRUMENT FOR MINI-STUDY 4: STRUCTURAL THEORY EXAMINATION PAPER (ST PAPER)

The test instruments for mini-study 4 were two Structural Theory examination papers from the two corresponding sessions (Appendix 8 and Appendix 9), i.e., examination papers from the Jan-May 1998 session and the June-Nov. 1998 session respectively. These examination papers were assumed to be equivalent with respect to content and cognitive emphasis although these papers were produced at six months interval. The assumptions of equivalence was based on the fact that:

• the same teaching staff who were teaching both semesters were responsible for choosing the items for both papers, (items were drawn from an item bank)

• the same guidelines which identified the topics/sub-topics to be included were used in both semesters
4.1 Reliability of the instrument
Finding a good estimate of reliability for the ST Paper was difficult because the students were given choices as to which questions they were to answer provided they responded to six items out of the nine possible items. Therefore, not all subjects were answering an identical set of six items.

The Cronbach alpha method was used to estimate the reliability with some modifications giving an $r_{xx}$ value of 0.75. It was decided that the Cronbach alpha coefficient would be estimated based on the most commonly answered set of six items and all possible alternative sets of items were assumed to be equivalent to the most common set. There was only a maximum of 25 subjects who responded to the same set of items. Therefore, the data for estimating the reliability was based on $n = 25$.

This assumption is fairly justified when the procedure used to design the examination papers is considered. First, the items in the examination papers had been randomly selected from a pool of items in an item bank. These items had been designed by a group of subject matter experts based on the guidelines provided by the polytechnic examination committee. Basically, the guidelines require the structural theory papers to:

1. Cover two types of structural members: flexural members and axial members which are part of four types of structural systems: beams, trusses, portal frames and columns.

2. Measure the subjects' ability to determine and evaluate the internal forces in the structures using quantitative and qualitative methods (graphical calculations), i.e., analyse structural problems qualitatively and quantitatively using the appropriate techniques.

4.2 Validity of the instrument
Validity of relevance to the instruments was content validity. As explained earlier the development procedure of the ST Paper (Chapter 8), and the test procedure, ensure that sufficient content was covered by each instrument irrespective of the combinations of items the subjects responded to. Although the two instruments
were not identical, they were nevertheless equivalent which was a consequence of the procedure used to design the instruments (recall Chapter 8).

Threat to external validity arising from non-equivalence of examination papers between different polytechnics was also not likely although ST Papers were individually designed for each polytechnic. This was because, the items had drawn from identical sets of items available in the item bank at each polytechnic and the design of the ST Paper was based a common set of guidelines (recall Chapter 8).

4.3 Summary
The Structural Theory instruments were not designed for the purpose of the study with a format that allows the subjects to answer questions of their choice. Consequently deciding on the most appropriate measure for estimating the instruments' reliability became difficult. Nevertheless, the reliability was estimated using the Cronbach alpha coefficient based on a set of six most answered items (n = 25). The Cronbach alpha coefficient was obtained as 0.75. The design procedure for the instruments appear to support some content validity.

5. CONCLUSION

This chapter evaluated three of the research instruments:

- the Attitude Questionnaire, the instrument for mini-study 2
- the SDI, the instrument for mini-study 3
- the ST Paper, the instrument for mini-study 4

The evaluation showed that:

i. The Attitude Questionnaire was effectively three instruments instead of one as it was originally designed. These instruments were found to be adequately reliable and valid in measuring the three corresponding constructs: the View of the professional role of S&D, the Value of the personal usage of S&D and the Tendency to use S&D. The reliability for the three instruments was 0.80, 0.66 and 0.68 respectively.
ii. The SDI was a fairly reliable instrument ($r_{xx} = 0.73$) that possessed content validity which was established through the design procedure. There was also some indication that it possessed concurrent validity as indicated by the positive correlation between the SDI and the SVATI ($r = 0.47$).

iii. The ST Paper, which was not specifically designed for the study, posed some difficulty to evaluate. Additional assumptions were made in the course of establishing its reliability. Finally, based on $n = 25$ the reliability was estimated to be 0.75.

Data collected using these instruments will be presented and analysed in the following chapters, Chapter 12, 13 and 14. The next chapter, Chapter 11, will present and analyse the sets of data for mini-study 1, which was collected using the SVATI (previously evaluated in Chapter 9).
CHAPTER 11

Data Analysis for Mini-study 1: The Effects of Teaching and Learning of Spatial Visualisation Skills on Spatial Visualisation Ability.

1. INTRODUCTION

This chapter is the first of four chapters on data presentation and analysis. This chapter presents and analyses the data for mini-study 1, which investigates the effects of teaching and learning of SV skills on SV ability. This chapter aims to answer the following research questions:

- Is the SV ability gain for the group of engineering students that was taught SV skills (treatment) significantly different than the group that was not, irrespective of gender?

- Between males and females engineering students, is the SV ability gain for females significantly different from males irrespective of treatment?

- Are females and males groups of engineering students affected differently by the treatment?

This chapter consists of three sections and a conclusion. The first section describes the methods used to analyse the data followed by the second and third section on the results of the data analysis.

2. METHOD OF DATA ANALYSIS

The data was analysed using both descriptive and inferential statistics. A two-way analysis of variance (ANOVA) instead of a pair of t-tests was used to test the research hypotheses. This was because the ANOVA permitted simultaneous comparisons between samples that have two independent variables and one dependent variable (such as found in the study) while each t-test could only test for significance for the difference between two groups (Black, 1999). In brief, a two-way ANOVA allows
for interactions between variables gender and treatment, as well as differences across each of the main effects.

Statistical significance/non-significance of the results were decided at the 5 % level of significance, which meant that there was a 5% chance of making a type I error or a 5% chance of rejecting the null hypothesis when it was actually true (Black, 1999). Adopting a lower significance level such as the 1% significance level, was not desirable because to do so would increase the chances of making a type II error, i.e., increase the chances of accepting the null hypothesis when it was actually false.

Making a type II error, i.e., not finding evidence of an effect of teaching that existed might only reinforce polytechnic lecturers' pre-conceived idea that extra teaching efforts do not make a difference to students' learning. Lecturer's view that students do not merit extra attention was based on casual observations but nevertheless appears to be supported by Sims and Sims (1995). According to Sims and Sims, educators in higher education institutions often do not understand how people learn, which frequently cause them to have the preconceived idea that "...one either learns or one does not" (p.1). Making a type II error is therefore, highly undesirable while making a type I error, i.e., finding a difference that did not really exist, could only lead to invalid efforts towards improving or changing teaching and learning practices which was more desirable than making a type II error.

The ANOVA has four underlying assumptions (Black, 1999):

- the underlying populations are normal for the trait
- there is homogeneity of variance across groups
- all measures are independent of each other
- component variances are additive

According to Black (1999), the ANOVA is quite a robust statistical tool. Therefore, normality of the underlying population for the trait under study was assumed for all cases in the study unless indication of abnormality was found to be extremely obvious such as when the shape of the sample distribution was highly skewed. Homogeneity of variance however, was checked specifically using an Excel worksheet in
accordance with Black (1999). All measures were assumed to be independent of each other and the component variances were assumed to be additive - a consequence of the research design. The statistical power of the test was calculated using Excel worksheet in accordance with Black (1999) and only reported where statistical significance was obtained.

3. RESULT OF DATA ANALYSIS ON THE SCORES OF THE OVERALL SVATI.

Figure 11.1 displays the distributions of the gain scores, illustrating the treatment’s main effect on the SVATI for the experimental and control groups. Both distributions appear to be approximately normal, indicating a high possibility that the distributions of the underlying population for the trait under study (gain score on the SVATI) was also normal.

![Figure 11.1. Distribution of gain scores for the experimental and control group. (n_{exp.} = 29 and n_{cont.} = 28): Treatment main effect.](image)

The distribution for the experimental group is positioned slightly to the right of the control group indicating a higher mean gain score ($\bar{x}$) for the experimental group. The descriptive statistics (means $\bar{x}$, standard deviations $s$, and cell sizes $n$) for the groups are given in Table 11.1.
Table 11.1. Descriptive statistics (means $\bar{x}$, standard deviations $s$, and cell sizes $n$) for the experimental and control groups.

<table>
<thead>
<tr>
<th></th>
<th>$B_1$ (Control)</th>
<th>$B_2$ (Experimental)</th>
<th>Gender main effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$ (Female):</td>
<td>$\bar{x} = 3.00$</td>
<td>$3.36$</td>
<td>$3.21$</td>
</tr>
<tr>
<td></td>
<td>$s = 1.77$</td>
<td>$2.94$</td>
<td>$2.46$</td>
</tr>
<tr>
<td></td>
<td>$n_f = 8$</td>
<td>$11$</td>
<td>$19$</td>
</tr>
<tr>
<td>$A_2$ (Male):</td>
<td>$\bar{x} = 3.00$</td>
<td>$5.28$</td>
<td>$4.08$</td>
</tr>
<tr>
<td></td>
<td>$s = 3.01$</td>
<td>$2.4$</td>
<td>$2.94$</td>
</tr>
<tr>
<td></td>
<td>$n_m = 20$</td>
<td>$18$</td>
<td>$38$</td>
</tr>
<tr>
<td>Treatment main effect:</td>
<td>$\bar{x} = 3.00$</td>
<td>$4.55$</td>
<td>$3.79$</td>
</tr>
<tr>
<td></td>
<td>$s = 2.68$</td>
<td>$2.73$</td>
<td>$2.8$</td>
</tr>
<tr>
<td></td>
<td>$n = 28$</td>
<td>$29$</td>
<td>$57$</td>
</tr>
</tbody>
</table>

Table 11.1 shows unequal cell sizes $n$ ($n_f < n_m$), a consequence of using intact classes of students. This Table also shows that there is a difference in means of the gain scores between gender irrespective of treatments [$\bar{x}_{fm}$, (4.08) > $\bar{x}_f$, (3.21)] and between treatments irrespective of gender [$\bar{x}_{exp}$, (4.55) > $\bar{x}_{con}$, (3.00)]. The relationships between the means in Table 11.1 are illustrated graphically in Figure 11.2.

Figure 11.2. Graphical representation of the means of the gains scores on the SVATI for the male and female samples in the experimental and control group.
Figure 11.2 shows that both male and female experimental groups have higher gain scores means compared to their corresponding control groups with a much smaller gain difference between the female groups. Consequently, two non-parallel lines (female and male lines) are generated, suggesting the possibility of gender-treatment interaction effect.

3.1 Hypotheses testing

Table 11.2 shows the result of the analysis on the hypotheses testing. It shows that the F value for the Gender main effect is less than its $F_{crit}$ value [$F, (1.44) < F_{critical}, (4.02)$]. This means that there was no main effects gender difference in gain scores. Therefore, the hypothesis which states that “There will be no statistically significant difference between the mean gain scores for the female and male samples...” was not rejected.

On the Treatment main effect, it is shown that the F value for treatment effects is greater than its $F_{crit}$ value [$F, (5.16) > F_{critical}, (4.02)$], indicating a statistically significant difference between the means of the gain scores of the experimental and the control group. Therefore, the hypothesis of “...no statistically significant difference between the scores for the control and the experimental group...” was rejected and the alternative hypothesis, “There will be a statistically significant difference between the means...” was accepted. The statistically significant result implies that the higher score of the treatment is unlikely to have occurred by chance alone. The power of the statistical test was 0.53, not very high.

Table 11.2. A two way ANOVA on the SVATI gain scores using Excel worksheet after Black (1999).

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>SS</th>
<th>df</th>
<th>MS($\sigma^2$)</th>
<th>$F$</th>
<th>$P$-value</th>
<th>$F_{critical}$</th>
<th>$\alpha$</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (A)</td>
<td>9.55</td>
<td>1</td>
<td>11.40</td>
<td>1.44</td>
<td>0.236</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Treatment (B)</td>
<td>34.30</td>
<td>1</td>
<td>29.96</td>
<td>5.16</td>
<td>0.027</td>
<td>4.02</td>
<td>0.05</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Interaction</td>
<td>12.20</td>
<td>1</td>
<td>12.73</td>
<td>1.84</td>
<td>0.181</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Within</td>
<td>352.34</td>
<td>53</td>
<td>6.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>408.43</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Finally, it is observed that the F value for the Interaction effect is less than its corresponding $F_{\text{critical}}$ value [$F, (1.84) < F_{\text{critical}}, (4.02)$], indicating a non-statistically significant interaction. Therefore, the null hypothesis, which states that “There will be no difference between the mean gain scores of the male and female samples across treatment” was also not rejected by the study.

A post-hoc analysis was not carried out on the results because there was no statistically significant interaction found.

3.2 Summary of the results
Statistical significance was found for the difference between the means of the treatment and the control group irrespective of gender. Statistical significance was however, not found in the difference between the means of the female and male groups, or in the interaction between gender and treatment.

3.2.1 What kind of inference can be made from the statistically significant results?
According to Black (1999),

A statistical test can only tell whether a difference in mean scores observed between those experiencing one treatment and the usual population that did not could have occurred as a random event but it cannot prove a change in one variable caused a change in another.

(Black, 1999, p. 355).

Therefore, what the statistical test has shown in this study is, the difference in scores of those who were taught SV skills and those who were not is unlikely to be a consequence of a random event but more likely to be due to a specific cause. It is suggested that the difference in the mean scores between the two groups was likely to be due to the effect of the treatment. This is because the study had been designed in such a way that the experimental group was just like the control group - apart from the treatment which was given to the experimental group (recall Chapter 5). However, there was a possibility that an attitude change accompanied by the appropriate efforts (a consequence of the attitude change) could have caused the much higher increase in SV ability of the experimental group. Nevertheless, this was
highly unlikely. Although a change in attitude towards SV skills - from less positive to more positive - was possible, this change was highly unlikely to be accompanied by extra efforts towards improving SV skills. This is because, knowing polytechnic students (from past experience), they would not put extra efforts on something that they think do not directly impact their examination grade. Therefore, with the identified variables being kept constant for the two groups (recall Chapter 5), except for the treatment, there was a high possibility that the improvement in SV ability in the experimental group was the consequence of the treatment.

This result is entirely consistent with those studies that used similar teaching approaches, which reported that SV skills are improved by teaching and learning and both males and females benefit equally from teaching and learning (Lord, 1985; Ben-Chaim, 1988; Tillotson, 1985; Seddon, Enialyeju and Jusoh, 1984 and Sorby and Baartmans, 1996a).

3.3 Educational significance of the outcome of the main effects of treatment

Besides statistical significance, the research findings also have some educational significance. Educational significance is indicated by several factors.

First, an increase in performance was achieved after only a relatively short period of teaching and learning intervention. There is a greater gain (5.8%) in the experimental group - whose mean increases from 13.45 to 19 (a gain of 16.8%) - than the control group - whose score increases from 16 to 19, (a gain of 10.7%). In view of the short time spent on the spatial visualisation instruction, i.e., six hours out of 120 hours or 5% of the total design course, the achievement is very significant indeed.

Secondly, the teaching and learning materials are those that could be easily developed or obtained by interested teachers without significant increase in workload or expenses. Expenses associated with the learning materials is low because for they only need low technology media to produce and present.

Thirdly, the result is educationally significant because the learning experience also appears to affect the affective domain as indicated by the positive feedback received from students - gained from recorded observations and informal discussions held at
the end of instruction. The general feeling on the effect of the SV skill activities was captured by the remark of one mature student who while using hand movements to describe the relationships between actual beam behaviour, internal actions and their representations said "I find this course very useful. Before this I could not see the connection between all these...". The subjects also appear to be exceptionally alert and eager (indicated by their frequent appropriate verbal responses to tasks given in class) to participate in class activities. It is possible that their active participation is due to the novelty of the teaching and learning activities/materials - numerical/quantitative analysis was not the dominant feature - that contrast with the traditional engineering teaching and learning. To assess the effects of the SV skills materials on civil engineering problem solving, post tests on structural design and structural theory problem solving were administered at the end of the semester, four months after the administration of the SVATI. The results of the data analysis of are given in Chapter 13 and 14.

In summary, although the mean of the experimental group is only 1.6 marks (5.8%) higher than the control group, the gain in SV skills appears to be educationally significant for it shows that

- appropriate teaching efforts do bring the desired learning outcomes

- striving for positive learning transfer does not necessarily require a high technological intervention, major changes to the curriculum or high financial cost

4. DATA ANALYSIS ON THE SCORES OF THE INDIVIDUAL COMPONENTS OF THE SVATI

The SVATI employs three types of spatial tasks, each of which were postulated to require slightly different solving strategies/skills. Analysing the subjects' performance on the individual group of tasks may be advantageous because it may yield information on the types of spatial skills that benefit most from the teaching and learning given previously and on the relationships between gender, type of skills and learning gains, if any.
Data analysis on the Cube construction items of the SVATI

Figure 11.3 displays the distribution of gain scores for the experimental and control groups on the cube construction items. This Figure, which illustrates the main effect of the treatment, shows that the score distributions are approximately normal. Therefore, the distribution of the underlying population for the trait under study was also assumed to be normal.

The descriptive statistics (means $\bar{x}$, standard deviations $s$, and cell sizes $n$) for the groups are given in Table 11.3. The cell sizes ($n$) are again unequal because this analysis is based on the same groups of subjects (recall Chapter 5). The difference between the means of the gain scores for female and male groups (irrespective of treatment) is very small, i.e., only 0.03, and most probably statistically non-significant. The difference between the means of the gains scores for the control and the experimental groups (irrespective of gender) is also very small, i.e., 0.11, and unlikely to be statistically significant.

There is however, a possible dis-ordinal interaction effect between gender and treatment as shown by the means of the gain scores in the first four cells. These data show that the mean gain score for the female in the experimental group ($\bar{x} = 0.55$) is
much smaller than both the means of the gains scores of the female in control group ($\bar{x}_f = 1.38$) and the male in the experimental group ($\bar{x}_m = 1.28$).

Table 11.3. Descriptive statistics (means $\bar{x}$, standard deviations $s$, and cell sizes $n$) on the Cube construction items of the SVATI.

<table>
<thead>
<tr>
<th></th>
<th>$\bar{x}$</th>
<th>$s$</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$ (Female)</td>
<td>1.38</td>
<td>0.55</td>
<td>0.96</td>
</tr>
<tr>
<td>$A_2$ (Male)</td>
<td>0.70</td>
<td>1.28</td>
<td>0.99</td>
</tr>
<tr>
<td>Treatment main effect</td>
<td>0.89</td>
<td>1.00</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Figure 11.4 illustrates graphically the relationships between the means given in Table 11.3. The crossing of the female and male lines suggests a possibility of an interaction effect between gender and treatment.

Figure 11.4. Graphical representation of the means of the gains scores on the Cube construction items for the male and female samples in the experimental and control group.
4.1.1.1 Hypotheses testing

Table 11.4 shows the result of the analysis on the hypotheses testing. It is found that the F value for the Gender main effects is less than its F critical value \( F, (0.00) < F_{\text{critical}} (4.02) \). This means that there is no statistically significant difference between the \( \bar{x} \) s of the female and male samples. Therefore, the null hypothesis which states that “There will be no statistically significant difference between the mean gain scores for female and male samples” was not rejected.

Table 11.4. A two way ANOVA on the Cube construction items gain scores using Excel worksheet from Black (1999).

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS((\bar{F}^2))</th>
<th>(\bar{F})</th>
<th>P-value</th>
<th>(F_{\text{critical}})</th>
<th>(\alpha)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (A)</td>
<td>0.01</td>
<td>1</td>
<td>0.01</td>
<td>0.00</td>
<td>0.953</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Treatment (B)</td>
<td>0.14</td>
<td>1</td>
<td>0.14</td>
<td>0.05</td>
<td>0.824</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Interaction</td>
<td>5.48</td>
<td>1</td>
<td>5.48</td>
<td>1.91</td>
<td>0.172</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Within</td>
<td>151.66</td>
<td>53</td>
<td>2.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>157.29</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On the Treatment main effect, it was again found that the F value is smaller than its corresponding \(F_{\text{critical}}\) value \( F, (0.05) < F_{\text{critical}} (4.02) \), indicating a non-statistically significant difference between the means of the gain scores of the experimental group and the control group. Therefore, the null hypothesis which states that “There will be no statistically significant difference between the mean gain scores for the experimental and control group” was also not rejected, implying that the observed difference could have occurred by chance alone.

Finally, the F value for the Interaction effect was also observed to be less than its \(F_{\text{critical}}\) value \( F, (1.91) < F_{\text{critical}}, (4.02) \), indicating a non-statistically significant interaction. Therefore, the null hypothesis, which states that “There will be no difference between the mean gain scores of the male and female samples across treatments” was also not rejected by the study. This outcome contradicts what is clearly indicated in Figure 11.4 to be a dis-ordinal interaction between gender and treatment. The statistical outcome implies that that the observed interaction is a consequence of a random event. Failure to establish statistical significance may be
due to a combination of factors, such as, the unequal cell sizes, the small samples and
the low reliability of the instrument ($r_{xx} = 0.55$), the last of which would have
increased the error variance components ($MS_{within}$) in the ANOVA calculation,
possibly masking treatment effects.

4.1.1.2 Summary of result on the Cube construction items

In summary, for the cube construction items, statistical significance was not found in
either the difference between the mean gain scores of the experimental and the control
groups (irrespective of gender) or in the difference between the mean gain scores
between females and males (irrespective of treatment). In other words, disregarding
gender, the teaching and learning of SV skills has no effect on SV skills related to
solving of cube construction tasks. Also, disregarding treatment, there was no
difference in the SV skills gain between gender.

Statistical significance was also not found for the interaction between gender and
treatment although this outcome was deemed to be inconclusive as explained in
section 4.1.1.1.

4.1.2 Data analysis on the Engineering drawing items of the SVATI

Figure 11.5 shows the distributions of the gains scores for the experimental and
control groups on the engineering drawing items. It illustrates the main effect of the
treatment. The distributions, which are approximately normal, suggest a normally
distributed underlying population for the trait under study. The descriptive statistics
(means $\bar{x}$, standard deviations $s$, and cell sizes $n$) for the groups are given in Table
11.5.

Table 11.5 shows that the difference in means of the gain scores across treatments
(irrespective of gender) is relatively large indicating a possible main (treatment)
effects ($\bar{x}_{exp.} = 2.52$, $\bar{x}_{cont.} = 1.21$). The difference between gender means
(irrespective of treatments), is also relatively large ($\bar{x}_m = 2.17$, $\bar{x}_f = 1.25$) indicating
a possibility for a statistically significant difference.
Figure 11.5. Distributions of gain scores on the Engineering drawing items for the experimental group \((n = 29)\) and the control group \((n = 28)\): Treatment main effect.

Figure 11.6 gives the graphical representation for the means of the gain scores shown in Table 11.5. This Figure shows the means of the gain scores of the experimental group to be generally superior to the control group and the trends of gains are similar for male and female. The approximately parallel lines shown in this figure indicates the absence of interaction effect between gender and treatment.

Table 11.5. Descriptive statistics (mean \(\overline{x}\), standard deviations \(s\), and cell sizes \(n\)) on the Engineering drawing Items of the SVATI.

<table>
<thead>
<tr>
<th></th>
<th>B1 Control</th>
<th>B2 (Experimental)</th>
<th>Gender main effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A_1) (Female)</td>
<td>(\overline{x} = 0.50)</td>
<td>(s = 1.41)</td>
<td>(n_f = 8)</td>
</tr>
<tr>
<td>(A_2) (Male)</td>
<td>(\overline{x} = 2.00)</td>
<td>(2.49)</td>
<td>(11) = (2.83)</td>
</tr>
<tr>
<td>Treatment main effect</td>
<td>(\overline{x} = 1.21)</td>
<td>(2.52)</td>
<td>(1.71)</td>
</tr>
</tbody>
</table>
4.1.2.1 Hypotheses testing

Table 11.6 shows the result of the analysis on the hypotheses testing. It is found that the F value for the Gender main effect is less than its F critical value \[ F, (2.36) < F_{critical}, (4.02) \]. This means that there is no statistically significant difference in the mean gain scores of female and male samples. Therefore, the null hypothesis, which states that “There will be no statistically significant difference between the mean gain scores for female and male samples” was not rejected.

On the Treatment main effect, it was found that the F value for treatment main effects is greater than its critical value \[ F, (4.76) > F_{critical}, (4.02) \] indicating a statistically significant difference between the means of the gain scores of the experimental group and the control group. Therefore, the null hypothesis which states that “There will be no statistically significant difference between the mean gain scores for the experimental and control group” was rejected. In other words, the observed difference between the experimental group and the control on the engineering drawing items could not have occurred by chance alone. The power of the statistical test was 0.55, not very high.
Table 11.6. A two way ANOVA on the Engineering drawing items gain scores using Excel worksheet from Black (1999).

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS((\sigma^2))</th>
<th>(F) (=)</th>
<th>(p)-value</th>
<th>(F_{\text{critical}})</th>
<th>(\alpha)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (A)</td>
<td>10.46</td>
<td>1</td>
<td>10.46</td>
<td>2.36</td>
<td>0.131</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Treatment (B)</td>
<td>21.12</td>
<td>1.00</td>
<td>21.12</td>
<td>4.76</td>
<td>0.034</td>
<td>4.02</td>
<td>0.05</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td>Interaction</td>
<td>1.48</td>
<td>1</td>
<td>1.48</td>
<td>0.33</td>
<td>0.566</td>
<td>4.02</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Within</td>
<td>235.26</td>
<td>53</td>
<td></td>
<td>4.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>268.32</td>
<td>56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Finally, the \(F\) value for the Interaction effect is observed to be less than the \(F_{\text{critical}}\) for it \([F, (0.33 < F_{\text{critical}}, (4.02)],\) indicating a non-statistically significant interaction as suggested by the approximately parallel lines in Figure 11.6. Therefore, the null hypothesis that states that "There will be no difference between the mean gain scores of the male and female samples across treatment" was not rejected.

4.1.2.2 Summary of results on the Engineering drawing items

In summary, for the engineering drawing items, statistical significance was only found in the Treatment main effect (irrespective of gender). In other words, regardless of gender, engineering students who received treatment gained more engineering drawing skills compared to those who did not receive the treatment.

Statistical significance was not however found in:

- the difference between the means of the female and male groups, irrespective of treatments, i.e., disregarding teaching and learning of SV skills, females and males engineering students do not have dissimilar gains in engineering drawing skills.
4.1.3 Data analysis on the Mental rotation items of the SVATI

Figure 11.7 shows the distributions of the gains scores for the experimental and control groups on the mental rotation items. This Figure illustrates the main effect of the treatment. The distributions appear to be approximately normal, indicating a normally distributed underlying population for the trait.

The descriptive statistics for the groups are given in Table 11.7. This Table shows that the difference in means of the gain scores across treatments (irrespective of gender) is relatively small (1.10 - 0.71 = 0.39) indicating that a statistically significant difference is unlikely. The difference in means of the gain scores for the Gender main effect is also relatively small (1.04 - 0.66 = 0.38) indicating little possibility for statistical significance in the difference.
Table 11.7. The descriptive statistics (means $\bar{x}$, standard deviations $s$, and cell sizes $n$) on the Mental rotation items of the SVATI.

<table>
<thead>
<tr>
<th></th>
<th>B1 (Control)</th>
<th>B2 (Experimental)</th>
<th>Gender main effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A1) Female</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>0.50</td>
<td>0.82</td>
<td>0.66</td>
</tr>
<tr>
<td>$s$</td>
<td>1.41</td>
<td>1.54</td>
<td>1.45</td>
</tr>
<tr>
<td>$n_f$</td>
<td>8</td>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td>A2 (Male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>0.80</td>
<td>1.28</td>
<td>1.04</td>
</tr>
<tr>
<td>$s$</td>
<td>2.07</td>
<td>1.49</td>
<td>1.81</td>
</tr>
<tr>
<td>$n_m$</td>
<td>20</td>
<td>18</td>
<td>38</td>
</tr>
<tr>
<td>Treatment main effect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>0.71</td>
<td>1.10</td>
<td>0.85</td>
</tr>
<tr>
<td>$s$</td>
<td>1.88</td>
<td>1.50</td>
<td>1.69</td>
</tr>
<tr>
<td>$n$</td>
<td>28</td>
<td>29</td>
<td>57</td>
</tr>
</tbody>
</table>

Figure 11.8 illustrates graphically the relationships between the means of the gain scores for the female and male samples of the experimental and control groups. This figure shows that the means of the gain scores of the experimental groups ($\bar{x}_{f(exp)}$, $\bar{x}_{m(exp)}$) is superior to the control groups ($\bar{x}_{f(contr)}$, $\bar{x}_{m(contr)}$). However, the nearly parallel lines indicate that there is unlikely to be any interaction between gender and treatment.

Figure 11.8. Graphical representation of the means of the gain scores on the Mental rotation items for the male and female samples in the experimental and control group.
4.1.3.1 Hypotheses testing

Table 11.8 shows the result of the analysis on the hypotheses testing. It is found that F value for the Gender main effects is less than its corresponding F critical value \([F, (0.66) < F_{critical}, (4.24)]\). This means that there is no statistically significant difference between the mean gain scores of female and male samples. Therefore, the null hypothesis which states that "There will be no statistically significant difference between the mean gain scores for female and male samples" was not rejected.

On the Treatment main effect, it is again found that the F value for the Treatment main effects is smaller than its F critical value \([F, (0.69) < F_{critical}, (4.24)]\) indicating a non-statistically significant difference between the mean gain scores of the experimental group and the control group. Therefore, the null hypothesis that states that "There will be no statistically significant difference between the mean gain scores for the experimental and control group" was also not rejected. In other words, the observed difference in the means of the gain scores between the experimental group and the control \((\bar{x}_{exp} = 1.10 \text{ and } \bar{x}_{cont} = 0.71)\) could have occurred by chance alone.

Table 11.8. A two way ANOVA on the Mental rotation items gain scores using Excel worksheet from Black (1999).

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>df</th>
<th>MS(\overline{s}^2)</th>
<th>(F)</th>
<th>(P)-value</th>
<th>(F_{critical})</th>
<th>(\alpha)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (A)</td>
<td>1.79</td>
<td>1</td>
<td>1.79</td>
<td>0.66</td>
<td>0.424</td>
<td>4.24</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Treatment (B)</td>
<td>1.88</td>
<td>1</td>
<td>1.88</td>
<td>0.69</td>
<td>0.412</td>
<td>4.24</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.26</td>
<td>1</td>
<td>0.26</td>
<td>0.10</td>
<td>0.760</td>
<td>4.24</td>
<td>0.05</td>
<td>n.s</td>
</tr>
<tr>
<td>Within</td>
<td>67.81</td>
<td>25</td>
<td>2.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71.75</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Finally, the F value for the Interaction effect is also observed to be less than the its \(F_{critical}\) value \([F, (0.10) < F_{critical}, (4.24)]\) indicating a non-statistically significant interaction. Therefore, the null hypothesis, which states that "There will be no difference between the mean gain scores of the male and female samples across
treatment', was not rejected by the study. In other words, there was unlikely to be an interaction effect between gender and treatment.

4.1.3.2 Summary of results on the Mental rotation items

In summary, for the mental rotation items, statistical significance was not found in any of the hypotheses tested. One possible reason is the dissimilarity between the learning materials that were used in the teaching and learning of SV skills and the test items. The learning materials dealt with objects that were constructed from building cubes, which are relatively simple objects that have square non-slanting surfaces. The test items on the other hand dealt with line drawings of more complex objects, which included slanting surfaces. Past studies which find improvement on the mental rotation skills after instructions were using learning materials which were very similar (almost identical) to the test items (Seddon and Shubber, 1985 and Shubbar, 1990).

Another possible reason for the absence of improvement in mental rotation skills is the non-explicit teaching of the measured skills. For example:

- subjects were not instructed to observe the effects of rotations on the objects they were manipulating although mental rotation was the measured construct

- subjects were not asked to draw views of objects other than those seen from the standard orthographic views although the mental rotation items were measuring the non-standard views.

Finally, the lack of mastery of depth cues among the polytechnic subjects could also be the reason for the non-significance finding. According to Seddon and Eniayeju (1986), the ability to visualise the effects of rotation transformations on diagrams of 3-dimensional structures is dependent on mastery of depth cues that are used to portray depth in the diagrams. They suggested that mastery of four types of depth cues is necessary for accurate predictions under rotation: relative size cue, overlap cue, foreshortened line cue and distortion of angles cue. However, mastery of depth cues was neither taught nor determined in the study. Furthermore, only three depth cues; the distortion of angle cue, the overlap cue and the foreshortened line cue were used for the items in the SVATI. The relative size cue was not provided in order to
be consistent with isometric drawing convention, which do not provide the foreshortened line cure.

4.2 Overall summary

Table 11.9 gives the summary of the outcomes of the statistical tests. On the overall SVATI, statistical significance was only obtained for the Treatment main effect. For the individual SVATI component, statistical significance was only obtained for the Treatment main effect on the engineering drawing items.

Table 11.9. Summary of the results of the statistical tests.

<table>
<thead>
<tr>
<th>Sections on SVATI</th>
<th>Hypothesis tested - differences between mean scores</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall SVATI</td>
<td>Between experimental and Control group</td>
<td>sig. P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Between gender</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Interaction between gender and treatment</td>
<td>n.s</td>
</tr>
<tr>
<td>Section I</td>
<td>Between experimental and Control group</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Between gender</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Interaction between gender and treatment</td>
<td>n.s</td>
</tr>
<tr>
<td>Section II</td>
<td>Between experimental and Control group</td>
<td>sig. P&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>Between gender</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Interaction between gender and treatment</td>
<td>n.s</td>
</tr>
<tr>
<td>Section III</td>
<td>Between experimental and Control group</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Between gender</td>
<td>n.s</td>
</tr>
<tr>
<td></td>
<td>Interaction between gender and treatment</td>
<td>n.s</td>
</tr>
</tbody>
</table>

5. CONCLUSION

This chapter set out to establish causal relationships between teaching and learning and spatial visualisation skills. SV skills in general (as measured by the total score of the SVATI) were shown to be improved after the teaching and learning activities that consisted primarily of object manipulations and sketching and drawing.
However, improvement in the components of the SV skills varied, showing the most improvement on SV skills associated with the engineering drawing problems and the least improvement in the SV skills associated with the mental rotation problems. The next chapter will investigate the relationship between attitudes towards sketching and drawing and SV ability.
CHAPTER 12

Data Analysis for Mini-study 2: Relationships between Attitudes towards Sketching and Drawing and SV Ability.

1. INTRODUCTION

Chapter 11 analysed the data from mini-study 1 and found that teaching and learning of SV skills affects SV ability as measured by the SVATI. This chapter will present and analyse the data from mini-study 2. This is to determine whether there are any relationships between SV ability and the three attitude constructs: the view of the professional role of sketching and drawing (S&D), the value of personal usage of sketching and drawing (S&D) and the tendency to use S&D.

This chapter aims to answer the following research questions:

- is there a difference between civil engineering students and architecture students in their attitudes towards S&D?
- is the assumption about the relationships between the three attitude constructs supported by empirical evidence?
- how are the three attitude constructs related to SV ability?

This chapter is divided into three sections and a summary. The first three sections will deal with each of the research questions in turn and the last section will summarise the results.

2. IS THERE A DIFFERENCE BETWEEN CIVIL ENGINEERING STUDENTS AND ARCHITECTURE STUDENTS IN THEIR ATTITUDES TOWARDS S&D?

Comparison was made to determine whether there is a difference in the attitude towards S&D between the civil engineering subjects and a group of architecture subjects - a group that is recognised to appreciate S&D. The civil engineering group consisted of two intact classes of subjects, (n = 57) from two Malaysian polytechnics.
and the Architecture group consisted of 19 subjects who had been purposely selected from the two polytechnics, the Ungku Omar polytechnic (UOP) and the Port Dickson Polytechnic (PDP) (recall Chapter 5).

Data for the study was collected via the Attitude Questionnaire (Appendix 4) which was administered simultaneously to the entire civil engineering sample prior to the SV ability pre-test. Having the attitude survey earlier than the SVATI pre-test eliminated any bias arising from sitting for the SVATI which consisted of drawings. For practical reasons, the Attitude Questionnaire was administered to the architecture group a week later. Steps were taken to eliminate any possibility of the Questionnaire coming into contact with the architecture subjects beforehand.

2.1 Method of data analysis

Descriptive and inferential statistics were both used in the analysis. Differences between groups were determined on the three Questionnaire components and not on the overall Questionnaire after finding only modestly strong correlations between the three components (recall Chapter 10, Section 2).

The pooled t-test was used to ascertain whether there is a difference between the two samples and statistical significance/non-significance was established at the 5% level of significance.

2.2 Results of data analysis

Results of the analysis on the three components will be presented in turn in the following order; the View of the professional role of S&D, the Value of the personal usage of S&D and the Tendency to use S&D.

2.2.1 The View of the Professional Role of S&D

Table 12.1 shows the descriptive statistics for the View of the professional role of S&D. It shows that the mean score of the architecture group, which is 46.74, is 7.3 points higher than the mean score of the engineering group, which is 39.44. In other words, the mean of the architecture group is 12.2% higher than that of the engineering group, which is calculated using Equation 12.1.
\[
\% = \left( \frac{\text{architecture mean} - \text{civil engineering mean}}{\text{possible score for the component}} \right) \times 100 \Rightarrow \text{(Equation 12.1)}
\]

\[
\% = \left( \frac{46.74 - 39.44}{5 \times 12} \right) \times 100 = 12.2\%
\]

Table 12.1. Descriptive statistics for the View of the Professional Role of S&D.

<table>
<thead>
<tr>
<th></th>
<th>Civil engineering</th>
<th>Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} )</td>
<td>39.44</td>
<td>46.74</td>
</tr>
<tr>
<td>( s )</td>
<td>5.82</td>
<td>4.33</td>
</tr>
<tr>
<td>( n )</td>
<td>57</td>
<td>19</td>
</tr>
</tbody>
</table>

Figure 12.1 displays the frequency distributions for the scores of the civil engineering and the architecture groups. This Figure shows that the architecture scores are dominating the higher end of the scale indicating the more positive view of the architecture group regarding the professional role of S&D.

The pooled \( t \)-test was used to test for statistical significance. The assumptions underlying this test are:

- normality of traits for the underlying population
homogeneity of variance

- independence of measure

- variances that are additive

The assumption for the normality of traits for the underlying population is satisfied as shown by the smoothed frequency polygon in Figure 12.2. The assumption for homogeneity of variance is also met as shown by the F-test results in Table 12.3. The rest of the assumptions are met through the design of the study.

![Smoothed frequency polygon](image_url)

Figure 12.2. The smoothed frequency polygon for the scores on the View of the Professional role of S&D.

2.2.1.1 Hypothesis testing

Table 12.2 shows the results of the statistical test. At the 5% significance level the results show that there is a statistically significant difference between the means of the two groups, \( t(4.02) > t_{\text{critical}} (1.99) \), with a power of 99.8%. Therefore, the null hypothesis that states 'there will be no difference between the groups' is rejected. In other words, the difference between the two groups was unlikely to be the outcome of a random event and more likely to be the outcome of a specific cause.
Table 12.2. Results of data analysis on the View of the professional role of S&D using Excel worksheet after Black (1999).

<table>
<thead>
<tr>
<th>Data:</th>
<th>Civil</th>
<th>Architecture</th>
<th>Test for homogeneity of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>39.44</td>
<td>46.74</td>
<td>$F$= 1.81</td>
</tr>
<tr>
<td>$s$</td>
<td>5.82</td>
<td>4.33</td>
<td>$P_{one-tailed}$= 0.05</td>
</tr>
<tr>
<td>$n$</td>
<td>57</td>
<td>19</td>
<td>$F_{crit 1-tail}$= 2.33</td>
</tr>
<tr>
<td>$df$</td>
<td>74</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Tails</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t(alpha)$</td>
<td>2.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>0.998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t$</td>
<td>4.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_{critical}$</td>
<td>1.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2.2 The Value of personal usage of S&D

Table 12.3 shows the descriptive statistics ($\bar{x}$ and $s$) for the Value of the personal usage of S&D. It shows that the architecture group has a mean score of 41.21 which is 4.54 points or 9% higher than the mean of the civil engineering group.

Table 12.3. Descriptive statistics on the Value of the personal usage of S&D.

<table>
<thead>
<tr>
<th></th>
<th>Civil engineering</th>
<th>Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>36.67</td>
<td>41.21</td>
</tr>
<tr>
<td>$s$</td>
<td>4.11</td>
<td>5.29</td>
</tr>
<tr>
<td>$n$</td>
<td>57</td>
<td>19</td>
</tr>
</tbody>
</table>

Figure 12.3 shows the frequency distribution of the scores on this component. The score on this component indicates how strong the subjects personally value S&D. The architecture’s distribution is again positioned towards the higher end of the scale indicating a higher value on personal usage of S&D held by the architecture group.
Figure 12.3. Distribution of scores on the Value of the personal usage of S&D for the Civil engineering, \((n = 57)\) and the Architecture \((n = 19)\) groups.

The pooled \(t\)-test is again used for the statistical test when it is found that all the assumptions for the \(t\)-test (normality of the trait, homogeneity of variance, etc.) are met.

2.2.2.1 Hypothesis testing

Table 12.4 shows the results of the statistical test. A statistically significant difference \((t > t_{\text{critical}})\) was found between the mean scores of the civil engineering group and the architecture group at the 5% significance level with a power of 96%.

Table 12.4. Results of data analysis on the Value of the personal usage of S&D using Excel worksheet after Black (1999).

<table>
<thead>
<tr>
<th>Data: Civil</th>
<th>Architecture</th>
<th>Test for Homogeneity of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\bar{x}) = 36.77</td>
<td>41.21</td>
<td>(F = 0.60)</td>
</tr>
<tr>
<td>(s) = 4.11</td>
<td>5.29</td>
<td>(P_{\text{one-tailed}} = 0.05)</td>
</tr>
<tr>
<td>(n) = 57</td>
<td>19</td>
<td>(F_{\text{crit 1-tail}} = 2.33)</td>
</tr>
<tr>
<td>(df) = 74</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Tails = 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>alpha = 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta = 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>power = 0.96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(t) = 3.79</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(t_{\text{critical}}) = 1.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This means that the difference in means is unlikely to be a consequence of a random event and more likely to be due to something specific.

### 2.2.3 The Tendency to use S&D

Table 12.5 shows the means for the two groups on the *Tendency to use S&D* component of the instrument. The score here indicates how frequently the subjects tend to make use of S&D. Again the architecture group reported a higher tendency to make use of S&D (as indicated by the higher mean score) compared to the civil engineering group. The architecture mean is 31.2, which is 5.88 points or 11.6% higher than the mean of the civil engineering group.

#### Table 12.5. Descriptive statistics for the *Tendency to use S&D*

<table>
<thead>
<tr>
<th></th>
<th>Civil engineering</th>
<th>Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>25.44</td>
<td>31.32</td>
</tr>
<tr>
<td>$s$</td>
<td>3.35</td>
<td>3.62</td>
</tr>
<tr>
<td>$n$</td>
<td>57</td>
<td>19</td>
</tr>
</tbody>
</table>

Figure 12.4 shows the distribution on the *Tendency to use S&D*. A score, which is nearer to the right end of the scale, would indicate a higher tendency to make use of S&D. Again, the architecture group appears to be more positive in their tendency to use (S&D).

![Distribution of scores on the Tendency to use S&D](image)

**Figure 12.4.** Distribution of scores on the *Tendency to use S&D* for the Civil engineering, $(n = 57)$ and the Architecture, $(n = 19)$ groups.
Again using the pooled $t$-test for the same reasons as the previous cases, a statistically significant difference was also found between the means of the two groups on the Tendency to use S&D with a power of 99.8% as shown in Table 12.6.

Table 12.6. Results of data analysis on the *Tendency to use S&D* using Excel worksheet after Black (1999).

<table>
<thead>
<tr>
<th>Data:</th>
<th>Civil</th>
<th>Architecture</th>
<th>Test for homogeneity of variance:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{x}$</td>
<td>25.44</td>
<td>31.32</td>
<td>$F =$ 0.86</td>
</tr>
<tr>
<td>$s$</td>
<td>3.35</td>
<td>3.62</td>
<td>$P_{\text{one-tailed}} =$ 0.05</td>
</tr>
<tr>
<td>$n$</td>
<td>57</td>
<td>19</td>
<td>$F_{\text{crit.1-tail}} =$ 2.33</td>
</tr>
<tr>
<td>$df$</td>
<td>74</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>Tails</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>0.998</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t$</td>
<td>6.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$t_{\text{critical}}$</td>
<td>1.99</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 2.3 Summary

In summary, the differences between the mean scores of the engineering group and the architecture group were found to be statistically significant on all components of the Attitude Questionnaire indicating that, compared to the architecture group, the civil engineering group was:

- less likely to be positive in their *Views of the professional role of S&D*
- more likely to have a lower *Value on the personal usage of S&D*
- more likely to have a lower *Tendency to make use of S&D*

The high statistical power for all reported tests (> 96%) is indicative of the credibility of the findings.
3. ARE THE ASSUMPTIONS ABOUT THE RELATIONSHIPS BETWEEN THE THREE ATTITUDE CONSTRUCTS SUPPORTED BY EMPIRICAL EVIDENCE?

The analysis in Chapter 10 shows that there is a statistically significant correlation between all components of the Questionnaire. However, this outcome was based on the analysis of the combined data (Architecture and Engineering data). To understand the relationships between the components and other variables that concern the engineering group, only data from the engineering group was used in the following analysis.

Three hypotheses were formulated to determine the relationships between the attitude components.

a) There will be no statistically significant correlation between the View of professional role and the Value of the personal usage of S&D as measured by the respective components of the attitude instrument.

b) There will be no statistically significant correlation between the Value of the personal usage and the Tendency to use S&D as measured by the respective components of the attitude instrument.

c) There will be no statistically significant correlation between the View of the professional role and the Tendency to use S&D as measured by the respective components of the attitude instrument.

These hypotheses are concerned with establishing associations between variables. To assess the strengths and directions of the associations, the coefficients of correlation between the variables were determined using a Product moment correlation formula. To test these hypotheses, the calculated coefficient $r$, was compared to the critical coefficients at the 5% level of significance for the relevant degree of freedom. The correlation coefficients between the instrument component are displayed in Table 12.7. The underlying assumption for using the product moment formula is that the distributions for the underlying population are approximately normal and the relationships between variables are linear.
Table 12.7. Product moment correlation coefficients between components of the Attitude Questionnaire for the Civil engineering sample (n = 57).

<table>
<thead>
<tr>
<th>View of professional role S&amp;D</th>
<th>Value of personal usage S&amp;D</th>
<th>Tendency to use S&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07</td>
<td>0.44 *</td>
<td>0.14</td>
</tr>
</tbody>
</table>

*p < 0.05

Table 12.7 shows that a positive correlation is found between all of the Questionnaire components, however, a statistically significant correlation was only found between the View of the professional role of S&D and the Tendency to use S&D. Therefore, only the third hypothesis “There will be no statically significant correlation between the View of the professional role and the Tendency to use S&D as measured by the respective components of the attitude instrument was rejected. The statistically significant result indicates that the observed correlation is unlikely to have occurred by chance alone but more likely to be the consequence of a specific cause. The scatter diagram in Figure 12.5 illustrates graphically the relationship between the scores of the two statistically significantly related components – the View of the Professional role of S&D and the Tendency to use S&D.

![Scatter diagram](image)

Figure 12.5. Scatter diagram illustrating the relationship between the View of the professional role of S&D and the Tendency to use S&D (r = 0.44, p < 0.05, n = 57).
The linear trend in the data points is an indicator of the linear relationship between the two components. The coefficient of determination, ($r^2 \times 100$), an indication of the percentage of shared variance is found to be 19% between the two components. This means that 19% of the factors accounting for variability are common to both components as illustrated in Figure 12.6.

![Figure 12.6. Venn diagram illustrating the shared variances between the View of the professional role of S&D and the Tendency to use S&D.](image)

The outcome of the statistical test does not reject the first and second null hypotheses (recall Table 12.7). Therefore, the positive correlations obtained between the variables in the first and the second hypotheses are likely to be the consequence of chance alone. The scatter diagram in Figure 12.7 illustrates the low correlation between the View of professional role and the Value of personal usage of S&D.

![Figure 12.7. Scatter diagram illustrating the relationship between the Value of personal usage of S&D and the Tendency to use S&D ($r = 0.14$, n.s, $n=57$).](image)
The absence of any relationship between the Value of personal usage of S&D and the Tendency to use S&D (the two attitude components found in the second hypothesis) is also illustrated by the scattered data points in Figure 12.8.

Figure 12.8. Scatter diagram illustrating the relationship between the View of the professional role of S&D and the Value of personal usage of S&D (r = 0.07, n.s, n = 57)

3.1.1 Summary
Statistically significant correlation only exists between the score on the View of the professional role towards S&D and the Tendency to use S&D. In other words, only how the subjects view S&D professionally and how often they say they use S&D is likely to be related. The subjects' personal value of S&D however, is not related to either to how they view the professional role of S&D or to how often they tend to use S&D.

4. HOW ARE THE THREE ATTITUDE CONSTRUCTS RELATED TO SV ABILITY?

Four hypotheses were tested in relation to attitudes towards S&D and SV ability. These hypotheses were stated as:

a) There will be no statistically significant correlation between the View of the professional role towards S&D as measured by the corresponding component of the Attitude Questionnaire and SV ability as measured by the SVATI post-test
b) There will be no statistically significant correlation between the \textit{Value of the personal usage of S&D} as measured by the corresponding component of the Attitude Questionnaire and SV ability as measured by the SV ability post-test.

c) There will be no statistically significant correlation between the \textit{Tendency to use S&D} as measured by the corresponding component of the Attitude Questionnaire and SV ability as measured by the SVATI post-test.

The Pearson product moment correlations for the pairs of variables stated in the above hypotheses were computed and compared to the critical coefficients for the relevant degree of freedom. The results of the analysis are shown in Table 12.8.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
 & View of professional role of S&D & Value of personal usage of S&D & Tendency to use S&D \\
\hline
SV ability & 0.07 & 0.18 & 0.36* \\
\hline
n & 57 & & \\
\hline
df & 55 & & \\
\hline
r_{crit} & 0.26 at 5\% significance level & & \\
\hline
\end{tabular}
\caption{Pearson product moment correlations between the Attitude constructs and the SV ability}
\end{table}

*p < 0.5

Table 12.8 shows that all of the Questionnaire components are positively correlated to SV ability. However, at the 5\% level of significance, it is found that only the \textit{Tendency to use S&D} is statistically significantly correlated to \textit{SV ability} (p < 0.5). This means that there is likely to be more than a chance association between the \textit{Tendency to use S&D} and \textit{SV ability}. The non-statistically significant correlations between SV ability and the Personal value of S&D and between SV ability and the View of the professional role of S&D indicate that the observed associations are likely to be the results of chance alone.

In other words, the subjects’ SV ability is unlikely to be related to how they View S&D professionally or how they value S&D personally. However, what they claim they do with S&D is highly likely to be related to their SV ability. The correlation coefficient is computed, based on the assumption that the relationships between the
variables are linear. Figures 12.9 to 12.11 illustrate graphically the relationships between the variables.

Figure 12.9. Scatter diagram illustrating the relationship between SV ability and the View of the professional role of S&D. ($r = 0.07$, n.s, $n = 57$)

The scatter diagram in Figure 12.9 illustrates the relationship between SV ability and the View of the professional role of S&D which is not statistically significant at the 5% level. Scatter diagram in Figure 12.10 illustrates the relationship between SV ability and the Value of personal usage of S&D.

Figure 12.10. Scatter diagram illustrating the relationship between SV ability and the Value of personal usage of S&D. ($r = 0.18$, n.s, $n = 57$)
The scattered data points clearly indicate the low correlation between the two variables. Figure 12.11 on the other hand shows a clearer linear trend in the relationship between SV ability and the Tendency to use S&D

![Figure 12.11. Scatter diagram illustrating the relationship between SV ability and the Tendency to use S&D (r = 0.36, p < 0.05, n = 57)](image)

Table 12.9 shows the correlation coefficients between all the Questionnaire components and between the Questionnaire components and SV ability. It shows that the Tendency to use S&D is statistically significantly correlated to the View of professional role of S&D. It also shows that the Tendency to use S&D is statistically significantly correlated to SV skills.

<table>
<thead>
<tr>
<th>Value of personal usage S&amp;D</th>
<th>Tendency to use S&amp;D</th>
<th>Spatial visualisation ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>View of professional role S&amp;D</td>
<td>0.07</td>
<td>0.44*</td>
</tr>
<tr>
<td>Value of personal usage S&amp;D</td>
<td>0.14</td>
<td>0.18</td>
</tr>
<tr>
<td>Tendency to use S&amp;D</td>
<td>0.36</td>
<td></td>
</tr>
</tbody>
</table>

p<.05

It appears that Tendency to use S&D is related to both the View of professional role of S&D and SV ability. Although the relationship is statistically significant, this does
not mean that one variable is causing the other. The temptation to claim a causal relationship is very high especially in the case between the Tendency to use S&D and SV ability, everyday experiences teach us that practice makes perfect. Therefore, frequent use of S&D might be causing an improvement in SV ability. However, a counter argument could also be put forward, that is, those who have better SV skills might tend to use S&D. Therefore, although in this case claim for causality appears to be plausible, the direction of causality is uncertain which invalidates the claim. Finally, the most appropriate inference that could be made remains to be an association one.

Integrating the findings from Chapter 11, a model for the relationships between the attitude constructs, the treatment and SV ability is suggested in Figure 12.12.

![Figure 12.12. Suggested model for the relationships between the attitude constructs towards S&D, teaching and learning of SV skills and SV ability, based on empirical evidence.](image)

Figure 12.12. Suggested model for the relationships between the attitude constructs towards S&D, teaching and learning of SV skills and SV ability, based on empirical evidence.

Figure 12.12 shows that the engineering subjects’ view of the professional role of S&D is statistically significantly correlated to their tendency to use S&D. It also shows that for them, tendency to use S&D is statistically significantly correlated to SV ability.

5. CONCLUSION

The results of the analysis in this chapter suggest that subjects’ Tendency to use S&D is not related to their Value of personal usage of S&D. However, their Tendency to
use S&D appears to be associated with perceived usefulness of S&D to their future career.

As to their relationships with SV ability, a relationship is only found between the Tendency to use S&D and SV ability. In other words, tendency to use S&D is directly related to SV ability while views of professional role of S&D that the subject have appears to be only indirectly related to SV ability.

The next chapter (Chapter 13) will present and analyse the data from mini-study 3 which investigates the relationship between SV ability and structural design problem solving and on how the learning materials used for enhancing SV skills may have influenced structural design problem solving.
CHAPTER 13

Data Analysis for Mini-study 3: Spatial Visualisation Ability and Structural Design Problem Solving.

1. INTRODUCTION

Chapters 11 and 12 analysed the data from mini-study 1 and 2 respectively. They showed that; (i) the teaching and learning of SV skills enhances SV ability, (ii) the View of the professional role of S&D is correlated to the Tendency to use S&D which in turn is correlated to SV ability. This chapter will present and analyse the data from mini-study 3 that has the following objectives, i.e., to:

(i) determine whether there is a relationship between SV ability and structural design problem solving,

(ii) determine the effects of teaching and learning of SV skills on structural design problem solving

This chapter will deal with the above objectives in turn and will then suggest ways in which the various factors (learning materials, the measure, etc.) may be related.

2. RELATIONSHIP BETWEEN SV ABILITY AND STRUCTURAL DESIGN PROBLEM SOLVING.

To determine the relationship between SV ability and structural design problem solving skills, only data collected from subjects who sat for both the SVATI pre-test and the structural design instrument (SDI) were analysed. The subjects were therefore, the semester six of the June-Nov. 1998 session and the number of subjects (who sat for both tests) was 43. The SVATI pre-test scores were used in the analysis to eliminate any confounding from the teaching and prior learning of SV skills. As a reminder, the pre-test scores consisted of the scores of both groups who had not been taught SV skills. The post-test scores on the other hand, consisted of the scores of those who had been taught SV skills as well as the scores of those who had not (recall Chapter 5, Figure 5.1).
Figure 13.1 displays the distributions of scores on the SVATI and the SDI. Figure 13.1 shows that the distributions for both the SVATI and the SDI are approximately normal indicating that the traits under study are normally distributed.

![Distribution of scores on (a) the SVATI and (b) the SDI](image)

Figure 13.1. Distributions of scores on (a) the SVATI and (b) the SDI (n = 43)

The scatter diagram shown in Figure 13.2 illustrates the relationship between SV ability and SD problem solving skill. The scatter diagram shows that the relationship between SV ability and structural design problem solving is approximately linear. The strength of the relationships is determined by computing the Product moment correlation coefficient between the two variables. The correlation coefficient between the two variables is calculated to be +0.48, indicating a modest positive relationship between them. The positive coefficient indicates that those who scored highly on the SVATI also tend to score highly on the SDI and vice versa. The critical correlation coefficient ($r_{critical}$) at the 5% significance level for the degree of freedom ($df$) = 41 is 0.3, which means, $r > r_{critical}$. Since $r > r_{critical}$, the correlation is said to be statistically
significant, suggesting that the observed correlation between the SV ability and SD problem solving is highly unlikely to be an outcome of a random event.

![Figure 13.2. Scatter diagram illustrating the relationship between SV ability and Structural design problem solving skills ($r = 0.48$, $p < 0.05$, $n = 43$)](image)

The index of determination, $r^2 \times 100$ is calculated to be 23%, indicating that 23% of the variances are common to the SVATI and the SDI. Although correlation in general does not indicate causal relationship between the correlated measures, the cause of the observed correlation between the SVATI and the SDI is suggested to be SV skills. This is because the SDI items had been specifically designed to demand the SV skills that were also demanded by SVATI items. A word of caution from Howe (1988) not to take an assumed underlying quality - supposedly shared between any two correlated measures - as a sure indication of it being the cause of the correlation has been noted. In this study, the demand for SV skills, the underlying skills that are suggested to be the cause of the correlation have been deliberately introduced in the two measures and not simply assumed.

Results on the effects of the teaching and learning of SV skills, which will be presented in the next section, give support to the causality claim.
3. EFFECTS OF TEACHING SV SKILLS ON STRUCTURAL DESIGN PROBLEM SOLVING.

A quasi-experimental design of Post-Test/observation with a control group (Black, 1999) using intact classes of semester six students was adopted for the study. The experimental group was the two classes of semester six students \( (n = 77) \) of the June-November 1998 session and the control group was two classes of the semester six students \( (n = 61) \) from the previous semester, i.e., the Dec. 1997 - May 1998 session.

Descriptive statistics were used to present the data and the pooled \( t \)-test was used to test for statistical significance. The use of the pooled \( t \)-test was justified having satisfied the following conditions:

- the distributions of the traits under study - the scores on the SVATI and the SDI - are approximately normal (recall Figure 13.1)
- the two groups, the control and experimental group, had homogeneity of variance \([F, (0.33) < F_{\text{critical}}, (1.63)]\) as shown in Table 13.2
- there is independence of data and the variances are additive, a consequence of research design

3.1 Results of data analysis

Figure 13.3 shows the distributions of the scores on the SDI for the experimental and the control group.

![Figure 13.3. Frequency distributions of the scores on the SDI for the control group \( (n = 77, \bar{x} = 23.99, s = 6.94) \) and the experimental group \( (n = 61, \bar{x} = 27.34, s = 12.03) \)](image-url)
The control group appears to have a smaller range of skills compared to the experimental group although this does not seem to be statistically significant as shown by the results of the F-test given in Table 13.2.

Table 13.1 shows the descriptive statistics for the two groups. This table shows that the mean score of the experimental group is higher compared to the control group. The mean of the experimental group is 27.34 and that of the control group is 23.99, i.e., the mean of the experimental group is 3.35 points higher than that of the control group.

### Table 13.1. Descriptive statistics on the SDI for the control and the experimental groups.

<table>
<thead>
<tr>
<th>Data:</th>
<th>Control</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} ) =</td>
<td>23.99</td>
<td>27.34</td>
</tr>
<tr>
<td>( s ) =</td>
<td>6.94</td>
<td>12.03</td>
</tr>
<tr>
<td>( n ) =</td>
<td>77</td>
<td>61</td>
</tr>
</tbody>
</table>

### 3.2 Hypothesis testing

Table 13.2 shows the results of the statistical tests. The statistical test shows that the difference between the experimental and the control group is statistically significant (\( t > t_{\text{critical}} \)).

### Table 13.2. Results of analysis on the SDI using worksheet in Excel from Black (1999).

<table>
<thead>
<tr>
<th>Data:</th>
<th>Control</th>
<th>Experiment</th>
<th>Test for homogeneity of variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{x} ) =</td>
<td>23.99</td>
<td>27.34</td>
<td>( F ) = 0.33</td>
</tr>
<tr>
<td>( s ) =</td>
<td>6.94</td>
<td>12.03</td>
<td>( P_{\text{one-tailed}} = 0.05 )</td>
</tr>
<tr>
<td>( n ) =</td>
<td>77</td>
<td>61</td>
<td>( F_{\text{critical}} = 1.63 )</td>
</tr>
<tr>
<td>( df ) =</td>
<td>136</td>
<td>136</td>
<td>( t )-test</td>
</tr>
<tr>
<td>tails = 2</td>
<td></td>
<td></td>
<td>power = 0.53</td>
</tr>
<tr>
<td>alpha = 0.05</td>
<td></td>
<td></td>
<td>( t ) = 2.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>( t_{\text{critical}} = 1.98 )</td>
</tr>
</tbody>
</table>
The statistically significant difference (although the power is just above 50%) indicates that the higher score obtained by the treatment group is unlikely to have occurred by chance alone. Therefore, the hypothesis of no difference between the two groups is rejected.

Having established earlier that the groups were equivalent by virtue of the polytechnic placement and selection procedure (recall Chapter 5), and that the confounding variables were controlled for by design, the higher gain score on the SDI for the experimental group is therefore, more likely to be the effect of the treatment. However, from the skewed distribution of the experimental group, there appear to be only 10%, i.e., only six students from the experimental group whom really benefited from the intervention/treatment.

3.3 Effects of teaching and learning of SV skill on structural design problems of different cognitive emphasis.

Investigating the effects of teaching and learning of SV skills on SD problems that are at a different cognitive emphasis was not initially one of the objectives of the study. However, in hindsight, it was decided that extending the data analysis to include the above objective would be beneficial because it may provide a better understanding of the relationships between SV ability and structural design problem solving.

Although the SDI as a whole was designed to measure problem solving skills in structural design, the individual items in the SDI were designed with different cognitive emphasis, (recall Chapter 8). However, for the purpose of the present analysis, these items will be broadly classified into the following three categories:

- the knowledge of concepts level - measures the knowledge of concepts of axis and planes in the context of bending moments
- the application level - measures the understanding of structural behaviour demonstrated by the ability to sketch the visual changes of structure under applied loads
- the analysis and evaluation level - measures the ability to analyse design problems and the ability to evaluate proposed design solutions
The following null hypotheses were formulated to guide the inquiry:

a) There will be no statistically significant difference between the means of the treatment group compared to the control group on the Knowledge of concept items of the SDI.

b) There will be no statistically significant difference between the means of the treatment group compared to the control group on the Application items of the SDI.

c) There will be no statistically significant difference between the means of the treatment group compared to the control group on the Analysis and evaluation items of the SDI.

3.3.1 Methods of data analysis
The pooled t-test was again used for the same reason as those given in Section 3.1: normality of distribution as indicated by the graph in Figure 13.4; homogeneity of variance as indicated by the F-test in Table 13.4 and independence of measure which was the consequence of the research design.

3.3.2 Results of data analysis
The results of the analysis on the three intellectual levels, the concept level, the application level and the analysis and evaluation level, will be presented next in turn.

3.3.2.1 Knowledge of Concept level
Table 13.3 displays the descriptive statistics for the individual components of the SDI, the Knowledge of concept, the Application and Analysis and evaluation components. This Table shows that the control group has a higher mean score compared to the experimental group on the concept items. However, the difference between the means is very small (0.29%) and unlikely to be statistically significant.
Table 13.3. Descriptive statistics on the Knowledge of concept, the Application and the Analysis and evaluation components of the SDI.

<table>
<thead>
<tr>
<th>Cognitive Level</th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>deviation</td>
<td>deviation</td>
</tr>
<tr>
<td>Knowledge of concepts of axes and planes of reference (10 points)</td>
<td>5.54 (55.4%)</td>
<td>1.59</td>
</tr>
<tr>
<td>Application - structural behaviour (33 points)</td>
<td>16.59 (50.3%)</td>
<td>8.49</td>
</tr>
<tr>
<td>Analysis and evaluation (57 points)</td>
<td>5.21 (9.1%)</td>
<td>4.79</td>
</tr>
</tbody>
</table>

Figure 13.4 shows the frequency distribution for the scores of the experimental and the control group on the Concept component of the SDI. It shows that the distributions of both groups are very similar.

![Frequency distribution graph](image)

Figure 13.4. Distributions of scores on the Concepts component of the SDI ($n_{exp.} = 61$, $n_{cont.} = 77$). Nov. 98 is the experimental group and May 98 is the control group.

### 3.3.3 Hypothesis testing

Table 13.4 shows the results of the statistical tests. It shows that the difference in means between the control and the experimental group is not statistically significant at the 5% level of significance. Therefore, hypothesis a) is not rejected and the observed difference is likely to be the consequence of chance alone.
Table 13.4. Results of analysis on the Concept component of the SDI using worksheet in Excel from Black (1999).

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Experimental</td>
</tr>
<tr>
<td>( \bar{x} )</td>
<td>5.83</td>
<td>5.54</td>
</tr>
<tr>
<td>( s )</td>
<td>1.29</td>
<td>1.59</td>
</tr>
<tr>
<td>( n )</td>
<td>77</td>
<td>61</td>
</tr>
<tr>
<td>( df )</td>
<td>136</td>
<td>136</td>
</tr>
<tr>
<td>tails</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>alpha</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

In summary, there appears to be no difference in the performance on the concept items between the control and the experimental group. This suggests that neither whole object rotations nor manipulations of beam models could enhance the understanding of axis and planes where bending moments is concerned.

Failure to transfer could be due to the dissimilarities between the whole object rotation and the beam rotation. For one, beam rotation is not a whole object rotation, but is a restrained rotation. In restrained rotation, a restraint to movement is placed on some part of the rotated object, which causes a bending effect rather than rotated object effect. This means the role of axis in the bending of beam may sometimes fail to be demonstrated. Therefore, although subjects manipulated beam models that produce bending, which naturally involve rotation, the role of rotation and the relationships between the various elements that are involved in producing the beam deformations may not be clearly demonstrated using the beam model or the building cubes.

3.3.3.1 The Application level
The mean of the experimental group is higher than the mean of the control group on the Application items (recall Table 13.3) and the difference in means looks likely to be statistically significant at the 5% level of significance. Figure 13.5 shows the distribution of the scores for the experimental and control group on the Application items.
Figure 13.5. Distributions of the scores on the application items \((n_{exp.} = 61, n_{cont.} = 77)\). Nov. 98 is the experimental group and May 98 is the control group.

### 3.3.4 Hypothesis testing

Table 13.5 shows the result of the statistical test. It shows that the difference in means between the control and the experimental group is statistically significant at the 5\% significance level, with a very high power of 99.9\%.

<table>
<thead>
<tr>
<th>Data</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>control Experimental</td>
</tr>
<tr>
<td>(\bar{x} = )</td>
<td>9.78</td>
</tr>
<tr>
<td>(s = )</td>
<td>3.63</td>
</tr>
<tr>
<td>(n = )</td>
<td>77</td>
</tr>
<tr>
<td>df ( = )</td>
<td>136</td>
</tr>
<tr>
<td>tails ( = )</td>
<td>2</td>
</tr>
<tr>
<td>alpha ( = )</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The mean of the experimental group is almost twice that of the control group (recall Table 13.2) which is a considerable difference in the amount of learning.

This outcome is therefore, academically significant because it reinforces the view that with the appropriate teaching and learning strategy, learning can occur. The outcome is especially encouraging for the teaching and learning of structural design because it...
shows that as little as twenty minutes of instruction time may be all that is needed to produce a long term positive learning transfer on the basic understanding of structural behaviour. As stated in Chapter 5, the time spent on learning to understand structural behaviour was only twenty minutes out of the total treatment time, which is six hours. Within this time, two types of activity were carried out:

(i) The teacher demonstrating the behaviour of a loaded beam and explaining the inter-relationships between deflections, the internal forces and the reactions using a flexible beam model, sketches of the visual deformation of the loaded beam, sketches of the distributions of its internal forces and the graphical representations of the supports' reactions.

(ii) The subjects co-operatively solving three structural behaviour problem by sketching the beam deformation, the moment distributions, the shear forces and the beam reactions on the blackboard.

The outcome is made more noteworthy by the fact that the interval between the treatment and the transfer test (SDI) was nearly four months (recall Chapter 5, Section 5). A possible explanation is the concrete model together with S&D may have facilitated meaningful learning of structural behaviour. In other words, the use of the beam model to illustrate deflections together with the use of S&D to illustrate beam deflections and structural actions may have facilitated the linking of the physical and concrete phenomena (deflection) to the more abstract ones (bending moments, etc). Thus, facilitating the conceptual understanding of structural behaviour.

3.3.4.1 Analysis and Evaluation level

At the analysis and evaluation level, the mean of the control group is found to be much higher than the experimental group (recall Table 13.3). In fact the mean of the control group nearly doubles that of the experimental group and is likely to be statistically significant.

Figure 13.6 illustrates the distribution of scores on the Analysis and evaluation component of the SDI for the experimental and the control group. It shows that approximately a third of the control group's scores are higher than the experimental group's scores.
3.3.5 Hypothesis testing

Table 13.6 displays the results of the statistical tests. It shows that the difference between the means of the experimental and the control group is statistically significant at the 5% level of significance. Therefore, hypothesis c) (p. 3-7) was rejected suggesting that the difference in means was unlikely to be the consequence of a random event alone.

This outcome is highly unexpected in view of the inference that could be made from it. For example, it could be inferred that the ability to analyse and evaluate a design is negatively affected by the teaching and learning of SV skills.

Table 13.6. Results of analysis on the Analysis and evaluation component of the SDI using Excel worksheet from Black (1999).

<table>
<thead>
<tr>
<th>Data</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>$\bar{x}$ $= \times $</td>
<td>8.38</td>
</tr>
<tr>
<td>$s$ $= \times $</td>
<td>4.59</td>
</tr>
<tr>
<td>$n$ $= \times $</td>
<td>77</td>
</tr>
<tr>
<td>$df$ $= \times $</td>
<td>136</td>
</tr>
<tr>
<td>tails $= \times $</td>
<td>2</td>
</tr>
<tr>
<td>alpha $= \times $</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Considering that the understanding of structural behaviour - on which the control group did poorly - is pre-requisite to the Analysis and evaluation items, to suggest that the teaching and learning of SV skills causes negative transfer is quite unjustified.

One factor, which could have contributed to the unexpected outcome, is poor time management on the part of the treatment subjects, indicated by responses of the treatment subjects that appeared to be provided in haste. For example:

- five subjects failed to give the appropriate form of responses indicating that they did not read the questions properly
- four subjects left these items unanswered
- very few got the first part of the items correct although the items are similar to Items 11 and 12 on which the experimental group scored high
- none fully answered the second part of these items

The treatment subjects might have spent too much time on the Application items - in which they had confidence, which left them with insufficient time to answer the remaining items, i.e., the analysis and evaluation items.

3.4 Summary of performance on the SDI items

In summary, the treatment group performed better on the SDI. However, increase in performance is only found on the Application items. The treatment group performed equally well with the control group on the concept items but performed worse on the analysis and evaluation items.

In general, the overall performance on the SDI items was poor. The average score was only 25% indicating that the SDI was exceptionally hard for the subjects although the questions posed should be within the realm of their capability.

The subjects’ performance also declined rapidly with increasing cognitive demands as illustrated by the graph in Figure 13.7. Figure 13.7 shows that the percentage score is the highest on the concept items, lower on the Application items and lowest on the Analysis and evaluation items. The percentages were calculated based on the highest

13-13
possible score for the corresponding skill category. For example, for the concept category, the highest possible score is ten and therefore, a score of 5.54 is 55.4%.

![Bar Graphs illustrating the performance on the Knowledge, Applications and Analysis and evaluation components of the SDI.](image)

**Figure 13.7.** Bar Graphs illustrating the performance on the Knowledge, Applications and Analysis and evaluation components of the SDI.

4. CONCLUSION

This chapter shows that SV ability is related to structural design problem solving. It also shows that teaching methods that are designed to improve SV skills can also have positive effects on problem solving in structural design. However, the degree of effect of the teaching and learning on the different cognitive emphasis varies.

The findings suggest that the teaching and learning of SV skills has the most influence on the understanding of structural behaviour as indicated by the higher performance on the Application items. However, the learning materials provided for teaching and learning of the SV skills do not appear to support the learning of conceptual knowledge that is related to bending moments, axis and planes of references. The effect of the learning materials on the analysis and evaluation skills is inconclusive.

In brief, improvement in SV ability could be translated into improvement in structural design problem solving if learners are provided with appropriate learning materials, such as materials that are conducive to meaningful learning experiences.
The next chapter will present and analyse the data from mini-study 4 that investigates the relationship between SV ability and problem solving in structural theory - another subject area in civil engineering.
CHAPTER 14

Data Analysis for Mini-study 4: Spatial Visualisation Ability and Problem Solving in Structural Theory

1. INTRODUCTION.

The results of data analysis in Chapter 13 have shown that teaching and learning of SV skills influences problem solving in structural design as measured by the SDI. This chapter will present and evaluate the data from mini-study 4 to determine the effect (if any) of the same teaching and learning materials on problem solving in structural theory a subject area, which is highly mathematical oriented and closely related to structural design.

This chapter is divided into three sections and a conclusion. The first section describes the method of data collection followed by the second section, which presents the results of the data analysis from mini-study 4. The third section compares the results from mini-study 3 and the mini-study 4 and the conclusion summarises the chapter.

2. METHODS OF DATA COLLECTION AND ANALYSIS

A quasi-experimental design of post-test with a control group (Black, 1999) using two intact classes of semester six students was adopted for the study. The experimental group was the two classes of semester six students \( n = 79 \) of the June-November 1998 session and the control group was two classes of the semester six students \( n = 66 \) from the previous semester, i.e., the Dec. 1997 - May 1998 session.

2.1 Research questions and hypotheses

Two research questions had been formulated for this enquiry, which were:

a) Is there a relationship between SV ability and examination performance in solving structural theory problems?
b) Does teaching and learning of SV skills employing object manipulations, sketching and drawing (S&D) enhance examination performance in solving structural theory problems?

Two null hypotheses were formulated for the above questions, which were:

a) There will be no statistically significant correlation between SV ability as measured by the SVATI and performance on structural theory problems as measured by the ST Paper.

b) There will be no statistically significant difference between the treatment group and the control group in their performance on structural theory problems as measured by the ST Paper.

2.2 Justification for the hypotheses

Skills learned from the teaching and learning of SV skills were expected to transfer to problem solving in structural theory as they did in the case of the structural design, and would be expected to manifest themselves by a higher examination score for the treatment group. This expectation is based on the following argument.

Structural theory problems share a common characteristic with SD problems in that they both deal with problems of structures, which are spatial in nature. Since SV skills have been found to be related to and to influence problem solving in structural design (Chapter 13), it is logical to expect that some relationship may exist between solving structural theory problems and SV ability.

Furthermore, structural theory problems share the characteristic of mathematics problems in that they both deal with mathematical procedures. As problem solving in mathematics has been shown to be related to SV ability, structural theory is also expected to be related to SV ability.

SV ability has also been suggested to facilitate conceptual understanding (Battista, 1994) therefore, SV ability may aid in building the relationship between the real structural phenomena and its mathematical models.
The diagram in Figure 14.1 represents the proposed relationships between the four concepts, SV ability, mathematics, structural theory problems and structural design problems, which lead to the research questions and hypotheses.

Figure 14.1. Proposed relationships between mathematics, structural design, structural theory and SV ability.

3. RESULTS OF DATA ANALYSIS

The results of data analysis are divided into two sections:

- Relationship between SV ability and performance on structural theory problems
- Effects of teaching SV skills on performance in structural theory problems.

3.1 Relationship between SV ability and performance on structural theory problems.
Integrating data from the earlier study on SV ability, a positive correlation between SV ability and structural theory (r = 0.18) was obtained. Nevertheless, this correlation was not found to be statistically significant at the 5% significance level indicating that the observed correlation could have arisen out of chance alone, and was not significantly different from zero.

The relationship between SV ability and structural theory is shown visually in a scatter diagram in Figure 14.2.

![Figure 14.2. Scatter diagram illustrating the relationships between SV ability and performance on structural theory problems (r = 0.18, n.s, n = 43).](image)

Since structural theory problems are similar to structural design and mathematics problems, which have been found to be correlated to SV ability, the result in this study is highly unexpected. However, according to Battista (1994), spatial thinking is not necessarily required in mathematical problem solving, especially if the learning had occurred through rote memorisation of procedures and manipulations of symbols. This type of learning may support the learning of procedural knowledge, i.e., the knowledge of *knowing how/instrumental understanding* but not necessarily the
knowledge of *knowing why/relational understanding/conceptual understanding*. Therefore, problems may be mechanically solved without knowing the reasons behind the mechanics of it or the relationships between the various concepts that are involved in it (Clement, 1981 and Luke, 1986).

The structural theory problems (recall Appendices 8 and 9) do not appear to require relational understanding or "knowing how skills" for they do not possess the characteristics of the types of questions that could be used to assess the degree of conceptual understanding as suggested by Clement (1981). According to Clement (1981) these characteristics include:

- drawing qualitative graphs
- solving problems with extra unnecessary information
- giving coherent verbal descriptions

Using the above criteria for evaluating the structural theory problems, it can be concluded that the problems in the ST Paper do not appear to require relational understanding because:

- drawing of qualitative graphs carries less than 25% of the total allocated marks
- none of the problems involve solving problems with extra information
- none of the problems require coherent verbal description - all answers are numerical in nature.

Therefore, the structural theory problems are mathematics problems that only demand *instrumental understanding* or *knowing how skills* for solving them. In other words, these structural theory problems only require knowing how to apply mathematical procedures and knowing how to manipulate mathematical symbols which most probably have been learnt through *rote memorisation of procedures and manipulations of symbols*. The subjects' extremely poor performance in the structural design paper (Chapter 13) where there was no previous similar items to be rote-learned appear to support the rote-learning hypothesis.
In brief, it may be concluded that there is no correlation between SV ability and the examination performance in solving structural theory problems in the ST Paper because these problems were likely to have been solved by rote memorisation of procedures and symbols manipulation which do not demand SV skills.

3.2 Effects of teaching SV skills on performance in structural theory problems.

Table 14.1 shows the descriptive statistics for the experimental and the control groups. The magnitude of the means and standard deviations for both groups are comparable to each other. The treatment group had a mean of 32.23 and standard deviation of 10.66 while the control group had a mean of 31.20 and standard deviation of 11.58.

<table>
<thead>
<tr>
<th></th>
<th>Experimental group</th>
<th>Control group</th>
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<tbody>
<tr>
<td>$\bar{x}$</td>
<td>32.23</td>
<td>31.20</td>
</tr>
<tr>
<td>$s$</td>
<td>10.66</td>
<td>11.58</td>
</tr>
<tr>
<td>$n$</td>
<td>66</td>
<td>79</td>
</tr>
</tbody>
</table>

Figure 14.3 show the frequency distributions for the two groups. The distributions are skewed to the right indicating a difficult paper for the subjects.

![Frequency Distributions](image)

Figure 14.3. Performance on structural theory problems for the treatment group ($n = 66, \bar{x} = 32.23, s = 10.66$) and the control group ($n = 79, \bar{x} = 31.20, s = 11.58$)
3.3 Hypothesis testing
Since normality of the trait's distribution for the underlying population appears to be violated (indicated by the highly skewed distributions in Figure 14.3), the non-parametric Wilcoxon-Mann-Whitney test was used instead of the parametric t-test in testing for statistical significance. Table 14.2 shows the results of the data analysis. It shows that statistical significance was not found in the difference between the means of the experimental and the control group at the 5% significance level indicating that the observed difference was the consequence of a chance event.

<table>
<thead>
<tr>
<th></th>
<th>Experimental group</th>
<th>Control group</th>
</tr>
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<tbody>
<tr>
<td>$W$</td>
<td>4533</td>
<td>5337</td>
</tr>
<tr>
<td>$n$</td>
<td>61</td>
<td>79</td>
</tr>
<tr>
<td>$\bar{x}$</td>
<td>32.25</td>
<td>31.20</td>
</tr>
<tr>
<td>$s$</td>
<td>10.72</td>
<td>11.65</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>$z(\alpha)$</td>
<td>1.96</td>
<td>Total $W$= 9870</td>
</tr>
<tr>
<td>$z(WMW)$</td>
<td>0.98</td>
<td>Check = 9870</td>
</tr>
</tbody>
</table>

3.4 Summary
Performance in solving structural theory problems as measured by the ST Paper is not related to SV ability. This does not however, mean that SV ability is not related to solving structural theory problems in general for there is some evidence to show that the problems in ST Paper do not demand other than instrumental understanding - knowing how to manipulate symbols and apply mathematical procedures. Therefore, it does not necessarily follow that SV ability is not related to structural theory problems that require relational understanding - knowing how variables, concepts are inter-related and why the prescribed procedures work.

To determine the relationship between SV ability and the solving of structural theory problems in general, problems need to be designed to demand more than simply instrumental understanding, which could be learned through rote-memorisation. The
problems need to be designed to demand relational understanding where subjects will have the opportunity to display other types of skills and solving strategies, which may include SV skills. Therefore, structural theory problems that test the understanding of the underlying concepts and relational understanding, is recommended for future study.

4. COMPARISON BETWEEN THE PERFORMANCE ON THE SDI AND THE ST PAPER

Figure 14.4 illustrates the distribution of scores on the SDI and the ST Paper for the experimental group. Although the total number of subjects in the structural design study was 66, the number of subjects who sat for both papers (SDI and the ST Paper) was only 61. Therefore, \( n = 61 \) was used to compare performances on the two instruments. Figure 14.4 shows that the performance of the experimental group is much better on the ST paper than on the SDI.

![Figure 14.4. Performance on the structural theory paper and the structural design paper for the experimental group (n = 61)](image)

Figure 14.5 shows the performance of the control group on the SDI and the ST Paper. Again, although the total number of subjects in the structural design study was 79, the number of subjects who sat for both papers was only 77. Therefore, \( n = 77 \) was used to compare the performances on the two instruments. Figure 14.5 also shows that the performance of the control group is better on the ST Paper than on the
SDI. It appears that, in general, both groups found the problems in the SDI to be more challenging than the problems in the ST paper as indicated by their inferior performance on the SDI. As suggested earlier, the ST problems only require stepwise algorithmic mathematical manipulation of identified formula, while the SD problems demanded the understanding of the relationships between the underlying concepts - relational understanding - which requires SV ability.

![Graph showing performance on the structural design instrument and structural theory paper for the control group (n = 77)](image)

**Figure 14.5.** Performance on the structural design instrument and structural theory paper for the control group (n = 77)

Integrating the results from Chapters 11, 12, 13, a model for the relationships between the various variables is presented in Figure 14.6.

![Diagram showing relationships between variables](image)

**Figure 14.6.** The relationships between the variables in the study based on empirical evidence.
Figure 14.6 shows that enhancing SV ability benefits problem solving in structural design but not problem solving in structural theory. Tendency to use S&D is directly related to SV ability and indirectly related to structural design problems solving.

5. CONCLUSION

The results of the analyses suggest that there is no relationship between SV ability and performance on structural theory problems as measured by the ST Paper. The results also show that the teaching and learning of SV skills does not influence performance in solving structural theory problems.

The lack of relationship between SV ability and examination performance in solving structural theory problems, which is contradictory to expectation, is attributed to the lack of demand on SV ability in the structural theory problems. The structural theory problems posed in the ST paper only demanded instrumental understanding or 'knowing how skill' and therefore, could be solved simply by rote memorisation of procedures and manipulations of mathematical symbols, which does not require SV ability.

The conclusions and implications of the findings from the entire data analysis chapter will be brought together in the next chapter, on conclusion and implications.
CHAPTER 15

Conclusions, Implications and Recommendations

1. INTRODUCTION

This study set out to investigate the relationships between four variables; teaching and learning of SV skills, SV ability, attitudes towards S&D (beliefs about S&D, personal values concerning S&D and tendency to use S&D) and civil engineering problems solving skills.

It was originally assumed that teaching and learning of SV skills would improve SV ability, which in turn would influence problem-solving skills in civil engineering subject matter. It was also assumed that SV ability is associated with attitudes towards S&D and that attitude of Civil engineering subjects towards S&D is less positive than that of architecture students who represent a group that appreciates S&D.

2. DOES TEACHING AND LEARNING OF SV SKILLS ENHANCE SV ABILITY?

This study showed that the teaching and learning of SV skills enhanced SV ability in general. This finding is consistent with the findings from previous studies that adopted similar teaching methods (Lord, 1985; Ben-Chaim, 1988; Tillotson, 1984; Seddon, Eniaiyeyeju and Jusoh, 1984 and Sorby and Baartmans, 1996a).

The results of this study did not, however, show any gender differences, which contradict previous research that show poorer performance of females compared to males on SV ability tasks (Ben-Chaim, Lappan and Houang, 1988; Eisenberg and McGinty, 1977 and Allen and Hogeland, 1978).

One possible explanation is the types of spatial tasks employed in the study may not be the ones that tend to elicit gender differences. Most reported findings on gender differences are on performances on mental rotation tasks (Hamilton, 1995, Vandenberg, 1978) while findings on other spatial tasks are varied. Alyman and
Peters (1993), for example, found that out of nine spatial tasks - that involved everyday objects and settings - males only perform better on two spatial tasks (one of which is a mental rotation task) and the effect size was less than 0.100. Therefore, even if females are weak in executing whole object mental rotation, they may not be weak in executing other SV processes. The SVATI, which consisted of three types of spatial tasks, may have provided the female subjects with the opportunity to demonstrate the full spectrum of their SV skills and thus they performed equally well as the males in the study.

Another possible explanation is the similarity in spatial experiences of the female and males in the study. Types and extent of spatial experiences have been frequently cited as one of the causes for gender-related difference in SV ability. If experience is the cause of the gender-related difference in SV ability, the lack of difference between males and females in the present study was not surprising. This is because the females in this study were students who chose to study civil engineering which is a male dominated profession and were therefore, not typical of females in general. Motivation to study civil engineering may have been inspired by spatial experiences that were similar to the males in the study (e.g., playing with building blocks, construction kits, etc.), which consequently led to the development of similar SV ability. In other words spatial ability may have dictated their courses preference which might explain the absence of gender related SV ability in the engineering samples. This is supported by Lord and Holland (1997) who found that there is no gender difference in SV ability in pre-service teachers who are specialising in subjects with high spatial content (e.g., mathematics, sciences, physical education, etc.). As expected, they did find gender difference in the groups of pre-service teachers who are specialising in less spatially oriented subjects, such as, history and English.

Furthermore, in contrast to the females in the previously cited studies, the females in the present study had had equal SV skills training (reading and interpreting engineering drawing) as their male counterparts. Similar training would have reduced the difference in the SV ability even if a difference existed initially. In other words, there is most probably no difference in the SV ability of the males and females in the study because of the reasons given.
Although there is some evidence to support no gender-related differences, confounding of the result from the unequal sample sizes still needs to be considered. This is because there is a possibility that the difference was not detected because of the unequal sample size, especially since the female sample in this study was very much smaller than the male sample. Therefore, future studies employing equal sample sizes is recommended to resolve the issue of the sample size on the finding.

In brief, the findings from this study suggest that for the population understudy, teaching and learning SV skills enhances SV ability and the benefit of instruction extends to both females and males. However, future studies employing equal male and female sample sizes are recommended to resolve the gender-related difference.

3. ARE VIEWS, VALUES, ACTION TENDENCY WITH RESPECT TO S&D, AND SV ABILITY INTER-RELATED?

It was anticipated that, for the civil engineering samples, statistically significant correlations would be found among the constructs. However, a statistically significant correlation was only found between the Tendency to use S&D and the View of the professional role of S&D. Although inconsistent with the tri-componential viewpoints (on which the instrument was based) this finding is consistent with the separate entity viewpoints which proposes that the beliefs (cognitive aspect), the values (affective aspect) and action tendency may or may not be related depending on the situations (Oskamp, 1991).

The high correlation between the Tendency to use S&D and the View of the professional role of S&D is expected, as the subjects are adult learners. According to Knowles (1989), a better career prospect is one of the factors that motivates adult learners in their educational undertakings. Positive correlation was also found between the tendency to use S&D and SV ability. It is possible that having a high SV ability encourages frequent use of S&D which is supported by Fennema and Tarte (1985), and Pribyl and Rodner (1985), who found that subjects with high spatial ability do tend to make use of drawing strategy more often in their problem solving. On the other hand, it is also possible that frequent use of S&D causes higher SV
ability which is indirectly supported by the findings from mini-study 1, which found higher gains in SV ability after teaching and learning of SV skills that employ object manipulations and S&D. A more controlled study is recommended to ascertain the exact nature of the relationship.

It was also originally assumed that compared to the architecture subjects, the civil engineering subjects would be less positive in their views, values and usage tendency with respect to S&D. Consistent with this assumption, it was found that the Civil engineering group is indeed less positive on all three. It is possible that the higher emphasis on S&D in the Architecture curriculum in combination with the prevailing educational practices may have contributed to the stronger manifestations of the constructs in the Architecture group. One such practice, is the streaming of students into science stream, arts stream and vocational stream after their PMR (recall Chapter 1). It is possible that the decreasing academic requirements together with the increasing importance of S&D from science to vocational stream might have unconsciously induced the association between poor academic performance and S&D. Another example is the practice of the polytechnics, which require good grades in technical drawing/art for entry into their architecture courses in contrasts with their demands for good grades in mathematics for their engineering courses. This practice might implicitly encourage the belief that S&D are important to architects while mathematics are important to engineers. On top of these, there is a tacit belief among engineering educators in general, that numerical methods are superior to diagrammatic methods in problem solving.

4. DOES TEACHING AND LEARNING OF SV SKILLS AFFECT PROBLEM SOLVING IN CIVIL ENGINEERING?

The literature has reported positive effects of spatial skills and the learning of mathematics (Winkle, 1997, Tillotson, 1984; Battista, Wheatley and Talsma 1989), science (Pribyl and Rodner, 1985; Tuckey and Selvaratnam, 1991 and Baker and Tally, 1974) and some technical subjects (Sorby, 1999; Baartmans and Sorby, 1996a and McGee, 1979). Therefore, it was anticipated that SV skills would be correlated to problem solving skills in civil engineering and that teaching and learning of SV
skills would enhance problem solving in civil engineering. Two types of problems were investigated; (i) less-structured problems - structural design problems and (ii) structured problems - structural theory problems.

Relationships between SV skills and structural design problem solving were consistent with the initial hypotheses, i.e., SV ability is correlated to problem solving and the learning of SV skills enhances problem solving skills in structural design. Maximum effect of instruction was found on the performance on application items, item that measure the understanding of structural behaviour. It is possible that the manipulation of the beam model and the sketching of beam deflections, bending moment distributions and beam support reactions may have facilitated relational understanding which has been associated with long term transfer in previous studies (Winkles, 1986).

However, neither effect nor correlation was found between the performance on structural theory and SV ability, which is inconsistent with the original hypothesis. One reason could be that the learning of structural theory had occurred through rote memorisation of procedures which is not associated with spatial ability (Battista, 1994). In view of the fact that the structural theory instrument was not specifically designed for the study, which consequently affected its validity and reliability (recall Chapter 10), a future study using a specifically designed instrument is recommended.

5. LIMITATIONS OF THE RESEARCH

The study is a field study that attempted to investigate the inter-relationships between learning and psychological variables in an engineering educational setting. This was the first study of its kind in Malaysia as no such study was carried out before (EPRD, 1999). Being a field study, it was naturally a complex and challenging piece of research to carry out, made even more challenging by the fact that all materials with the exception of the ST Paper were specifically designed almost single-handedly for the study by the researcher herself. As such, it was no great surprise that the following limitations become apparent during the progress of the research. For min-study 1, the sample sizes were less than ideal for the factorial design method of data
analysis (recall Chapter 11). Besides having too small a sample, the condition was made worse by the unequal size of the male and female samples. However, the unequal sample sizes were unavoidable as the study employed intact classes of students. The statistically non-significant dis-ordinal interaction (although clearly observed on a graph in Figure 11.4) may have been the price paid at the expense of ecological validity. Although larger sample is possible, the unequal males and female sample could not be avoided if intact classes are used.

For the attitude study, a better research design that includes taking a measure of the SV ability of the architecture subjects (using the SVATI) would have been an improvement from the current design where the SV ability of the architecture subjects were assumed. Administering a post-test on attitude towards S&D to the Civil engineering subjects may also be beneficial because it may assess any changes in attitude associated with the treatment.

The length of the treatment was also found to be too short to produce a maximum effect of instruction, as indicated by the small increase in learning found in the study. A longer period of over six weeks may be more realistic where students may be assisted and tutored in applying their newly learned SV skills to problem solving in structural design and structural theory.

On the instruments in general, all of them could benefit from additional evaluation and refinements. The number of items was found to be less than ideal for optimum reliability for all instruments. For example, the reliability of the SVATI components could be raised to an acceptable level of 0.7 if the number of items in each component were to be increased to 28. The validity and reliability may also be improved by having a more extensive data on subjects' solution strategies on which the design of the instrument could be based. In hindsight, considering the amount of effort involved in the design of the SVATI, the researcher would have saved considerable time and effort if a commercially available SV ability instrument had been used, although the researcher would then have missed a valuable learning experience.

The heterogeneous nature of the SDI items introduced difficulty in scoring and may have been the cause of the less than optimum responses from subjects. It would have
been easier to score and would have facilitated higher rate of responses if multiple-choice format had been used for all items. Consequently, with homogeneous items, the instrument reliability may also have been increased, as heterogeneity in test items is known to reduce instrument reliability (Ebel, 1965).

It also became apparent during the data analysis stage that using a specifically designed structural theory instrument would have been better, as the quality of the ST Paper which was not designed for the study proved to be difficult to evaluate (recall Chapter 10). Therefore, if difficulties such as the one encountered with the ST Paper are to be avoided, achievement test instruments that are specifically designed are recommended for future studies.

6. IMPLICATIONS

If SV ability appears to be important to problem solving and learning in general, lecturers need to pay more attention to ensuring that these skills are properly developed in engineering students. In other words, the teaching and learning of SV skills need to be integrated into the engineering curriculum. Remedial lessons have to be provided for those students who do not possess good SV skills especially since SV skills have been indicated as pre-requisites to all intellectual skills (recall Chapter 4).

In trying to improve SV skills, views, values and action tendency with respect to S&D may have to be taken into considerations as these variables have been found to be related to SV ability. Therefore, besides teaching the specific SV skills, it may be advantageous to educate the engineering students on the role of S&D in their future profession, which may motivate them in the use of S&D, which in turn affects their SV ability.

For teaching and learning in general, educating the students on the relevance of the learning materials to their future work could be one of the ways to motivate the students in their studies.
Considering that positive gains in learning were obtained through a teaching strategy that progresses from the concrete to the abstract, starting with concrete models before progressing to more abstract ones may increase learning gains.

The positive findings of the study are expected to be beneficial in the following ways, which may enhance the effectiveness of teaching and learning in Civil engineering in general.

- It may promote a more positive attitude in polytechnic civil engineering lecturers and civil engineering students towards the use of visual graphical representations as an aid to problem solving.

- It may increase teachers' and students' awareness towards the importance of using the appropriate strategy (spatial, numerical or verbal strategy) in problem solving.

- It may increase confidence in problem solving ability for those students that have good spatial skills but nevertheless lack the necessary mathematical skills.

- It may promote a change of attitude towards the relevance of spatial skills in teaching structural design in particular and other subjects in general, prompting the need to review and revise the current curriculum.

- It may open debate as to the relevance of the current civil engineering curriculum in providing the engineering skills as envisioned in the goals of engineering education.

7. FUTURE RESEARCH

Three directions are suggested for future research.

- extending the study to include college students of different types of institutions

- carrying out a validation study on the research instruments
• investigating the effect of applying the derived learning hierarchies in the teaching and learning of Civil engineering

Extending the study to include the university civil engineering population, for example, would increase the generalisability of the study to population of college students who are of higher academic ability. As explained in Chapter 5, the polytechnical population is a group of college students who possess lower entry qualifications when compared to university students.

Carrying out validation studies on the research instruments that have been designed for the study could be another direction of future research. With further evaluations and refinements these instruments have the potential for wider applications in educational or occupational setting. For example, the SVATI could be adopted as a standardised test to assess students' SV ability in engineering courses in Malaysian colleges. The SDI on the other hand could be adopted as a diagnostic test to assess civil engineering students' understanding of basic structural behaviour which would ensure students misconceptions are recognised and remedied before in-depth teaching and learning of structural design is carried out. However, before these instruments could be employed as such, further evaluations and refinements are necessary in order to improve their reliability and validity. Therefore, carrying out validation studies on these instruments could be one direction of future research.

Several learning hierarchies concerning the design of a reinforced concrete member were also derived in the study (Chapter 4). These learning hierarchies have the potential of increasing the effectiveness of teaching and learning of structural design and are therefore, worth investigating. Investigating the effectiveness of the teaching and learning of structural design that is based on these learning hierarchies could be another direction of future research.

8. CONCLUSION

The study reported in the present paper has many shortcomings, notwithstanding the limitations associated with field experiments, but it does demonstrate that SV ability is important to civil engineering problem solving. Since it is established that SV ability
can be improved through teaching and learning, it is therefore, suggested that conscious effort be made to monitor SV skills in students. There is also some evidence to indicate that the View of the professional role of S&D and the Tendency to use S&D are related to SV ability. Therefore, enlightening the students on the relevance and importance of S&D may encourage better appreciation of S&D, which may in turn affect SV ability.

Besides these findings and their implications, this study also generated seven learning hierarchies related to the design of a reinforced concrete member, one aptitude instrument, one attitude measure and one achievement test. Suggestion for future research include extending the study to other higher institutions, validating the instruments on a larger sample from the population and investigating the effectiveness of teaching and learning of structural design employing the learning hierarchies derived in the study.


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REFERENCE-10


APPENDIX 1

Procedural task analysis: design process of a reinforced concrete column.

1. INTRODUCTION

Before going into the specifics of the analysis, some general points on columns such as its role in a structure and how it is functionally different from other structural members need to be presented.

1.1 The role of columns in structures.
Columns are vertical compression members of a structural frame intended to support the load-carrying beams. Columns transmit loads from the upper floors to the lower levels and to the soil through the foundations, i.e., columns play a critical role as a load-carrying element in structures.

Extreme care therefore, is required in designing a column particularly because failure in columns, which more often than not is a compression failure, provides little visual warning. Structural column failure is also of major significance in terms of economic as well as human loss. For example, failure of one column in a critical location can cause the progressive collapse of the adjoining floors and the ultimate total collapse of the entire structure.

1.2 Differences between column and beams (or slabs)
Viewpoint Publications (1987) cited three important aspects of a column, which differentiate its design from that of a beam.

- sections are subjected to combined moment and axial load rather than just moment as it is normally in beams

- a considerable number of combinations of moment and axial load may be possible which frequently results in cases of bi-axial bending

- bending of the column will lead to lateral deflections, which if significant, can affect the capacity of the column, as in a slender column
Columns are generally classified into either short or slender depending on their dimensions. The ensuing task analyses will, however, only focus on the design process of a short column, which is relatively more common compared to the slender columns.

1.3 Overview of the design process of a reinforced concrete member.

Before going into column design *per se*, some background information on the design process of reinforced concrete member in general will be provided as the foundation for column design.

1.3.1 Trial and adjustment

One of the characteristics of a reinforced concrete design process is 'trial and adjustment'. Trial and adjustment is necessary in the proportioning of a reinforced concrete member because a large number of parameters are involved, such as geometrical widths, depths, area of reinforcements, steel strain, concrete strain, and steel stress. Such an array of parameters must be considered because reinforced concrete is often a site constructed composite in contrast to the standard mill fabricated beams and column sections in steel structures. The choice of concrete sections are therefore, based on assumptions of conditions at site, availability of the constituent materials, particular demands of the owners, architectural and headroom requirements, the applicable codes and environmental conditions.

A trial section needs to be chosen for each critical location in a structural system. The trial section must be analysed to determine if its nominal resisting strength is adequate to carry the applied factored load. More than one trial is often necessary to arrive at the required section. The first design input step generates into a series of trial-and-adjustment analyses.

The trial-and-adjustment procedures for the choice of a concrete section lead to convergence of analysis and design. Thus every design is an analysis once a trial section is chosen.

Nevertheless the design process can be divided into two broad stages

- initial design: member sizing and reinforcement estimating
• final design- refinement and evaluation: checking member size and reinforcements requirements against the design criteria (evaluation) and making changes (refinement)

1.4 Design process of a reinforced concrete column: Task analysis

The outcome of the analysis will be a set of skills that are necessary to design. However, the design objectives, design activities pertaining to column design will also be presented to aid understanding of the design process.

1.4.1 Objective of column design

The objective of a short column design is to design a column which satisfies the short column classification, has the capacity to resist the applied loads and is able to withstand the impacts of environmental elements. Although quantitative analysis forms a major part of the design process, it will be shown that the use of qualitative analysis especially that of qualitative spatial analysis would improve the efficiency of the process (reduce the number of numerical iterations).

1.4.2 Activities and Necessary skills

Several design activities emerge from the analysis, which could be broadly classified into the initial design activities and the evaluation activities.

1.4.2.1 Initial design

Figure 3.1 illustrates the design process for a short column. Member sizing and reinforcement estimating constitute the initial design while the rest of the activities constitute the evaluation and refinement stage.

The initial design is a suggestion for a possible concrete cross-section, the types of steel reinforcement, the area of steel reinforcements that are stated in terms of the number of steel bars, their diameter and their arrangements.

The area of concrete section and steel reinforcements are computed using "rules of thumbs" which do have some empirical basis. The ability to manipulate mathematical formulations is an essential skill here.
The steel arrangements are governed by

- **fire resistance requirements**: fire resistance requirement is stated in terms of hours. The stated hour is the maximum number of hours a structure could be exposed to, before fire begins its damaging effect on the steel reinforcements. Thickness of concrete cover gives the required protection to the steel. Therefore, the fire resistance requirement is translated into millimetres of concrete cover in the design. This concrete cover affects the positioning of the steel reinforcements, which in turns affects the arrangements of the steel.

- **durability requirements**: durability requirement influences arrangements of steel. The steel reinforcements need to be protected by concrete to avoid damage from corrosive or damaging elements in the environment. The types of exposure the structure experiences will dictate the thickness of cover needed.

Member sizing therefore, requires the designer to juggle many criteria and constraint at one time to ensure that he/she arrives at a proposal that does not require too much refinement. The design loads, allowable deflections, fire resistance and durability are
a few of the variables that could govern the design. Consideration of structural efficiency dictates that the minimum possible amount of materials is used and the minimum allowable cross-sections for the given design loads is desirable. However, using the minimum cross-section may violate fire resistance requirements or/and durability requirements. Therefore, normally the two latter constraints will override the efficiency requirement.

Being able to assess the impacts of the various constraints on the design proposal solution is important because it could reduce the workload involved in the design process. Qualitative analysis skills, which include spatial visualisation skills, are an integral part of the assessment skills.

Reinforcement estimating on the other hand involves estimating the quantity of the reinforcement needed for a column, which is based on the worst possible axial loads imaginable. Assessments of loads form the most important aspect of reinforcement estimating. Spatial visualisation ability helps in this process by enabling the designer to perform mental simulation on the effects of the various load combinations.

Spatial visualisation ability may also aid in the decision of reinforcement arrangements especially when there are several constraints need to be considered simultaneously.

1.4.3 Design evaluation and refinement
The evaluation and refinement stage has the following major features.

- applications of a wide range of concepts and knowledge of mathematics and the natural sciences

- evaluation of design against the design criteria which are either set by government regulations, e.g. a local building must use 70% of local materials or by industry standards e.g. codes of practice BS8110, while others are set by the client, e.g. the building is for physically impaired residents.

The Institute of Structural Engineers (1985) gave the following general procedure for the final design of a short column carrying moment and axial load which has been incorporated into the flow chart in Figure 3.1.
Step 1: Check that the column is not slender.

Step 2: Check that the section size and cover comply with the requirements for fire resistance.

Step 3: Check that cover and concrete comply with requirements for durability.

Step 4: Calculate axial loads and moments (design loads and moments) according to clause 4.5.3.

Step 5: Design section and reinforcement.

All the five steps in design require some form of spatial skills either simple or complex. The following sections explain and give illustrations on how these spatial skills are employed in the problem solving process. It will be shown that dealing with spatial information is unavoidable and the need for spatial skills is compelling.

**Step 1: Checking the slenderness of column.**

Figure 3.2 shows the procedure for assessing whether a column is short or slender.

![Flowchart showing the procedure for assessing whether a column is short or slender.]

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**Figure 3.2. Procedure for assessing whether a column is short or slender.**
To do this, the slenderness ratios (the ratios of the effective heights to the column depths, $l_{ex}/h$ and $l_{ey}/b$ are required). $l_{ex}$ is the effective height with respect to bending of the column about the x-axis while $l_{ey}$ is the effective height with respect to bending of the column about the y-axis.

The effective height of a column $l_e$ is directly proportional to its clear height $l_0$. Since a column has two principle planes (and two axes of bending), it therefore, has two clear heights. The procedure used to determine $l_0$ with respect to column bending about a given axis is displayed in Figure 3.3. To solve for $l_0$, the visualisation of the associated column elevation, which demands spatial visualisation skills, is needed as illustrated by the shaded boxes in Figure 3.3. Spatial visualisation ability is therefore, necessary for checking the slenderness of a column.

The effective height of a column is also dependent on the rigidity of the joints at the two ends of the column. The relationship between $l_e$, $l_0$, and the ends conditions represented by the formula $l_e = \beta l_0$ where $\beta$ is the coefficient of effective height which is dependent on the ends conditions.

![Figure 3.3. Procedure to determine the clear height of a column.](image-url)
Even for the calculation of the ratio of effective heights \( \frac{L_e}{h} \) and \( \frac{L_e}{b} \) requires spatial visualisation skills the dimension to be labelled as 'h' or 'b' is dependent on the axis of bending. Although rote memorisation of the relationship between h, b and the axes is possible, the result will be meaningless manipulation of symbols and numbers, which may result in errors.

Finally, to determine the column coefficient \( \beta \), with respect to bending about a given axis, the designer needs to identify and compare the column dimension (depth) to the beam/slab dimension (depth) that are relevant to the problem of bending about that particular. He/she therefore, needs to resolve the following questions, which involve spatial reasoning.

- which beams/slabs are relevant to the problem?
- which column dimension is relevant?
- which beam/slab dimensions are relevant?

Figure 3.4 clarifies the terms, clear height, column depth, beam depth and plane of bending. In Figure 3.4, the plane of bending is in the plane of the paper and the axis for bending is perpendicular to the plane of the paper. If this axis is called the x-axis, the plane of bending shown in the Figure shown will be the y-y plane.

Figure 3.4. Definitions of depth of column, depth of beam, clear height and plane of bending.
Failure to resolve the relationships between axis of rotation, plane of rotations, beam and column dimensions has more far-reaching consequences than simply making a mathematical blunder. It affects the classification of end conditions, which in turn affects the selection/computation of $\beta$ that will lead to the wrong assessment of $(l_e)$. Ultimately, the inability to understand the relationships between bending, axis, planes and the relevant dimensions will incur higher cost or even failure as illustrated by Figure 3.5.

Figure 3.5. The cumulating effects of failure to resolve the relationships between axis for rotation, plane of rotations and member dimensions.
In summary, assessing the slenderness of a column requires spatial visualisation ability. The particular design composite skills, which are identified to require this ability, are given by the shaded oblongs in Figure 3.6, which are:

- **the ability to classify the end conditions of a given column**
- **the ability to determine the clear height of a column with respect to bending of the column about a given axis**

The required generic spatial skills identified are:

- **the ability to perceive the relationship between axis for rotation and plane of rotation**
- **the ability to predict what an object would look like if viewed from a different perspective**

**Step 2: Evaluating design compliance with fire resistance requirements.**

Compliance with fire requirements is achieved by meeting the minimum size requirement and the minimum cover requirement. The number of column surfaces that are exposed in the event of a fire governs the minimal column size. To determine the number of exposed column surfaces, a plan of the column and the connected structures need to be visualised. One such exposure condition is illustrated in Figure 3.7. This Figure illustrates a column with a maximum of three surfaces exposed, i.e., in the event of a fire in room A.

Knowing the number of exposed surfaces helps the designer in deciding on the member size and cover required. However, sometimes other requirements may be in conflict with the fire resistance requirement. For example, a designer would like to have the reinforcement steel as close to the surface of the concrete as possible to enhance the moment carrying capacity of the section, which may breach fire resistance requirements. In such a situation, mental simulation visualisation may help by reducing the number of iterations needed in the design process.
Figure 3.6. Checking for fire resistance requirements and durability requirements.
To reduce dependence on working memory, a designer uses sketches in his/her work. Sketches are a form of spatial representation which is known as spatial product (Liben, 1981). Spatial visualisation ability is necessary for sketching.

Two skills required here are

- being able to predict what an object would look like from a different perspective
- being able to sketch or do free-hand drawing

Step 3. Evaluating compliance with durability requirement.

Durability of a concrete structure is dependent on:

- the environmental conditions to which the concrete structure is exposed
- the grade of concrete (strength) from which the structure is constructed
- the concrete cover provided for the steel inside the structure

For a specific concrete grade and environmental condition, the concrete cover will be the determining factor for durability. The problem of durability can therefore, be reduced to a two dimensional spatial problem as illustrated in Figure 3.8.
Two skills required here are:

- being able to predict what an object would look like from a different perspective
- being able to sketch or do free-hand drawing

Step 4. Computing axial loads and moments (design loads and moments).

Computation of axial loads is quite a straightforward exercise but the computation of bending moments involves some of the skills required in Step 1. The moment due to applied loads could result in bending in one of the two principle planes, x-x or y-y plane or both. The designer has to determine the plane of bending or the axis for bending first before he/she could represent the event using a mathematical model.

Inappropriate choice of plane (or axis) will result in inappropriate choice of mathematical models and the repercussions could be serious especially if the column is not symmetrical about both axes, i.e., when the second moment of area I, for the column section, are unequal about the two principal axes.

Poor understanding of the relationships between bending, axis and planes may result in the computed I being larger than the actual I, i.e., resulting in thinking that the column is stronger than it actually is.
A column may frequently experience bi-axial bending due to unsymmetrical arrangement of beams framing into it. A beam on the other hand only experiences bending about a single axis, which is induced by the vertical loads that it supports (Figure 3.9 (b)). The difference in orientation between the longitudinal axes of beams and columns (resulting in problems in three-dimensions), which is made worse by the use of identical symbols is a common source of error in the computation of column moments.

The longitudinal axis is vertically oriented for column and horizontally oriented for beam and therefore, the cross-sections are vertical and horizontal for beam and column respectively. The convention is, to use the symbols ‘x’ and ‘y’ to annotate the two axes of reference, for the cross-sections. As a result, there are two cross-sections, which are perpendicular to each other using the same annotations for axes of reference, which are of different orientation (Figure 3.10). Since beams and columns are physically connected, the designer must be able to differentiate between the two identical reference systems and also to identify the relationship between them where appropriate. Understanding the concept of axes as a frame of reference is therefore, extremely important.

Figure 3.9. (a) Bending tendencies for column under vertical loads and (b) Bending tendencies for a beam under vertical loads
Figure 3.10. x-y co-ordinate system presented on two different planes. (a) on a horizontal plane (column cross-section) and (b) on a vertical plane (beam cross-section)

Just and Carpenter (1985) conclude in their study that choice of cognitive co-ordinate system could explain for the differences in performance on spatial tasks between subjects of low ability and high ability. In their study the use of different cognitive co-ordinate systems by subjects were found to affect strategy (spatial or analytical) in problem solving and time taken to solve the problem.

In the case of the column design, there is only one co-ordinate system which was used to derive the mathematical models (formula found in the codes) to represent the behaviour of the structure. The designer’s cognitive co-ordinate system must coincide with the conventional system in order to make the available mathematical model valid.

The difficulties in dealing reference system could also lead to inappropriate choice of substitute frame or sub-frame being made for the analysis of moments. Deciding the substitute frame or sub-frame for the moment analysis requires the ability to visualise arrangements of structural elements in three dimensions.

Skills relevant here are

• the ability to identify the common axis of reference between column and beam section when the beam and column is monolithic
the ability to identify the structural sub-frame (the column and beams to be considered) to be used for moment distribution calculation, i.e., the ability to visualise spatial arrangements in three-dimension

Step 5: Finalising the section and reinforcement.

This is the confirmation stage, when finally a choice is made as to what constitutes the most suitable solution after evaluating the detail solution against the design criteria as stated in the codes, and in the design brief. Spatial visualisation helps in the interpretation of charts and diagrams.
APPENDIX 2

Lesson Plan for Developing Spatial Visualisation Skills (1).

AIM: To develop SV ability through object manipulations and free hand sketching.

ENTRY SKILLS: students should be able to draw lines using a pencil

OBJECTIVE:

1. Able to sketch from observation demonstrating the ability by sketching the isometric drawing from observation of the actual object.

2. Able to draw an object from memory demonstrating the ability by sketching the isometric of an object which has been removed from the seen.

3. Able to sketch an object from imagination demonstrating the ability to sketch the isometric drawings of buildings based on coded plans.

<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Events/Prescriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken to the whole group</td>
<td>Media: Live instruction, written instruction.</td>
<td>Gaining attention:</td>
</tr>
<tr>
<td></td>
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<td>Introduce the subject by saying.</td>
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<td></td>
<td>For the next few hours we are going to be involved in an exercise to improve our spatial visualisation ability.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>We make use of spatial visualisation skills to solve problems related to Calculus, Estimating Surveying, Hydraulics, Structures, (O.H.P)</td>
</tr>
<tr>
<td>Spoken to the whole group and using the O.H.P.</td>
<td>The teacher and the O.H.P.</td>
<td>Inform the learner of the objective: Inform the learner that they are going to learn to be a better learner and problem solver by improving their spatial visualisation ability. How is it done? through sketching and object manipulations.</td>
</tr>
<tr>
<td>Action</td>
<td>Media</td>
<td>Events / Prescriptions</td>
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</tbody>
</table>
| Spoken words to the whole group and isometric drawing shown on the O.H.P. | Live instruction and the O.H.P. | Indicate the main stages involved-  
  • isometric drawing  
  • orthographic drawing  
  • object transformation-rotation  
  • application to structural problem-structural behaviour.  
  • (shown on O.H.P)  
  (OHP1)  
  **Presenting the stimulus material.**  
  Ask students to group themselves into 4 students to a group. Introduce the materials they are going to use; the building blocks, the coded plans and the isometric paper.  

  **Stimulate recall of prerequisite.**  
  Ask the learners whether they can remember the attribute of an isometric drawing? Simulate recall with an isometric drawing shown O.H.P.  

  * (OHP2) |
| Spoken words and demonstration with object by teacher hands on experience for the students. | The teacher and the O.H.P. | **Providing learning guidance and eliciting performance:**  
  • **Stage A:**  
  Inform students that they are going to learn to draw isometric drawing of objects with the objects being present.  

  Explain how an isometric view is drawn. Demonstrate on OHP. Lines are drawn to represent  
  • edges  
  • intersection between surfaces  
  • 30° angle between the line and the base edges |
| Give handouts given to students on how to draw | Instruction sheets, sheet 1 and 2 | |

**APPENDIX 2-2**
**Action**

**Media**

**Events / Prescriptions**

•

**Remind them:**
(Object is made up of cubes, there are many intersection lines; only draw the intersection lines between surfaces, forget about the intersection between cubes).

Explain how the object is going to be built using a coded plan and what a coded plan stand for.

Give these instructions in written form:
1. build the building according to the coded plan
2. sketch the isometric drawing from their corner view on paper provided
3. rotate the mat (paper) and repeat sketching for the other view.

* EXERCISE SHEET 1

Stage B: Inform students that now they are going to sketch the isometric drawings without rotating the paper. Give them written instructions.
1. sketch the isometric drawing for the view that you can see (figure 2.1.8).
2. repeat for the views that you cannot see.
3. give guidance, ask them to get up and see the desired view for themselves if they cannot.

Providing feedback and Assessing performance: assess their performance and give appropriate feedback when required as they perform the tasks.

(Contextual problem: there is only one object and four people trying to make use of them. Anticipated problem everybody will be trying to tilt and rotate, manipulate the object, -
Solution: each person draw the isometric view as seen from their angle and then rotate the mat to get the other views.)

APPENDIX 2-3
<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken words to the whole group.</td>
<td>Live instruction exercise sheets.</td>
<td>Enhancing transfer. Ask students to do exercise 2.1.</td>
</tr>
</tbody>
</table>

* EXERCISE SHEET 2- FIGURE 2.1.8, (OHP3) Events / Prescriptions

* EXERCISE SHEET 3
Lesson Plan for Developing Spatial Visualisation Skills (2).

AIM: To develop SV ability through free hand sketching of multiple views.
ENTRY SKILLS: students should be able to draw lines on paper using a pencil.

OBJECTIVE:
1. Able to interpret multiple views, demonstrating the ability by
   • sketching the plan, front and right views given the isometric drawing.
   • sketching the isometric drawing given the three orthographic drawings,
   • choosing the appropriate set of orthographic drawings from a set of drawings given the isometric.

<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Events/Prescriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken to the whole group and showing an OHP of an engineering drawing.</td>
<td>Live instruction and OHP</td>
<td>Gaining attention. Show an engineering drawing of a plan, front and side elevation of a building on OHP.</td>
</tr>
<tr>
<td>Spoken to whole group and demonstration on one computer.</td>
<td>Teacher and OHP.</td>
<td>Inform the learner of the objective: the objective is for them to be able to interpret multiple views so which will help them in design.</td>
</tr>
</tbody>
</table>

* OHP1

Stimulate recall of prerequisites and Presenting the stimulus material: Present a diagram on OHP which demonstrate how the orthographic views are extracted.
* OHP2 page 18,19,20,21 and 22 instructor’s manual.
<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Events / Prescriptions</th>
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</thead>
<tbody>
<tr>
<td>Oral review by instructor.</td>
<td>Teacher</td>
<td>Providing feedback:</td>
</tr>
<tr>
<td>Students doing a short quiz of two questions.</td>
<td>Exercise sheet 2</td>
<td>provide feedback as they do exercise 2.2</td>
</tr>
<tr>
<td>Discussion of answers.</td>
<td>Live instruction.</td>
<td>Assessing performance and Enhancing retention and transfer:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Give isometric view choose the orthographic drawing of plan, front and elevation related to it.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Given a structural drawing draw the isometric of the intersections between column and beam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* SHEET 3 SIMPLIFIED STRUCTURAL DRAWING</td>
</tr>
</tbody>
</table>
Lesson Plan for Developing Spatial Visualisation Skills (3).

**AIM:** Will be able to solve spatial problems, which requires mental rotation.

**ENTRY SKILL:** Able to interpret line drawings as being a representative of a solid object.

**OBJECTIVE:**
Will be able to mentally transform a given pictorially depicted object by rotating it in space demonstrating the ability by choosing the correct answer from a set of pictorially depicted objects where only one of them is that of the given object.

<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Events/Prescriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken words to the whole group of students</td>
<td>Live instruction</td>
<td>Gaining attention .</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inform students that in solving structural engineering problems we are often required to do mental simulation (rotation). Imagine what an object look like from a different perspective for example. If we are weak in this we might have trouble trying to solve a problem. For example, when we interpret drawing we actually construct the three-D in our mind and then we move it around, (we maintain it in our mind). Show figure 2.2.2 Show torch light on the object.</td>
</tr>
<tr>
<td>Spoken words to the whole group</td>
<td>Live instruction</td>
<td>Inform the learner of the objective.:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the objective is for you to learn to perform this mental rotation process so that it will help you in your structural design and structural analysis.</td>
</tr>
<tr>
<td>Spoken to whole group</td>
<td>Teacher</td>
<td>Stimulate recall of prerequisites and Presenting the stimulus material: mention the isometric views and the orthographic view before this. These are views that we could obtain through rotation. If we have an actual object (give object) we could rotate it about an axis to get these views (by object manipulation) show isometric views, orthographic views.</td>
</tr>
<tr>
<td></td>
<td>Sample designs on paper</td>
<td></td>
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</tbody>
</table>
Repeat the aim: to be able to predict what an object would look like from any perspective. In reality this is what is happening in life, we come from different direction we see different perspective of an object, building etc.

How to do this, progress from rotation about a specific axis and then rotation about any imaginary line.

Show a difference between translation and rotation. Rotation is movement about an axis.

Explain what is an axis: an axis is an imaginary line of reference. It does not exist in physical from but we could make it visible by making a representation of it such as by drawing a straight line.

Explain that in our in order to locate anything we need to have three axis which we call axis x, axis y and axis z which are perpendicular to each other. Show a diagram (Sheet 1)

Explain that how we physically manipulate object is how we mentally do them as well. The important thing is to be able to keep the shape of the object in the mind and imagine it being moved as we did with the real object.

Show drawings and how object are being rotated in them. (sheet 2)
<table>
<thead>
<tr>
<th>Action</th>
<th>Media</th>
<th>Events / Prescriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spoken words to group and oral review by instructor to individuals who require guidance.</td>
<td>Teacher and sample designs computer printouts, which are available on the screen as well.</td>
<td>Providing learning guidance and eliciting performance/Providing feedback:</td>
</tr>
</tbody>
</table>

- **Task:** sheet 3

<table>
<thead>
<tr>
<th>Group marking</th>
<th>Media</th>
<th>Events / Prescriptions</th>
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<tbody>
<tr>
<td>Paper and pencil</td>
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<td>Assessing performance:</td>
</tr>
<tr>
<td>Written copy</td>
<td></td>
<td>Exercise: sheet 4</td>
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<tr>
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<td></td>
<td>Enhancing retention and transfer:</td>
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<tr>
<td></td>
<td></td>
<td>Short test.</td>
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<td>Sheet 5. 5 items.</td>
</tr>
</tbody>
</table>
Lesson Plan for Developing Spatial Visualisation Skills (4).

AIM: To develop the understanding of structural behaviour through 2-Dimensional spatial visualisation.

ENTRY SKILLS: Understand the meaning of the three types of deformation, deflection, shortening, elongation, shearing, twisting demonstrating the ability by verbally stating the type of deformation in question when presented to them as a demonstration.

OBJECTIVE:

Able to predict the behaviour of structure under a given loading and support conditions demonstrating the ability by

1. sketching the deformation of a simply supported beam under uniformly distributed load
2. sketching the visual deformation of a cantilever beam under uniformly distributed load and point load
3. sketching the visual deformation of a fixed ended beam under uniformly distributed
4. sketching the visual deformation of a column given the multiple views and the type of loading as well as support condition.

<table>
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<tr>
<th>Action</th>
<th>Media</th>
<th>Events/Prescriptions</th>
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<tbody>
<tr>
<td></td>
<td>Live instruction</td>
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Gaining attention:

- Tell the students that they are now going to apply their visualisation skills to a specific area in structural design problems known as the understanding of structural behaviour. This is the understanding of how the structure will respond to loads and deformation-internal actions which result in visual changes. Actions: axial forces-shortening/lengthening, bending moment-curving, torque-twisting, shearing force-slicing
Inform the learner of the objective: the objective is so that they are able to make accurate prediction on the visual changes of the shape of the structure which could be used to make predictions of the internal actions. This will help in structural analysis, which is important to structural theory as well as structural design.

Stimulate recall of prerequisites and presenting the stimulus material:
Mention tension, compression, torque, shear and demonstrate using a foams which are pre-lined to demonstrate the effect of these forces on the model structure. Show, the shortening and the lengthening of lines as a sign of tension and compression. Relate to reinforced concrete, provision for steel and area of concrete.

Mention rotation- trying to understand how structures behave requires the understanding of the inter-relationship between elements, which exist in 3-D space. Structure is a combination structural behaviour involves rotation tension and compression and support condition.
You might not see rotation, but rotation exists under restraint condition. It is not free rotation.

Providing learning guidance and eliciting performance/ Providing feedback/:
Involves
• prediction of visual deformation for a given load and support condition-simply supported beam under point load.
• sketching the expected deformation
• manipulation of structural models
• confirmation and correction of prediction
• repeat for fixed ended beam, cantilever, free end column, fixed ended column, frames-fixed ended column, pinned column-foam partially fixed to manila card.
Repeat for slab and show how the deformation is related to the distribution of loads between the supports (beams) and thus we get load on beam. Therefore assessment of load on beam is also related to visualisation. (load path). The shape of the slab will reveal relatively speaking how much load are
Events / Prescriptions

Live instruction, foam models, paper and pencil
- going to the beams. (qualitative analysis-without using numbers as versus quantitative using numbers that we frequently used. In design we start with qualitative analysis and proceed to quantitative as a check.

Assessing performance:
Given a multi-view drawing (structural drawing) predict and sketch the visual deformation of the column and beam.

Enhancing retention and transfer:
Given a set of engineering drawing (one problem) determine the load on the foundation and the deformations and suggest the reinforcement.

Reference:


CIVIL ENGINEERING DEPARTMENT
UNGKU OMAR POLYTECHNIC
MALAYSIA

SPATIAL ABILITY TEST ON PROCESSING OF TWO AND THREE DIMENSIONAL SPATIAL INFORMATION

INSTRUCTIONS

1. Answer all questions within the allocated time.

2. Stop when you reach the end of each section and wait for further instruction before you continue to the next section.

3. Hand in your test paper to the staff on duty at the end of the test session.

Note: This test consists of 8 (EIGHT) printed pages excluding the front page.

TEST OBJECTIVE: to assess your ability to process information related to two and three-dimensional spatial information.

| Name | :----------------------------------------------------------------- |
| Reg. No. | :----------------------------------------------------------------- |
Section I: 5 minutes

Figure 1 illustrates the solving strategy for Q1-Q10. Go to page 2, read the instruction and answer the questions.

Step 1
Identify the design on the surface of the cube on the right which correspond to the pattern on the two dimensional pattern on the left.

Step 2
Align the design on the flat pattern to the corresponding design on the cube.

Step 3
Fold the flat pattern in your mind to obtain the cube on the right.

Figure 1. Solving strategy for question 1 to 10.
Instruction: The two dimensional pattern on the left could be folded up to form the cube on the right. For Q1 - Q10 identify the correct cube corresponding to the given pattern. Indicate your answer with an (X) in the appropriate circle.

Q 1.

Q 2.

Q 3.

Q 4.

Q 5.

Go to the next page.
Q 6.

Stop.

APPENDIX 3-4
Instructions: For Q1-Q5, identify the correct orthographic views for the isometric view given on the left.
Instructions: For Q6 - Q11, choose the correct isometric view for the given orthographic views. Indicate your answer with an (X).

Q. 6
Plan

Front View Right View

Q. 7

Q. 8

Go to the next page.
Section III: 5 minutes

Instructions: One of the four alternatives on the right is the same object shown on the left as seen from a different view.
For Q1 - Q8 identify the correct alternative that represents the left-hand side object. Indicate your answer with an (X)

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<td>Q. 7</td>
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APPENDIX 3-9
ATTITUDE QUESTIONNAIRE

The purpose of the questionnaire is to get your opinions on the use of drawing and sketching in general. Please read the statements given and indicate your opinion by putting a tick (✓) in the appropriate boxes. Please response to all statements.

Legend:

5 = Strongly agree  2 = Disagree
4 = Agree           1 = Strongly disagree
3 = Uncertain

1. I'm not good at expressing my ideas using drawing and sketches.................................

2. I do not use sketches to answer questions in tests or examinations unless instructed to......................................................

3. Drawing and sketching skills are not required in order to be successful in my study area..............................................................

4. I rarely make use of drawing or sketches to express my ideas. ..............................

5. I do not spend much time in my drawing subject because there are other subjects which are more important..............................

6. Creative thinking and not logical thinking are required to interpret engineering drawing............................................................

7. My future success does not depend on drawing skills..............................................

8. Education is the main factor in ensuring a person become a skillful at sketching and interpreting drawing.................................
Legend:

5 = Strongly agree  2 = Disagree
4 = Agree  1 = Strongly disagree
3 = Uncertain

9. Most examination questions could be solved easily without resorting to drawing and sketching .........................................................
   1  2  3  4  5

10. I would not take drawing if it is not made compulsory.................................................................
    1  2  3  4  5

11. Mathematics is for engineers and drawing is for architects............................................................
    1  2  3  4  5

12. Craftsman makes use of drawing and sketching to communicate....................................................
    1  2  3  4  5

13. Sketching and drawing is an essential communication tool for those who are in the technical and sciences ........................................
    1  2  3  4  5

14. The ability to draw is important in order to be academically successful in my field........................
    1  2  3  4  5

15. I rarely use drawing/sketches to communicate.................................................................................
    1  2  3  4  5

16. I often find difficulties in reading and translating drawings............................................................
    1  2  3  4  5

17. In test or examination, I use sketches and diagrams to help me solve problems................................
    1  2  3  4  5

18. Drawing skill is not essential except for engineering drawing. ....................................................
    1  2  3  4  5

19. Drawing is hard to master within a short time .................................................................................
    1  2  3  4  5
Legend:
5 = Strongly agree  2 = Disagree
4 = Agree  1 = Strongly disagree
3 = Uncertain

20. Drawing is an interesting activity

21. I need a long time if I were to be good at drawing

22. Sketching and drawing is not essential in everyday communication

23. Students who are good at drawing are usually poor in the sciences

24. Higher marks should be given for preparation of detail drawings as compared to orthographic drawings

25. Assignments involving drawings should be reduced because it is tedious and takes up a lot of time

26. The time allocated for learning drawing is not sufficient to achieve a high level skill

27. Time allocated for drawing lessons should be reduced and replaced by more important subjects

28. Free-hand sketching should be taught to students in my field of study

29. I need to improve my skills in sketching and reading and translating drawing

30. My skills in reading and interpreting drawing is sufficient for project supervision work

31. Drawing should be made compulsory up to the final semester

32. I often find that diagrams and drawing are confusing
# APPENDIX 5.
Grouping of attitude statements for split-half analysis.

<table>
<thead>
<tr>
<th>1st half</th>
<th>2nd half</th>
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<tbody>
<tr>
<td><strong>Component 1: View of the professional role of S&amp;D</strong></td>
<td><strong>Component 5</strong></td>
</tr>
<tr>
<td>3-Bidang pengajian saya tidak memerlukan kemahiran melukis dan melakar</td>
<td>7-Kejayaan masa depan saya tidak bergantung kepada kemahiran melukis.</td>
</tr>
<tr>
<td>3-Drawing and sketching skills are not required to be academically successful in my field.</td>
<td>7-My future success does not depend on drawing skills.</td>
</tr>
<tr>
<td>6-Pemikiran secara kreatif dan bukan pemikiran lojik diperlukan untuk mentafsir lukisan kejuruteraan</td>
<td>13-Penyampaian idea dalam bentuk lukisan tidak penting bagi mereka yang berkecimpung di bidang sains atau teknikal</td>
</tr>
<tr>
<td>6-Creative thinking and not logical thinking is required to interpret engineering drawing.</td>
<td>13-Sketching and drawing is an essential communication tool for those who are in the technical and sciences</td>
</tr>
<tr>
<td>12-Penyampaian idea dalam bentuk lukisan penting bagi mereka yang berkecimpung di bidang seni dan krafangan.</td>
<td>14-Kemahiran melukis penting untuk kejayaan dalam bidang pengajian saya.</td>
</tr>
<tr>
<td>12-Craftman makes use of drawing and sketching to communicate.</td>
<td>14-The ability to draw is important in order to be academically successful in my field.</td>
</tr>
<tr>
<td>8-Pendidikan adalah faktor utama yang menentukan seseorang itu boleh melukis dan membaca lukisan.</td>
<td>18-Kebolehan melukis tidak perlu bagi subjek lain kecuali lukisan kejuruteraan</td>
</tr>
<tr>
<td>8-Education is the main factor in ensuring a person become skilful at sketching and interpreting drawings.</td>
<td>18-Drawing skill is not essential except for engineering drawing.</td>
</tr>
<tr>
<td>22-Lakaran/lukisan tidak perlu dalam komunikasi harian.</td>
<td>9-Hampir semua soalan-soalan ujian dan peperiksaan boleh diselesaikan dengan mudah tanpa penggunaan lukisan</td>
</tr>
<tr>
<td>22-Sketching and drawing is not essential in everyday communication.</td>
<td>9-Most examination questions could be solved easily without resorting to drawing and sketching</td>
</tr>
<tr>
<td>11-Matematik adalah untuk jurutera dan lukisan adalah untuk arsitek</td>
<td>23-Seseorang pelajar yang mahir melukis selaunya lemah di bidang sains</td>
</tr>
<tr>
<td>11-Mathematics is for engineers and drawing is for architects.</td>
<td>23-Students who are good at drawing are usually poor in the sciences.</td>
</tr>
<tr>
<td>Component 2: Value of the personal Usage of S&amp;D</td>
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<tr>
<td>30-Kemampuan saya untuk membaca lukisan adalah memadai bagi tugas-tugas pengawasan projek di tapak bina</td>
<td>30-My skills in reading and interpreting drawing is sufficient for project supervision work.</td>
</tr>
<tr>
<td>19-Melukis adalah satu kemahiran yang sukar dikuasai dalam masa yang singkat</td>
<td>19-Drawing is hard to master within a short time.</td>
</tr>
<tr>
<td>31-Subjek lukisan perlu dijadikan subjek yang wajib hingga ke semester akhir bagi pelajar-pelajar dalam bidang pengajian saya.</td>
<td>20-Melukis adalah satu aktiviti yang menyerokan.</td>
</tr>
<tr>
<td>31-Drawing should be made compulsory up to the final semester.</td>
<td>20-Drawing is an interesting activity</td>
</tr>
<tr>
<td>32-Saya sering mendapati bahawa gambarajah dan lakaran adalah mengelirukan.</td>
<td>21-Saya perlukan masa yang panjang sekiranya ingin menguasai kemahiran melukis.</td>
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<tr>
<td>32-I often find that diagrams and drawings are confusing.</td>
<td>21-I need a long time if I were to be good at drawing.</td>
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<tr>
<td>25-Tugasan yang melibatkan penyediaan lukisan patut dikurangkan kerana ianya memakan masa yang panjang dan melibatkan kerja-kerja yang cerewet.</td>
<td>16-Saya sering mengalami masalah dalam membaca lukisan.</td>
</tr>
<tr>
<td>25-Assignments involving drawings should be reduced because it is tedious and takes up a lot of time.</td>
<td>16-I often find difficulties in reading and translating drawings.</td>
</tr>
<tr>
<td>24-Jangka-masa yang diperuntukan bagi mempelajari subjek lukisan tidak memadai untuk mencapai tahap kemahiran yang tinggi</td>
<td>24-Bagi setiap tugas lukisan, pembahagian markah haruslah lebih tinggi bagi penyediaan butiran terperinci berbanding dengan penyediaan lukisan pandangan ortografik</td>
</tr>
<tr>
<td>26-The time allocated for learning drawing is not sufficient to achieve a high level skill.</td>
<td>24-Higher marks should be given for preparation of detail drawings as compared to orthographic drawings</td>
</tr>
<tr>
<td>1-Saya kurang mahir menyampaikan idea dalam bentuk lukisan dan gambarajah</td>
<td>29-Saya perlu meningkatkan kemahiran saya di bidang melukis dan membaca lukisan.</td>
</tr>
<tr>
<td>1-I'm not good at expressing my ideas using drawing and sketches.</td>
<td>29-I need to improve my skills in sketching and reading and translating drawing.</td>
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</table>
CIVIL ENGINEERING DEPARTMENT
UNGKU OMAR POLYTECHNIC
MALAYSIA

STRUCTURAL ANALYSIS AND DESIGN TEST
SEMESTER 6
( 50 minutes )

INSTRUCTION:
1. Answer all questions.
2. Answer questions 1 -16 on the test paper itself.
3. Answer questions 17-18 on separate answer sheets. Write your name on all your answer sheets.
4. Hand in all your question papers and answer sheets at the end of the test.

Note: The test paper consists of 18 questions and 8 (EIGHT) printed pages (excluding the front page).

TEST OBJECTIVE: To measure your ability to solve structural design problems related to 2-dimensional and 3-dimensional spatial visualisations.

Name :-------------------------------------------
Reg. No. :----------------------------------------
SECTION A (25 minutes)

INSTRUCTION: The diagrams below illustrate a column supporting a point load P. The line of action of the load lies on the y axis at an eccentricity ‘e’. Answer questions 1-5 based on the figure. Consider the following statements and tick (√) in the appropriate box.

| Q 1. The column axis is in the x-x plane only. |
| Correct | Incorrect |
|——— |——— |
| | |

| Q 2. Load P is going to cause bending of column about the y-axis |
| Correct | Incorrect |
|——— |——— |
| | |

| Q 3. Load P is going to induce a bending moment about the x-axis |
| Correct | Incorrect |
|——— |——— |
| | |

| Q 4. The column axis is in the x-x and y-y plane. |
| Correct | Incorrect |
|——— |——— |
| | |

| Q 5. Load P is going to cause the column axis to deflect in the x-x plane. |
| Correct | Incorrect |
|——— |——— |
| | |

A column supporting a point load P

Column

Column axis

APPENDIX 6-2
INSTRUCTION: The diagrams below show a plan, a front elevation and a side elevation of a structural frame supporting a point load P. Answer questions 6-10 based on this figure. Consider the following statements and tick (√) your answer in the appropriate box.

Q 6. The line of action of load P is in the y-y plane

<table>
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<th>Correct</th>
<th>Incorrect</th>
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Q 7. Load P is going to cause the beam axis ST (see front elevation) to deflect in the y-y plane.

Q 8. Load P is going to induce bending moment in the unloaded beam.

Q 9. The column axis is going to deflect neither in the x-x nor the y-y plane

Q 10. The side elevation is a projection onto a plane parallel to the x-x plane.

A reinforced concrete frame subjected to a point load P
Question 11 Consider the beams in Figures 1, 2, and 3 and sketch the following on each figure in the spaces provided under each beam:-

(i) the deflected shape of the beam,
(ii) the bending moment diagram,
(iii) the reactions of the supports.
Question 12. The diagrams below show two idealised reinforced concrete structural frames, P and Q. As a result of the loading conditions shown, the frames will experience geometrical deformations which is a combination of lateral and rotational movements. For the sake of simplicity we will assume that all the joints remain in their fixed positions in space i.e. lateral movement at joints are prevented. By exaggerating the actual deformations, the deflected shape of column XYZ can be sketched as shown in frame P.

Following the same argument, sketch:

(i) the deflected shapes of columns ABC and DEF on frame P
(ii) the deflected shape of column GHI on frame Q.

Use the appropriate column line as the base line for each of your sketch.
Question 13 Tick all contributions to the total load on beam BE
(a) self weight of other beams joined to beam BE.
(b) self weight of column BC
(c) self weight of beam BE
(d) self weight of first floor slab
(e) imposed load on roof slab
(f) imposed load on first floor slab

INSTRUCTION: To questions 14-16 circle the letter of the chosen answer

Question 14 Calculate the area of slab to be supported by beam BE
A 90 m²  B 27.5 m²  C 13.8 m²  D 55 m²

Question 15. The uniformly distributed load supported by beam BE is
A 63.6 kN/m  B 60 kN/m  C 47.5 kN/m  D 49.3 kN/m

Question 16. Each of the diagram A, B, C and D in the figure below shows part of the plan view for the floor (refer to drawing on the previous page) which includes beam BD and beam BG that support the slab. Those sections, which are shaded darker than the rest represent the possible proportion of the load from the slab that, will be distributed to beam BD. Choose a diagram, which most accurately illustrates the proportion of the load on the slab that is supported by beam BD.

---

APPENDIX 6-7
INSTRUCTIONS: Answer question 17-18 on the answer sheets provided.

Question 17. The figure below shows a continuous reinforced concrete beam fixed at one end, supporting a uniformly distributed load (for example a beam supporting a bridge deck).

(i) Sketch (as you did in question 11):-
(a) the deflected shape of the beam under the given loading condition.
(b) the bending moment diagram for the beam
(c) the reactions of the supports.

A continuous reinforced concrete beam supporting a uniformly distributed load.

(ii) For each section X-X, Y-Y and Z-Z decide on the best combination of most appropriate beam section for the stress distribution across the section and the name of type of bending moment. Select from the sets of descriptions (A,B,...,F) given in Table 1.

Indicate your answer by writing the section designation followed by the chosen description. Sample answer: Section Q-Q Chosen combination: D

Table 1. Beam cross-sections, stress-distributions across the sections at the serviceability limit state and the types of bending moments.
Figure 1 shows the plan, building sections, beam and column sections for a two storey reinforced concrete building. All columns are braced in the x and y direction. All measurements are in mm unless stated otherwise. Problems 1-5 are based on the drawings in Figure 1 and the following data.

- Imposed load (Qk) : 3.5 kN/m².
- Thickness of slab (h) : 250 mm
- Concrete density (γ) : 24 kN/m³
- Characteristic strength of concrete (f_{cu}) : 35 N/mm²
- Characteristic strength of steel (f_y) : 460 N/mm²

Figure 1 (a) First floor plan , (b) section S-S; (c) section T-T; (d) column section R-R and (e) beam section Q-Q.
PROBLEM 1

Calculate:
(i) the total axial load in kN supported by column BD
(ii) the uniformly distributed load in kN/m supported by beam BE
(iii) the total axial load in kN transmitted to column AB
Sketches showing the area and volumes of slab, beam and columns relevant to the calculations are required.

PROBLEM 2

For each column there are two alternatives substitute sub-frames that could be used to determine the bending moment in the column (using simplified moment distribution method).
(i) Sketch the elevation of the most appropriate substitute sub-frame/s (showing the relevant columns and beams) to be used for assessing the bending moment/s on:
   (a) column AB
   (b) column HE
The sketches should be clearly labelled and dimensioned.
(ii) Using appropriate diagrams/sketches, explain why you choose one substitute frame over the other.
(iii) Sketch the deflected shape of the column ABC as seen on the x-x plane when the beams are equally loaded with a uniformly distributed load of w kN/m.

PROBLEM 3

Consider column AB.
(i) Sketch its projections (including the relevant beams and column/s) on the:
   (a) Y-Y plane
   (b) X-X plane
(ii) Calculate it’s clear height \( l_a \) and show it on the relevant sketch [(a) or (b)] for the bending of the column about
   (a) the minor axis
   (b) the major axis
(iii) Calculate its second moment of area about y-y axis \( I_{yy} \)
Include a fully dimensioned sketch of the column section with the relevant axis in place.

PROBLEM 4

Figure 2 illustrates the definitions for the different types of end conditions for a column as found in the Codes of Practice BS8110.
Figure 2 Definitions of column end conditions for (applicable to top or bottom ends)

For bending about the y-y axis determine the end conditions at the:
(a) top of column BC
(b) top of column AB
Include dimensioned sketches of the relevant joint elevations.

PROBLEM 5

Consider column BC.
(i) Sketch the projections (include dimensions) of the column (including the beams and columns framing into it) on the:
   (a) X-X plane and
   (b) Y-Y plane.

(ii) Determine whether the column is short or slender using the procedure in BS8110.
PROBLEM 6.

The singly reinforced pre-cast concrete beam in Figure 3 is going to be used as a propped cantilever beam with an overhang as illustrated in Figure 4. It will be subjected to mild exposure and the fire resistance requirement is at least 4 hours. The bending moments across cross-sections at A, B and C have been identified to be approximately 400 kNm. The pre-cast beam is made from concrete of characteristic strength \( f_c \), 35 N/mm\(^2\) and steel of characteristic strength \( f_y \) 460 N/mm\(^2\).

Evaluate the adequacy of the pre-cast beam to satisfy the above design requirements.

Include the following items in your solution.

(i) a sketch the deflected shape of the beam
(ii) a sketch of the bending moment diagram
(iii) a sketch illustrating all the reactions (axial forces and moments).
(iv) your evaluation of the section and your own design solution presented in cross-sections for sections A-A, B-B, C-C and in longitudinal section for the beam OABC.

---

**Figure 3 Cross-section of the pre-cast reinforced concrete beam.**
PROBLEM 7

A two span one way slab ABCD is to be designed to support a uniformly distributed load (u.d.l) as illustrated in Figure 5.

(i) Sketch:

(a) the bending moment diagram of the slab
(b) the deflected shape of the slab
(c) the stress distribution across section B-B at the ultimate limit state
(d) the stress distribution across section E-E at the ultimate limit state

(ii) Table 1 gives four design proposals for the design of section B-B (refer to Figure 5). Evaluate the adequacy of each of the proposed sections in terms of:

(a) its capacity to resist the induced stresses and bending moments, and
(b) the ease of construction and economy.
(c) Your evaluation must be based on the following factors:
   • the relative area of the main and the transverse reinforcement
   • the positions of the main and transverse reinforcement in relation to the tension/compression surfaces
Table 1. Four proposals for the design of cross-section B-B of slab ABCD shown in combinations of varying areas and arrangements of the longitudinal and transverse steel.

PROBLEM 8

Figure 6-8 show three reinforced concrete beams (designed according to the limit state design method) under various loading and support conditions.
(i) For each of the beam:
   (a) Sketch their deflected shape under the given loading conditions
   (b) Sketch their bending moment diagram
   (c) Sketch their reactions (vertical, horizontal and moment)
(ii) For the identified sections A-A to G-G, choose the most likely descriptions of these sections from the descriptions (A to F) in Table 2. Write your answer in the spaces allocated at the end of the question.

Table 2 Beam cross-sections, stress-distributions and signs of bending moments.

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<th>Steel areas across sections</th>
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Answer 8

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INSTRUCTIONS TO CANDIDATES:

1. Please answer FOUR (4) questions from section A and TWO (2) questions from section B. (If you answer more than the required number of questions, only the first four questions from A and the first two from B will be marked).

2. The allocated marks for section A is 60% and for section B is 40%.

3. Please write on both sides of the answer sheets.

This paper consists of (7) printed pages including the cover.
SECTION A

Question 1

Continuous beam ABCD is loaded as shown below.

Support C settles by 8 mm.

a) Using the moment distribution method, determine the moments at all supports given that I and E are uniform for all spans. \( EI = 36 \times 10^3 \text{kNm}^2 \)

b) Sketch the shear force diagram for the beam.

(25 marks)

Question 2

Frame ABCD is loaded with a vertical point load of 40 kN. Support A is fixed while support D is pinned. The second moment of area, I of AB = CD = I while that of BC = 2I. Determine the resultant moments on ABCD using the moment distribution method.

(Page 1)
Question 3

The frame shown in the next page has members of identical cross-sections. If a point load is applied at joint G and the modulus of elasticity for the material is $E = 200 \text{kN/mm}^2$, determine the minimum cross-sectional area (for all members) that would produce a 6 mm vertical displacement at joint G. 

(25 marks)

![Frame diagram]

Question 4

A uniformly distributed loads of 30 kN/m of 8 meter length is moving over beam ABC starting from A. The beam is simply supported at B and C.

Determine:

a. The maximum reaction at support B 
   (8 marks)

b. The maximum positive shear force at X 
   (8 marks)

c. The maximum positive moment at X 
   (9 marks)

![Beam diagram]
Question 5

Determine the maximum force in members BC and CJ if 25 m length of live load of 30 kN/m and a 120 kN point load move over the truss.

![Diagram of a truss structure]

Question 6

a) State the assumptions for Euler's theory. (9 marks)

b) Figure below shows the cross-section of a 5000-mm hollow, square column. This column is carrying a compressive load of 800 kN. As a consequence, the column shortens by 7 mm. Determine the critical load for this column if the column is pinned at both ends. (16 marks)

![Diagram of a square column cross-section]
SECTION B

Question 1

Based on the figure shown below, determine the vertical displacement at C if $E = 240 \times 10^3 \text{ N/mm}^2$ and the cross-sectional area is $10^3 \text{ mm}^2$ for all members.

![Diagram of a triangular structure with labeled points A, B, C, and measurements of 3 m, 6 m, and 4 m]

Question 2

For the above frame,

a) Sketch the influence line for members BC and EI. (20 marks)

b) Determine the maximum tensile force in member BC when a point load of 60 kN and a uniformly distributed load of 20 kN/m moves along the top of the frame. (5 marks)
Question 3

a. Based on the diagrams given below, determine the maximum moment when the loads move across beam AB

\[ \alpha = \alpha \left( \frac{1}{L/r} \right) \] when both ends of a column are pinned.

b. i. Prove that \( \alpha = \alpha \left( \frac{1}{L/r} \right) \) when both ends of a column are pinned.

ii. Sketch the graph for the critical stress against the slenderness ratio.
INSTRUCTIONS TO CANDIDATES:

1. Please answer FOUR (4) questions from section A and TWO (2) questions from section B. (If you answer more than the required number of questions, only the first four questions from A and the first two from B will be marked).

2. The allocated marks for section A is 60% and for section B is 40%.

3. Please write on both sides of the answer sheets.

This paper consists of (6) printed pages including the cover.
SECTION A

Question 1

Continuous beam ABCD is loaded as shown below. A is a fixed support and D is a simple support. Second moment of area for AB = CD = I while that of BC = 2I.

Using the moment distribution method, determine the resultant moments and sketch the shear force diagram if support C settles by 25 mm.

Assume $E = 200 \text{kN/mm}^2$ and $I = 20 \times 10^6 \text{mm}^4$

Frame ABCD is loaded with a vertical point load of 40 kN and a horizontal point load of 10 kN. The second moment of area of AB = CD = I while that of BC = 2I. Support A is fixed while support D is pinned. Determine the internal moment at points A, B, C and D using the moment distribution method.

(Page 1)
Question 3

For the truss below, determine the vertical displacement at C given that the cross-sectional area for each member is 2000 mm$^3$ and the modulus of elasticity (E) = 210 GN/m$^2$.

![Truss Diagram]

(25 marks)

Question 4

Beam AB is simply supported at A and B. Sketch the influence line for the shear force and the bending moments at point C. If a live load of 15 kN/m and a set of live loads - as shown below - move along the beam from opposite ends, determine:

a) the maximum positive shear force and the maximum negative shear force at C

b) the maximum bending moment at C

![Beam Diagram]

(25 marks)
Question 5

For the frame below:

a) Sketch the influence line for the reaction at support A.

b) Sketch the influence line for the internal forces in member CD and DH.

c) Determine the tensile force and the compressive force for member DH if a live load of 20 kN and a uniformly distributed live load of 8 kN/m are moving along the top of the frame.

(25 marks)

Question 6

a) State the assumptions for Euler's theory.

b) Figure below illustrates the cross-section of an 8-meter T-column. This column is carrying a compressive load of 600 kN. As a consequence, the column shortens by 6mm. Determine the critical load for this column if the column is pinned at both ends.

(25 marks)
SECTION B

Question 1

Based on the above figure, determine the vertical displacement at C if the cross-sectional area and the modulus of elasticity (E) of each member are 2000 mm$^2$ and 210 kN/mm$^2$ respectively. (25 marks)

Question 2

a)  

self-weight of beam = 1 kN/m

For the above beam determine:

i) the maximum shear force at point 8 m from the left end (at x) (7 marks)

ii) the maximum moment at point x. (7 marks)
b)

For the above frame,

i) sketch the influence line diagram for member CD (6 marks)

ii) if a 10 kN/m move across this frame, what is the maximum force in member CD (5 marks)

Question 3

For the above frame:

a) Determine the resultant moments at A, B, C and D using the moment distribution methods. (20 marks)

b) Sketch the moment distribution diagram (5 marks)
## APPENDIX 10

### Results of the item analysis on the overall SVATI

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### APPENDIX 11

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APPENDIX 13

Item analysis on Section III of the SVATI.

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This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles. An illustration of this principle is given below, where the same single object is given in five different positions. Look at each of them to satisfy yourself that they are only presented at different angles from one another.

Below are two drawings of new objects. They cannot be made to match the above five drawings. Please note that you may not turn over the objects. Satisfy yourself that they are different from the above.

Now let's do some sample problems. For each problem there is a primary object on the far left. You are to determine which two of four objects to the right are the same object given on the far left. In each problem always two of the four drawings are the same object as the one on the left. You are to put Xs in the boxes below the correct ones, and leave the incorrect ones blank. The first sample problem is done for you.
Do the rest of the sample problems yourself. Which two drawings of the four on the right show the same object as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.

Answers: (1) first and second drawings are correct
(2) first and third drawings are correct
(3) second and third drawings are correct

This test has two parts. You will have 3 minutes for each of the two parts. Each part has two pages. When you have finished Part I, STOP. Please do not go one to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

Work as quickly as you can without sacrificing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.
PART II

11.

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GO TO THE NEXT PAGE