Please cite as:

(School of Physics, University of Sydney)
Abstract

This project aimed to quantitatively measure the ability of first year science students to transfer their mathematical skills and knowledge to a physical context. An instrument used in earlier studies to measure transfer of mathematical knowledge was modified for this project, and tested with 49 student volunteers. A Transfer Index was developed to measure the degree of transfer of the students mathematics skills and knowledge and analysed alongside the variables developed from student records. The statistical results suggest that the UAI is a good overall measure of a student’s high order cognition and that students who take harder HSC mathematics courses have better abstraction abilities than other students. The results also indicate that the nature of assessment of the HSC may lead students to take a surface approach to learning, evidenced by a general lack of significant correlation between the Transfer Index and HSC subjects. Interviews with students provided qualitative data from which both cognitive resources and processes involved in transfer were identified. Other factors that influence the transfer process such as student expectations and literacy skills were also identified from the interviews.
Acknowledgments

To Manju — your guidance, gentle approach and endless offers of hot chocolate have made this process enjoyable and fruitful. Thanks to Peter and Sandra for your discussion, suggestions and general assistance.

To Associate Professor Anne Green — your encouragement and helpfulness even from before I began honours has been invaluable.

Thanks to the SUPER group for all the journal clubs, and for making me feel welcome as part of the research team. Many thanks to Sal for helping me survive the writing process (you know what you did!)

To my best friend Beck — your love and radiant spirit have inspired, challenged and impacted me. Thank you.

To the One who sustains, strengthens, encourages and loves perfectly — without you everything is meaningless.

And lastly thanks to \LaTeX for making this report look as good as it does.

I certify that this Thesis contains work carried out by myself except where otherwise acknowledged.

Signed ...................................

November 10, 2004
Statement of Contributions to Report

- The original transfer instrument was developed by Sandra Britton, Peter New, Manju Sharma and David Yardley, and modified for use in this project by Britton, New, Sharma and myself.

- Dr Rachel Wilson provided generous consultation on research methods and statistical analysis.

- Eve and Hannah in the Student Support Office provided valuable assistance in attaining student records, and in general help!

- Paul Ferguson and David Young provided equipment and technological assistance for the recording and analysis of the interviews.

- The concept for the Transfer Index was invented and developed by myself.

- The mixed method approach of incorporating qualitative analysis to the project was at the instigation of myself.

- The investigation into graphing ability (graphicacy) was incorporated at my request.

Author notes

Due to the diversity of terminology involved in this project and the related body of literature, a glossary of terms is provided in Appendix A.

This project has clearance from the University of Sydney Human Ethics Committee.
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Chapter 1

Introduction

The mind is so specialized into a multitude of independent capacities that we alter human nature only in small spots, and any special school training has a much narrower influence upon the mind . . . than has commonly been supposed. (Edward Thorndike, 1906)

Transfer of learning is the ability to use skills and knowledge in a different context to the one in which the skills and knowledge were learnt. It is a fundamental, if implicit, assumption of the modern day education system that students possess this ability. However, there has been much debate amongst researchers who have tried to describe the transfer process as to the frequency, and conditions required for transfer.

The aim of this project is to quantitatively measure the ability of first year science students to use skills and knowledge learned in mathematics courses, in other contexts — specifically science. The ability to transfer mathematics skills into physics is of crucial importance in a student’s development as a scientist, and in their future careers.

The research questions to be answered are:

Can the transfer of mathematics skills and knowledge of first year science students be quantitatively measured?

How do students see their transfer process?

In this report the literature about transfer, particularly in an educational setting, is reviewed in Chapter 2. To answer the first research question, a transfer instrument was used to test student’s ability to apply logarithmic and exponential concepts in a physical context, as described in Chapter 3. Chapter 4 describes the development of a Transfer Index from the data, and of other variables from students records. The statistical analyses performed to investigate the relationships between the variables are described in Section 5.1, while Section 5.2 describes the interviews that were conducted in order to address the second research question.

The results are discussed and analysed using the theoretical frameworks discussed in Chapter 6, and suggestions for future research are made.
Chapter 2

Survey of the subject

*The test and use of a man’s education is that he finds pleasure in the exercise of his mind*

(Carl Barzun)

2.1 Introduction to Transfer

The nature of transfer, and the variables affecting its occurrence in different contexts, have been examined and debated for at least a century (see Rebello & Zollman (2004) and Barnett & Ceci (2002) for brief surveys). The importance of transfer cannot be overstated — if knowledge and learning cannot be applied outside the original learning context, they are very limited in usefulness. Transfer has even been described as the “ultimate goal of education” by some researchers (McKeough & Lupart, 1995). There have been a lot of studies of ‘generic’ transfer — the type that enables the education of primary school children to be useful and that makes workplace and sporting training worthwhile. In one sense, the obviousness of transfer is such that it does not need to be stated, yet researchers have encountered many difficulties when it comes to describing this ubiquitous transfer, either qualitatively or quantitatively. There has been a great deal of research conducted on transfer over the past century, and recently there has been research carried out that narrows the gap between different views of transfer.

This survey of transfer will first look at the work of cognitive psychologists, then at some problems with cognitive research from a scientific perspective. The survey then turns to the work of science and mathematics education researchers and outlines the theoretical framework that is the broader context of this project.

2.2 Cognitive Psychology

A review of transfer must begin with the work of cognitive psychologists, who were amongst the first researchers to study transfer. Questions that have stirred the interest of those studying transfer include (Barnett & Ceci, 2002):

- Can we transfer what we learn?
- How similar does the learning context have to be to the transfer context?

In the times that we live, the rapid growth of knowledge and the increasing ease of accessibility to information makes it harder than ever for school syllabuses and tertiary courses to keep pace with changes. The result is that a great deal of information that students learn is redundant by the time they finish studying. What, then, is the point of studying? High school
and tertiary qualifications are highly valued in the workforce, but the assumption made by educators and employers is that students learn, and can apply, far more than mere information. Generic skills such as critical analysis, problem solving and independent thinking are espoused by institutions as desirable, and are expected to be shown by graduates (University of Sydney, 1997).

In addition to the ‘training’ of students in secondary and tertiary education is workplace training that is directed towards increasing skills of workers specifically for use in the workplace, where the training is often off-site (Hesketh, 1997). If transfer of skills learnt in a training context does not occur, then there is a great deal of wasted time and money being spent on training, and education in general (National Research Council, 1994). Of particular concern is the criticism from some researchers that there is negligible empirical support for the view that training is generalizable (Schooler, 1989). If these critics are right then there needs to be a re-assessment of educational and training philosophies on a grand scale.

So what evidence is there that transfer occurs? The number of studies and experiments conducted on this point is large, so only notable and historic studies are examined here.

2.2.1 History of transfer research

The early debate about the existence of transfer was fueled by Charles Judd, who in 1908 reported an experiment where fifth and sixth-grade boys threw darts at underwater targets. For deeper targets, those who had received instruction in refraction were more successful at hitting the targets than those who had not learnt about refraction (Judd, 1908). Judd’s results were used by proponents of the doctrine of formal discipline as evidence that particular types of learning can produce thinking skills that go beyond the original learning context. However, this position was in opposition to the work of Thorndike who failed to find notable evidence for this type of transfer (Thorndike & Woodworth, 1901). The ensuing debate is one that has not been resolved conclusively, prompting Barnett & Ceci (2002) to produce a taxonomy for far transfer (see Figure 2.1). As used by Barnett & Ceci, far transfer refers to the type of transfer in which educators are most interested — the application of knowledge and skills to dissimilar contexts, at later times, in novel ways.

The need for a taxonomy arose from the diversity of research on transfer, with various studies attempting to describe transfer in various ways with different methods. Barnett & Ceci (2002) have categorised the body of work on transfer into the following four groups:

- Studies of analogical transfer (transfer involving the use of analogies)
- Investigations of the doctrine of formal discipline
- Attempts to teach intelligence and “higher order skills”
- Evaluations of the effects of schooling

2.2.2 Taxonomy for Far Transfer

Due to the diversity of transfer research, it is difficult to compare different studies and to discuss results without a common reference or framework. Although acknowledged by the authors as lacking ‘sharp edges’ (in regard to generating quantitative predictions), Barnett & Ceci’s taxonomy is useful for positioning this project in regard to other work, and in seeing the way forward for future research by those concerned with transfer.

---

1 The education theory that the learning of subjects such as Latin and mathematics strengthened the individual’s reasoning powers.
The taxonomy has the following dimensions of context (see Figure 2.1): Knowledge domain; Physical context; Temporal context; Functional context; Social context and Modality. According to these dimensions, this project only deals with non-near transfer in the Knowledge Domain — all of the other contexts are near transfer (see Section 6.1.5).

<table>
<thead>
<tr>
<th>A Content: What transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learned skill</td>
</tr>
<tr>
<td>Performance change</td>
</tr>
<tr>
<td>Memory demands</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B Context: When and where transferred from and to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge domain</td>
</tr>
<tr>
<td>Both clearly academic</td>
</tr>
<tr>
<td>Physical context</td>
</tr>
<tr>
<td>Both academic but one nonevaluative</td>
</tr>
<tr>
<td>Temporal context</td>
</tr>
<tr>
<td>Both clearly academic</td>
</tr>
<tr>
<td>Functional context</td>
</tr>
<tr>
<td>Social context</td>
</tr>
<tr>
<td>Both written, multiple choice vs. essay</td>
</tr>
<tr>
<td>Modality</td>
</tr>
</tbody>
</table>

Figure 2.1: Barnett & Ceci’s taxonomy for far transfer (2002)

### 2.2.3 Bloom’s taxonomy

The other taxonomy pertinent to this study of transfer is Bloom’s taxonomy for categorising levels of abstraction in educational settings. The taxonomy has six levels of cognitive behaviour that range from the simple recall of facts at the lowest level, through increasingly more complex and abstract mental levels, to the highest order which is classified as evaluation. The levels are (with verb examples that represent intellectual activity on each level):

- **Knowledge**: arrange, define, label, list, memorize
- **Comprehension**: classify, describe, discuss, explain, identify
- **Application**: apply, choose, demonstrate, dramatize, illustrate
- **Analysis**: analyze, appraise, calculate, categorize, compare, contrast
- **Synthesis**: arrange, assemble, collect, compose, construct
- **Evaluation**: appraise, argue, attach, judge, predict, select, support

This categorisation of cognitive ability was used in evaluating levels of cognition for this project (see Sections 4.2.2 and 6.1.1).
2.3 Illustration of problems with Cognitive Research

A well-known example of testing for analogical transfer involves the use of the following example as a training problem:

You have a patient with an inoperable stomach tumour. There are some rays that, at sufficient intensity, destroy organic tissue. How can you free the patient of the tumour without destroying the healthy tissue surrounding it? (Gick & Holyoak, 1980).

In studies using this example, students have been shown an analogous problem:

A general wishes to capture a fortress located in the centre of a country. There are many roads radiating outward from the fortress. All have been mined so that while small groups of men can pass over the roads safely, a large force will detonate the mines. A full-scale direct attack is therefore impossible.

The general’s solution is to divide his army into small groups, send each group to the head of a different road, and have the groups converge simultaneously on the fortress. The analogous solution to the tumour problem is to use multiple machines to emit low-intensity rays from different directions. These rays will converge on the tumour, and their combined effect will destroy it, with limited damage to the surrounding tissue.

In the study by Gick & Holyoak where this example was used, most of the college students participating in the study solved the radiation problem when prompted to think about the military solution. This result has been seen as an example of successful analogical transfer, but on closer examination the analogy appears to break down.

From a scientific viewpoint, the relationship between military strategy and radiation treatment is a tenuous one at best. For a start, a fortress under siege will retaliate, and the smaller each attacking party, the more likely that they will be held at bay (and the military strategy of attacking a fortress in the middle of a country is not clear). While a cancerous tumour will grow and spread, it will not respond to ‘attack’ in the same way that an attacked fortress will. On further thought, the purported similarity between the soldiers approaching the fortress and the tissue-destroying radiation is not apparent — the soldiers are the ones in danger as they approach the fortress, while the radiation endangers the healthy tissue surrounding the tumour, for which there is no analogous component in the military problem. So for a student who thinks ‘too much’ about the two problems, there is negligible similarity between the two situations, and prompting students to think about one in order to solve the other may well lead to negative transfer — where students perform worse than if they had received no training (Novick, 1988). This may well explain the lack of transfer found by Reed (1989) in a study that used a similar procedure of an analogical training problem.

This example demonstrates some of the potential difficulties faced when it comes to measuring transfer, and particularly the danger of creating situations where the task at hand becomes a matter of the subject being required to meet the experimenter’s pre-determined expectations, which disregards both the meaning made by the subject, and other factors such as sociocultural environment (Lobato, 2003).

The current project took a sample of students who sat a written test, and interviewed them to determine their understanding of the transfer process, following Lobato’s suggestion of shifting to an actor’s (learner’s) point of view. This position of trying to view the situation from the learner’s perspective reduces the danger of an experimenter-centered analysis. It also leads to understanding how individuals construe similarity between problems, rather than pre-determining how they should see things, and what they should see. This approach, which was used in the current project, is discussed further in Section 5.2.
2.4 Framework for comparing Theoretical Approaches to Education Research

The nature of education research tends to be goal-oriented, trying to answer questions such as “What do we have to do to get students to learn more effectively?”. But to treat education scientifically, an observationally-based framework is required, in which different models of student thinking can be compared. Redish (2003) has proposed and detailed such a theoretical framework. Redish’s work gives this project a framework that has a solid foundation in well-established fields: neuroscience, cognitive science and observational science of humans. It is hoped in the future that the framework will broaden to take into account far more complex processes — those of human emotion.

The framework is concerned with the cognition of individuals and how it interacts with the environment. The framework consists of a two-level system — a knowledge-structure level and a control-structure level. On the knowledge-structure level, structures of association are dealt with — how resources go together. Resources are compiled knowledge elements, which may be at different structural levels in different individuals. The control-structure level deals with identifying the environment and cuing certain associational patterns. Control incorporates the ideas of frames and epistemic games: activities that use particular knowledge and associated processes to solve problems (see Section 2.4.1).

Redish’s framework also includes a structure of memory that is helpful for the current project (Figure 2.2). The transfer of information from working memory to long-term memory requires repetition and time (up to weeks). Long-term memory is divided into declarative memory — knowledge that can be articulated, and implicit memory — procedural and motor memories, as well as habits and conditioned responses.

Figure 2.2: A map of the structure of human memory (Redish, 2003)

Memory is obviously a very complex phenomenon, and there are different models of it to the one above, but a small amount of understanding about its structure can substantially contribute to effective teaching and learning. Principles about memory from cognitive science that are useful in this regard are (from Redish (2003)):
• Memory has two functionally distinct components: working (short-term) memory and long-term memory

• Working memory can only handle a small number of data blocks

• Long-term memory contains vast amounts of information in declarative and implicit memory

• Getting information from long-term memory to working memory may be difficult and time consuming

The relation of this model of memory structure to the current project is discussed in Section 6.1.5.

2.4.1 Science and Mathematics Education Research

One of the views arising from cognitive psychology that has informed and directed mathematics and science education researchers is that of situated learning. Originally proposed by Lave & Wenger (1991), situated learning takes into account variables external to a student as affecting transfer (e.g. social interactions). As outlined by Rebello & Zollman (2004), the situated learning idea combined with the perceived similarity idea of Hoffding (1892) led to Lobato’s “Actor-oriented Transfer Model” where transfer is defined as the “personal creation of relations of similarity” (Lobato, 2003, p. 18). This ‘student-centered’ approach bears strong resemblance to the dominant educational philosophy of constructivism, where learning is seen as a distinctly social process in which students’ prior learning, beliefs and expectations play a large role in determining their future learning. In science education, it is now generally accepted that students’ alternative conceptions\(^2\) must be challenged and shown to be lacking before they will abandon their current thinking and adopt accepted scientific views (Driver, 1995; Matthews, 2000). Hammer & Elby (2001) have pointed out the importance of taking into account students’ epistemological beliefs\(^3\), as this determines how they think about a situation: their frame (Goffman, 1974; Tannen, 1993; Fillmore, 1985). A frame is an interpretation of a situation according to expectations — it helps an individual to answer the question “What kind of activity is this?”

Researchers at Kansas State University have developed a framework to analyse student interviews that takes into account dynamic transfer — the in situ transfer and knowledge construction by students in a teaching interview environment (Rebello & Zollman, 2004). The framework has four major components: External Inputs; Tools; Workbench and Answer (Figure 2.3).

*External Inputs* refers to information provided by the interviewer — it includes questions or other materials such as audio-visual resources. *External inputs* can promote either positive or negative transfer, as they can cause a student to think in a particular way. *Tools* are cognitive ‘entities’ used in student reasoning. They may be pre-existing, or created by the student during the interview. *Tools* are an answer to the question “What is it that is transferred?” The *Workbench* describes mental processes and decision-making by the student. These processes may use the external inputs and tools. Lastly, the *Answer* is a stopping point in a student’s reasoning process that is not necessarily the final outcome — it may, at times, be a question.

The adaptation of this framework to the current project is described in Section 5.2.

Science Education Research

This project is a continuation of the work of Britton *et al.* (2004), using a modified version of the instrument that they developed. Britton, New and Sharma will be referred to as the research

\(^2\)Conceptions which are not the scientifically accepted view.

\(^3\)Beliefs about knowledge and knowledge construction.
team due to their ongoing role in the project.

The goal of the original project was to design an instrument to test the ability of students to transfer mathematical skills and knowledge to other disciplines, and to see if transfer can be measured quantitatively. The project was developed to fill a hole in the literature where it appears that there has been essentially no research done on transfer of mathematics from high school to university. The resulting instrument developed by the research team consisted of questions grouped in several components: computer science, physics, microbiology and (pure) mathematics. The use of the instrument to develop a ‘rating’ for transfer is described in Section 3.1.

There have been attempts by universities around the world to improve the use of mathematics in science, by teaching it ‘in context’ (Chia, 1987). However, Gill (1999a) discusses this situation at King’s College London and concludes that the mathematics is then tied to that context, which does not improve the situation. This highlights the importance of understanding the nature of transfer and the variables that affect the extent to which it occurs.

Gill (1999b) has also examined undergraduate understanding of mathematics using a pre-test. He discovered a pattern that “an all round understanding of graphs on the pre-test predicted success on the later mathematics examination, despite an almost total lack of graph questions on that examination” (p.557). Gill’s conclusion is that there is mathematical understanding related to understanding graphs and slopes that may underpin higher order mathematical concepts. However, he was unable to say whether an integrated understanding of graphs is a result of, or a pre-requisite for, deep mathematical understanding. This is a question which will be probed during this project (see Sections 5.1.1 and 6.1.1). The term for this integrated understanding of graphs is graphicity.

Mathematics Education Research

Tuminaro (2004) has recently completed a cognitive framework for describing and interpreting student use of mathematics in the context of physics. The major components of his framework are:

- Mathematical Resources
- Epistemic Games
- Frames
Mathematical resources is Tuminaro’s answer to the question “What are the cognitive tools involved in formal mathematical thinking in physics?”. They include intuitive mathematics knowledge; reasoning primitives (abstract cognitive elements); symbolic forms (these describe students’ intuitive understanding of equations (Sherin, 2001)); and interpretive devices (resources that determine student interpretation of equations). These resources can exist in inactive, primed or active states.

Epistemic Games are coherent activities that are ‘played’ during mathematical thinking and problem solving. Tuminaro (2004) extends the definition of Collins & Ferguson (1993) to include observation of what students actually do. Epistemic games can be differentiated by their ontology and structure. The ontology of an epistemic game has two components: the knowledge base (set of mathematical resources activated during the game) and an epistemic form (a target structure that guides inquiry).

Frames help in understanding the choices of a student in a particular context. Tuminaro’s definition follows that of Goffman (1974) and Tannen (1993) (Section 2.4).

Epistemic Games can be identified with the Workbench of Rebello & Zollman (2004), and Mathematical Resources with Tools. See Section 6.1.2 for further details on the connections between these frameworks, and their application to the current project.

2.5 Summary

There is a large and diverse body of literature in the field of transfer, from both cognitive psychologists and educational scientists. It is only with the advent and development of accepted frameworks for transfer and educational science that helpful debate and comparison of research can be undertaken. Such frameworks are adopted in this project, by Barnett & Ceci (2002) and Redish (2003) respectively.

Tuminaro (2004) and Rebello & Zollman (2004) also provide frameworks which will be used throughout this report to interpret the results of the test, and analyse student understanding of transfer through the interviews.
Chapter 3

Development and Implementation of the Transfer Instrument

If someone offers to furnish a sure test, ask what the test was which made the sure test sure
(Author Unknown)

This chapter will give a brief history of the study that begat this project, explain modifications made to the original instrument and describe the data collection methods for the project. The term ‘the test’ shall be used to refer to the transfer instrument used in this project.

3.1 Earlier iterations of the test

This investigation of the transferability\(^1\) of mathematics skills by first year science students at the University of Sydney was begun by Britton et al. (2004). It started as a cross-disciplinary study to examine the ability of students to use mathematics in a variety of science contexts (see Section 2.4.1. Students who used the instrument attempted the science components in random order, with the mathematics component attempted last.

The formula used to measure transfer was:

\[
\text{Transfer score} = z\text{-score for first attempted component} - z\text{-score for mathematics}
\]

The results reported that the distribution of transfer scores followed a normal distribution, although this formula has some serious limitations in that it does not give an accurate measure of those who do very well in both components, or very poorly in both components. These end-errors have been addressed in this project (see Section 4.1).

The second iteration of the test was implemented by Wu (2003), who ran the study with 2nd and 3rd year physics students at the University of Sydney. The instrument used in Wu’s transfer study consisted of only two components — a microbiology component and a mathematics component. Wu’s study identified four distinct categories of students, dividing them into groups that had:

1. Very poor transferability
2. Poor transferability
3. Good transferability

\(^1\)A measure of a student’s ability to transfer the content under investigation.
4. Very good transferability

Wu concluded that there were no differences between the 2nd and 3rd year students in terms of ability to transfer, or their ability to work with graphs (a measure of their graphicacy).

3.2 Current Implementation of the Test

The original version of the test had four components with one each for mathematics, physics, microbiology and computer science. The version used by Wu (2003) used only two components: mathematics and microbiology. The test used in this project was similar to Wu’s in that it had a mathematics and a microbiology component, but these were modified for use in this project by the research team.

If the current project is motivated by the ability, or lack thereof, of students to use mathematics in physics, why did the test use a microbiology context? The context of the microbiology question is bacterial concentration as a function of lethal heat. It is assumed that the vast majority of science students are familiar with the concept of bacteria. If a physics context were to be used, it would contain concepts such as resistance and capacitance, or beams of photons: concepts that a lot of students would likely not be comfortable with. As the project aims to understand the transfer of mathematics skills and knowledge to science, the use of a ‘broader’ context will not hinder this aim. Additionally, microbiology is not taught until second year, so no student is necessarily advantaged by being intimately familiar with the physical context chosen for Section B.

First year Science students at the University of Sydney volunteered to sit the test, as a response to lecture visits and mass emails. The first part of the test (Section A) contained only pure mathematics questions about logarithms and exponentials. The second part of the test (Section B) was a multi-part microbiology question about bacterial concentration that used the same mathematical skills and knowledge as Section A. Note that logarithms and exponentials are taught in the NSW Mathematics Higher School Certificate\(^2\) (HSC) course (formerly known as 2 Unit Mathematics) (Board of Studies NSW, 1997), which is assumed knowledge for first year Science, so all students sitting the test would have completed this course (or an equivalent one).

The two sections of the test are shown below:

<table>
<thead>
<tr>
<th>SECTION A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Solve the following equations for ( x ):</td>
</tr>
<tr>
<td>(a) ( x^{-1} = 3 )</td>
</tr>
<tr>
<td>(b) ( \ln x = 0 )</td>
</tr>
<tr>
<td>(c) ( e^{3x} = 12 )</td>
</tr>
<tr>
<td>(d) ( \log(2x) = 4 )</td>
</tr>
<tr>
<td>(e) ( e^{2x} = 5^{-k} )</td>
</tr>
<tr>
<td>(f) ( \ln(x^2) = \ln 5 + \ln x )</td>
</tr>
</tbody>
</table>

2. Simplify the expressions:
| (a) \( \ln(e^x \times e^{2y}) \) |
| (b) \( \log(10^a/10^b) \) |
| (c) \( \log_4(8 \times 2^{-x}) \) |

\(^2\)The final year matriculation program in secondary school education in New South Wales, administered by the Board of Studies.
Certain bacteria in food are killed by heat. When a bacterial culture dies its cell concentration decreases exponentially.

If \( N_0 \) is the initial cell concentration of bacteria in food, and \( N \) is the cell concentration at time \( t \) minutes after the food containing the bacteria is heated to a lethal temperature \( T \)°C, then

\[
N = N_0 \times 10^{-kt},
\]

where \( k \) is a positive constant which depends on the properties of the bacterium.

The Decimal Reduction Time, \( D_T \), is the length of time required for the cell concentration to decrease to one tenth of its original value at a given lethal temperature \( T \).

1. Express \( k \) in terms of the decimal reduction time \( D_T \).

2. The graph below shows how the cell concentration \( N \) (cells/g) of the bacterium *Staphylococcus aureus* (“golden staph”), present in a quantity of poultry stuffing, decreases at a temperature of 62°C.

![Graph showing cell concentration decrease](image)

(a) What was the original cell concentration, \( N_0 \), of golden staph in the poultry stuffing?
(b) What is the Decimal Reduction Time, \( D_{62} \), for golden staph?
(c) Write a formula for \( N \) using the values you found in (a) and (b).
(d) When \( \log N \) is plotted against \( t \) the following graph results.

![Log N graph](image)

i. What is the value of \( N \) when \( t = a \)?
ii. What are the values of \( a \) and \( b \)?

3. The function \( N_0 \times 10^{-kt} \) can be written as \( N_0 e^{-ct} \).

Find an expression for \( c \) in terms of \( k \).
The test was administered in two parts, with two separate groups of students being tested less than two weeks apart. The sample size for the first test was $N=30$, and $N=19$ for the second test.

3.3 Interviews

From the cohort that attempted the test, seven were interviewed within two weeks of completing the test. The goal of the interviews was to elicit information about the thought processes of the students while sitting the test — were they aware of transferring the mathematics from Section A to Section B, and if so, what prompted the transfer? Four interviews were videotaped for analysis and the results of this analysis and its relation to the results from the test are discussed in Sections 5.2 and 6.1.2.

3.4 Marking the test

Section A of the test had nine parts, while Section B had seven. Each of these parts was marked either one (for a correct answer) or zero (incorrect). The Section A parts were easily marked correct or incorrect, while the Section B parts were awarded one for displaying correct use of the underlying mathematical concept. Minor algebraic errors were not penalised.

3.5 Collection of other data

The students who sat the test gave permission for their university records to be accessed, yielding their high school (if applicable) and first semester results. The size of the data group for HSC results was $N=36$. High school results included the University Admissions Index (UAI — used for entry into NSW universities) and marks for individual HSC subjects. The sample size for individual subjects were less than 36, but data from only two individual subjects was used in the analysis (see Section 4.2).

The university records also provided age and gender, which are important variables to consider in any attempt to explain learning phenomena.

3.5.1 Overview of cohort

It is important to note that the students who volunteered for participation in the study were self-selecting — they were not randomly selected. As such, they are non-representative of first year science students. Of the 49 students, only seven were female, and they were generally high-achieving students, as shown by the mean UAI of 94.
Chapter 4

Development of Variables

The primary purpose of the Data statement is to give names to constants; instead of referring to pi as 3.141592653589793 at every appearance, the variable Pi can be given that value with a Data statement and used instead of the longer form of the constant. This also simplifies modifying the program, should the value of Pi change. (Fortran manual for Xerox Computers)

Most studies that have attempted to measure transfer have been quantitative only in the sense that the data sets generated were large enough to perform some kind of statistical analysis. But the only studies known to the researcher that try to quantify transfer in some way are those that used a pre- and post-test methodology (Singley & Anderson, 1989; Hake, 1998). In these studies, the transfer was measured as a type of gain. An example is from Hake (1998), who defines average normalised gain as the ratio of the actual average gain to the maximum possible average gain:

\[
\text{Normalised gain} = \frac{\% < \text{post} > - \% < \text{pre} >}{100 - \% < \text{pre} >}
\] (4.1)

where \( \text{pre} \) is a measure of student understanding on a pre-test, and \( \text{post} \) is performance measured following some kind of instruction or training.

The present study is thought to be unique in the attempt to quantify the degree of transfer of assumed knowledge. Accordingly, a transfer ‘rating’ had to be devised, tested and revised. This process is explained below, followed by an explanation and description of the other variables used in this project.

4.1 Development of the Transfer Index

Using the results of the test, a measure of transfer was devised, based upon correlating performance on matching questions between the two sections of the test, in terms of the mathematics involved in answering the questions.

The correlation scheme attempts to overcome the shortfalls of the z-score treatment of Britton et al. (2004) (see Section 3.1) while still giving an accurate report of a student’s level of transfer. The basic idea is that a mark is given for each correlated pair — a high mark if the particular piece of mathematics skill or knowledge has been used correctly in both sections, and a low mark if it was used in Section A but not in Section B. So each correlated pair then has a transfer score, and overall transfer is the sum of these scores. With this scheme, someone who achieves well in both sections is likely to get a high transfer rating. This overcomes the earlier problems encountered by researchers on this project of end-effects, whereby an inanimate object taking the test would have obtained a relatively high transfer score, while someone who got everything completely right would have a moderate transfer score (Britton et al., 2004).
The first iteration of this scheme awarded scores of 3, 2, 1 and 0 respectively for a correct answer in both sections, Section B right only, Section A right only, and neither right. The reason for awarding 1 for only Section A correct was that it displays evidence of knowledge, but on consideration it was decided that a correct answer in Section A but not in the corresponding part of Section B did not show any evidence of transfer, and so the following scheme (summarised in Table 4.1) was adopted.

<table>
<thead>
<tr>
<th>Section A score</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section B score</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Transfer score</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4.1: Allocation of Transfer Score to mapped questions

Each question in Section A was mapped to a question in Section B that required the use of the same mathematics, generating seven pairs of mapped questions (see Table 4.2). If a student gave the right answer in both sections, they were given 2 for that set of questions. If they did not get it right on both sections, they were given 0. If they answered Section A correctly but did not get the corresponding question in Section B right, they were given 0, as this does not indicate that transfer has occurred. Lastly, if they answered incorrectly on Section A but correctly on Section B, they were given 1 for that set of questions. This reflects the view that transfer has occurred, but to a lesser degree than when answering correctly on both sections. There may be a subconscious process at work when answering Section A that prepares students for Section B — see Section 5.2.3 for further discussion.

It must be noted here that there is a distinct difference between the situations represented by the two right-most columns in Table 4.1. If a student displays knowledge in Section A and not in Section B, they clearly have not transferred that knowledge. Yet if a student scores zero in Section A and in Section B, then little can be adequately said about this situation — how can someone transfer something that they don’t (appear to) have? At this stage, the Transfer Index does not attempt to discriminate between the two situations, however unsatisfactory that may be.

The overall Transfer Index given to a student was the normalised sum of the individual transfer scores on the seven pairs of mapped questions.

\[
Transfer\ Index = \frac{\sum_{n=1}^{7} Transfer\ Score}{14} \times 100
\]  

<table>
<thead>
<tr>
<th>Section A</th>
<th>Mapping in Section B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(a)</td>
<td>1</td>
</tr>
<tr>
<td>1(b)</td>
<td>2(d)(i)</td>
</tr>
<tr>
<td>1(c)</td>
<td>3</td>
</tr>
<tr>
<td>1(d)</td>
<td>–</td>
</tr>
<tr>
<td>1(e)</td>
<td>3</td>
</tr>
<tr>
<td>1(f)</td>
<td>–</td>
</tr>
<tr>
<td>2(a)</td>
<td>2(d)(ii); 3</td>
</tr>
<tr>
<td>2(b)</td>
<td>1; 2(d)(ii); 3</td>
</tr>
<tr>
<td>2(c)</td>
<td>2(d)(ii); 3</td>
</tr>
</tbody>
</table>

Table 4.2: Mapping of Section A questions to Section B

It is important to note, from Table 4.2, that only four parts in Section B are involved in the mapping, and hence in the generation of the Transfer Index. This is a by-product of the naturalistic setting of this project: the research team endeavored to examine transfer in a real educational setting, rather than contriving a test with a one-to-one mapping between all questions on both sections. There are difficulties associated with this naturalistic approach.
involving a trade-off between having a natural, non-contrived setting, and being able to use a greater proportion of the test answers in the calculation of the Transfer Index.

4.2 Explanation of project variables

4.2.1 High School Variables

As outlined in Section 3.5, the UAI and marks for individual HSC subjects were obtained for 36 students. All of these students had attempted at least one of Physics, Chemistry and Biology, as well as at least one mathematics subject in high school. For analysis, the average mark of a student’s school science subjects was calculated \( HSC_{AvScience} \). The purpose of the average science mark was to obtain an overall performance rating in science that could be used as a measure of a student’s ability in the field. However, to test the graphicity hypothesis, Physics was chosen as the most applicable of the HSC science subjects.

To gain entry to first year science at the University of Sydney, students have to do the Mathematics (2 Unit) course at HSC level (or higher). For the cohort that did the test, there were three categories of HSC level mathematics courses. To simplify the explanation of these categories and later discussion, the Mathematics course will be referred to as 2 Unit, the Mathematics Extension 1 course as 3 Unit, and the Mathematics Extension 2 course as 4 Unit.

Some students had only completed 2 Unit, some had done 2 Unit and 3 Unit, and some had done 3 Unit with 4 Unit. Logarithms and exponentials are taught primarily in 2 Unit, but the 3 Unit course contains this content also. Initially, 3 Unit was chosen as the subject to include in the analysis, as there were nearly twice as many students who had done it compared to 2 Unit, and the course covers the content in more detail. But preliminary analysis yielded some unexpected results, and on closer inspection it was found that there was a mediating variable that determined a student’s 3 Unit mark - the choice of either 2 or 4 Unit Mathematics to accompany it (see Section 5.1.1 for details). This led to the splitting of the 3 Unit mark into two variables, depending on whether a student had also done 2 Unit \( (HSC_{Maths3/2}) \), or 4 Unit \( (HSC_{Maths3/4}) \).

The UAI, Physics, average science mark and the two categories of 3 Unit mark comprise the HSC variables: \( UAI, HSC_{Physics}, HSC_{AvScience} \), \( HSC_{Maths3/2} \) and \( HSC_{Maths3/4} \).

It is important to recognise the difference between the UAI and marks from the HSC. UAIs are calculated by the University Admissions Centre (UAC) according to a student’s top 10 units of approved HSC subjects, in a rather complicated fashion. A brief explanation goes like this: the marks given to UAC by the NSW Board of Studies include raw and aligned marks, and then UAC “takes marks provided by the Board and estimates what these marks would have been if all courses had been studied by all students” (UAC, 2004). These scaled marks are aggregated and students are given a percentile which indicates their ranking with respect to other UAI-eligible students. These percentiles are then modified according to what they would have been if all the students completing the School Certificate (awarded after Year 10) had completed Year 12, and then rounded to the nearest 0.05: these are the UAIs. The upshot of all of this is that the UAI is intentionally different from a simple average of HSC marks: it is a ranking of students for the purpose of university entrance, and it is a linear distribution. According to the NSW Board of Studies, “The UAI is a numerical measure of a student’s overall academic achievement in the HSC in relation to that of other students” (UAC, 2004).

The importance of this distinction between the UAI and marks of individual HSC subjects will be discussed further in Sections 5.1.2 and 6.1.1.
4.2.2 Test Variables

The Test variables include Section A and Section B, which are simply the normalised marks from the corresponding sections of the test. Transfer is the normalised Transfer Index as described above (see Equation 4.2), while Graph refers to the normalised mark of a student on the graphing-related questions of Section B: Q.2(a),(b) & (d). The first two parts of these graphing questions require comprehension and graph reading skills, while part 2(d) requires comparison between graphs, interpretation and calculations — showing higher order cognitive thinking, if Bloom’s taxonomy (Bloom, 1956) is adopted.

4.2.3 University variables

The University variables are simply averages of the first semester marks in mathematics (Uni-Maths) and science (UniScience). All of the students except two completed two mathematics subjects (mostly calculus and linear algebra courses), while all but six students completed at least one subject in biology, chemistry, physics or earth sciences.

The Generic variables were obtained from individual student records, with Age calculated to the nearest month at the time of the test. All of the variables are summarised in Table 4.3.

<table>
<thead>
<tr>
<th>HSC</th>
<th>Test</th>
<th>University</th>
<th>Generic</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAI</td>
<td>Section A</td>
<td>UniMaths</td>
<td>Age</td>
</tr>
<tr>
<td>HSCPhysics</td>
<td>Section B</td>
<td>UniScience</td>
<td>Gender</td>
</tr>
<tr>
<td>HSCAvScience</td>
<td>Transfer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSCMaths3/2</td>
<td>Graph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSCMaths3/4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3: Categorisation of Project Variables
Chapter 5

Data Analysis

*Lies, damn lies and statistics* (Mark Twain)

This chapter describes the analysis of the data from the test (Section 5.1) and the interviews of students (Section 5.2). The statistical analysis consisted of searching for correlations between the variables (Section 5.1.1), and using these correlations to inform the selection of variables for multiple regression models (Section 5.1.2). The statistical methods were discussed with Dr Rachel Wilson, lecturer of Research methods in the Education Faculty. The interview analysis consisted of a mapping of students’ comments to the interview framework developed by Rebello & Zollman (2004), and adapted for this project (Section 5.2.2), as well as the natural emergence of a range of themes associated with transfer (Section 5.2.1).

5.1 Statistical Analysis

In order to select the appropriate statistical test to use with the variables defined in the previous chapter, the data were tested for normality\(^1\). Using SPSS for Windows\(^2\), the One-Sample Kolmogorov-Smirnov test\(^3\) (K-S test) for goodness-of-fit was used to determine if the samples represented by the project variables were drawn from a normal population. The null hypothesis is that the sample has been drawn from a normal population, and the test returns a p-value that represents the probability that the null hypothesis is correct.

The project variables that were excluded for non-normality according to the K-S test were *Section A*, *Transfer*, *Graph*, and *Age* (Table 5.1). Clearly, *Gender* has only two possible values, and was thus excluded from normality testing.

<table>
<thead>
<tr>
<th>Variable</th>
<th>K-S Z statistic</th>
<th>N</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section A</td>
<td>1.44</td>
<td>49</td>
<td>0.03</td>
</tr>
<tr>
<td>Transfer</td>
<td>1.35</td>
<td>49</td>
<td>0.05</td>
</tr>
<tr>
<td>Graph</td>
<td>1.51</td>
<td>49</td>
<td>0.02</td>
</tr>
<tr>
<td>Age</td>
<td>1.85</td>
<td>49</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Table 5.1: Variables that are not normally distributed

The K-S Z statistic\(^4\) for *Transfer* indicates that it could be accepted as normal (p>0.05),

---

\(^1\)Normal data in this setting is that which can be modeled by a Gaussian.

\(^2\)A commercially available statistical analysis and data management system.

\(^3\)The Kolmogorov-Smirnov test compares the cumulative probabilities of values in the data set with the cumulative probabilities of the same values in a specified theoretical distribution.

\(^4\)The greatest difference in cumulative probabilities across the entire range of values.
with Mean = 58 and Standard deviation = 36, but after examining a plot of the distribution of the Transfer Index (see Figure B.1 in Appendix B), it was decided to assume non-normality.

This result meant that nonparametric tests had to be used for these variables. As three of the four Test variables are on this list, and this project has transfer at the centre of its inquiry, all correlations were performed using the nonparametric Spearman’s rho (\(\rho_s\)).

5.1.1 Correlations

Statistical correlations were performed in seeking to answer the following questions:

1. Which, if any, of the Test variables best predict(s) UniMaths and UniScience?
2. Do any of the HSC variables predict Transfer, or other Test variables?

The question of prediction cannot be answered by correlations alone, but they were used as a starting point to determine strength of association (see Section 5.1.2 for further detail). The results of the correlations between project variables are shown in Tables 5.2 and 5.3. The p values refer to the significance level of the corresponding Spearman’s rho e.g. a p-value of 0.01 indicates that the coefficient is significant beyond the 1% level (\(p < 0.01\)). Insignificant correlations are indicated by n.s. (not significant). The sample size is indicated by N.

<table>
<thead>
<tr>
<th>Section</th>
<th>Uni Maths</th>
<th>Uni Science</th>
<th>Transfer</th>
<th>Uni Maths</th>
<th>Uni Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(\rho_s=0.56)</td>
<td>(\rho_s=0.59)</td>
<td>(\rho_s=0.62)</td>
<td>(\rho_s=0.61)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N=47</td>
<td>N=43</td>
<td>N=47</td>
<td>N=43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>Uni Maths</th>
<th>Uni Science</th>
<th>Transfer</th>
<th>Uni Maths</th>
<th>Uni Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>(\rho_s=0.66)</td>
<td>(\rho_s=0.63)</td>
<td>(\rho_s=0.58)</td>
<td>(\rho_s=0.64)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N=47</td>
<td>N=43</td>
<td>N=47</td>
<td>N=43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>UAI</th>
<th>HSCAv Science</th>
<th>HSC Physics</th>
<th>HSCMaths 3/2</th>
<th>HSCMaths 3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>(\rho_s=0.45)</td>
<td>(\rho_s=0.44)</td>
<td>(\rho_s=0.48)</td>
<td>(\rho_s=0.56)</td>
<td>(\rho_s=0.61)</td>
</tr>
<tr>
<td></td>
<td>N=36</td>
<td>N=36</td>
<td>N=26</td>
<td>N=11</td>
<td>N=20</td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>p&lt;0.05</td>
<td>n.s.</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Section</th>
<th>UAI</th>
<th>HSCAv Science</th>
<th>HSC Physics</th>
<th>HSCMaths 3/2</th>
<th>HSCMaths 3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>(\rho_s=0.57)</td>
<td>(\rho_s=0.36)</td>
<td>(\rho_s=0.25)</td>
<td>(\rho_s=0.92)</td>
<td>(\rho_s=0.57)</td>
</tr>
<tr>
<td></td>
<td>N=36</td>
<td>N=36</td>
<td>N=26</td>
<td>N=11</td>
<td>N=20</td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
<td>n.s.</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transfer</th>
<th>UAI</th>
<th>HSCAv Science</th>
<th>HSC Physics</th>
<th>HSCMaths 3/2</th>
<th>HSCMaths 3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\rho_s=0.58)</td>
<td>(\rho_s=0.39)</td>
<td>(\rho_s=0.22)</td>
<td>(\rho_s=0.57)</td>
<td>(\rho_s=0.57)</td>
</tr>
<tr>
<td></td>
<td>N=36</td>
<td>N=36</td>
<td>N=26</td>
<td>N=11</td>
<td>N=20</td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.05</td>
<td>n.s.</td>
<td>n.s.</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Graph</th>
<th>UAI</th>
<th>HSCAv Science</th>
<th>HSC Physics</th>
<th>HSCMaths 3/2</th>
<th>HSCMaths 3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\rho_s=0.51)</td>
<td>(\rho_s=0.38)</td>
<td>(\rho_s=0.31)</td>
<td>(\rho_s=0.79)</td>
<td>(\rho_s=0.58)</td>
</tr>
<tr>
<td></td>
<td>N=36</td>
<td>N=36</td>
<td>N=26</td>
<td>N=11</td>
<td>N=20</td>
</tr>
<tr>
<td></td>
<td>p&lt;0.01</td>
<td>p&lt;0.05</td>
<td>n.s.</td>
<td>p&lt;0.01</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

Table 5.2: Correlation of Test variables with University variables

Table 5.3: Correlation of Test variables with HSC variables

A comparison of the two tables reveals that University and Test variables generally have stronger associations than Test and HSC variables. The most notable exceptions are the

---

5Variables that can not be modeled by a normal distribution.

6A nonparametric test of correlation. Spearman’s test works by first ranking the data, and then applying Pearson’s equation to those ranks.
associations between $HSCMaths3/2$, and Section B and Graph. These very high correlations are discussed in Section 6.1.1.

Other notable features of this analysis are the lack of correlation between two of the HSC variables, $HSCAvScience$ and $HSCPhysics$, and the Test variables, as well as the different levels of association of the two HSC Maths variables with the Test variables. See Section 6.1.1 for discussion of these results.

To be able to say that one (or more) variable(s) predicts another one, regression needs to be carried out on the variables concerned. At this stage of the project, the associations given by the correlations informed the selection of variables for multiple regression analysis, in conjunction with other considerations described in Section 5.1.2.

In addition to the associations between the Test and other project variables, a very interesting association was found between Transfer and Graph ($\rho_s = 0.72$, $N = 49$, $p < 0.01$). This was the strongest correlation besides the extremely high ones involving $HSCMaths3/2$, and it supports the findings of Gill that “mathematical understanding related to the understanding of graphs and their slopes . . . may underly [sic] the ability to understand a number of higher order concepts” (Gill, 1999b). The value of $\rho_s$ (higher than 0.7) is a very strong one in the context of social research (Evans, 2004; Field, 2000), so it is a result to carefully note for further analysis. Section 6.1.1 discusses this association further.

The Mediating Variable Problem

As mentioned in Section 4.2.1, initially the marks for 3 Unit Mathematics were included as one of the HSC variables. When the correlations were examined, it was found that the 3 Unit marks only correlated weakly with Graph, and not with any of the other Test variables. This unexpected result led to an examination of the scatter plots of the 3 Unit marks and the Test variables. These plots suggested that there were two distinct groups of marks within the 3 Unit cohort. Further investigation showed that this was true, and that the underlying factor that discriminated between these two bodies — the mediating variable — was a student’s accompanying mathematics HSC course.

For the cohort that sat the test, no student who had combined 2 and 3 Unit Mathematics on the HSC got a mark higher than 50 for 3 Unit Mathematics. Conversely, no student who combined 3 and 4 Unit Mathematics got a mark lower than 60 for 3 Unit. The combination of these two groups in the 3 Unit course led to the initial non-correlation that was found in the 3 Unit marks. The distinct nature of these two groups can be seen in Figures B.2 and B.3 in Appendix B.

5.1.2 Multiple Regression Models

To be able to determine causality, a substantive model of causation is required (Kinnear & Gray, 2000). This involves more than simply applying multiple regression to the variables that are most strongly correlated — it requires a framework to give a reason why those variables would be expected to have a predictive relationship. A comprehensive predictive model would include all possible variables and eliminate alternative explanations (see Section 6.1.1), but in the models that follow, the project variables alone are used to best determine their dependency on each other.

The chronology of the variables in the project is HSC → Test → University, while Age is measured at the time of the Test, and Gender is of course, independent of time. This places a limit on the predictive powers of variables (e.g. UniMaths cannot predict $HSCMaths3/2$),

---

$^7$A sound theoretical rationale to guide the addition of new predictors, which can affect the relative contributions of other variables in the model.
but what else should be expected? For this project, only regression models that include \textbf{Test} variables will be considered. There are thus two sets of regressions models to be considered — firstly, the prediction of \textit{Transfer} from the HSC variables and secondly, predicting \textbf{University} variables from \textbf{Test} variables.

It is also possible to develop regression models with \textit{Graph} as the dependent variable, but for brevity of analysis and discussion, only the models involving \textit{Transfer} are considered.

The HSC variables expected to have a bearing on \textit{Transfer} are \textit{UAI}, \textit{HSCAvScience} and either \textit{HSCMaths3/2} or \textit{HSCMaths3/4}. But on what basis can the two mathematics variables be discriminated? They can not both be included as they are mutually exclusive with regard to students, yet they both represent marks in the same HSC subject. In this situation the results of the correlations can inform the selection of variables — \textit{HSCMaths3/4} has a significant correlation with \textit{Transfer}, while \textit{HSCMaths3/2} does not. This model is shown in Figure 5.1.

The second set of regression models involves the prediction of university results from the \textbf{Test} variables. For both \textit{UniMaths} and \textit{UniScience}, \textit{Transfer} and \textit{Graph} were expected to predict the results. The other \textbf{Test} variables were not included, as Section A of the test is not similar in content to the first semester mathematics subjects concerned, and the microbiology content in Section B is not covered until second year. These models are shown in Figure 5.2.

In all of the models, \textit{Age} and \textit{Gender} were included, as these are often significant predictors in education research.

### 5.1.3 Results of Multiple Regression

The procedure that was followed for each of the models (Figures 5.1 — 5.2) was to enter into SPSS all of the variables shown on the left hand side as independent variables, and the variable on the right hand side as the dependent variable. The output was then analysed to determine whether one of the variables had an insignificant impact, and it was then removed and the procedure repeated until the remaining variable(s) had satisfactory levels of significance as part of the model. The decision to remove variables from the models was based upon the significance of the standardized Beta coefficients\(^8\) ($\beta$); the result of the test of the null hypothesis that there is no linear relationship between the independent and dependent variables; and an analysis of

---

\(^8\)The coefficient when all variables are expressed in standardised (z-score) form; the result of an operation that divides the difference between each independent variable value and its mean by the standard deviation of that independent variable.
the output plots. These plots test for homoscedasticity\(^9\) and normality of the errors\(^{10}\), which are two of the most important assumptions about the variables in a regression analysis (Field, 2000).

For the first model, the result was that the variables Gender, Age and HSCAvScience were excluded — Gender due to there being no females amongst the students selected by the model, and the other two on the basis of significance as discussed above. The \(R^2\) value for the resulting model (Figure 5.3) was 0.38 \((N=20, \ p<0.05)\), and the plots did not show any violation of the above assumptions. The \(R^2\) represents the amount of variance in the dependent variable explained by the independent variables in the final model — 38% in this case. The standardized coefficients are \(\beta = 0.21 \ (p<0.05)\) for UAI and \(\beta = 0.50 \ (p<0.05)\) for HSCMaths3/4. The \(\beta\) values show the relative contribution of the variables to the model. HSCMaths3/4 is a much more significant predictor in this model than UAI.

The second category of model moved from prediction of Test variables to using Test variables as the independent variables, with dependent University variables. For UniMaths as the dependent variable, the variables Gender, Graph and Age were excluded, leaving Transfer as the only independent variable, with \(R^2 = 0.38 \ (N=47, \ p<0.01)\).

With UniScience as the dependent variable, Gender and Age were excluded leaving Graph and Transfer as the independent variables, with \(R^2 = 0.48 \ (N=43, \ p<0.01)\). The standardized coefficients are \(\beta = 0.38 \ (p<0.05)\) and \(\beta = 0.37 \ (p<0.05)\) respectively (see Figure 5.4).

These results are discussed in Section 6.1.1.

### 5.2 Interviews

Seven students from the test cohort volunteered to be interviewed about their involvement. Four interviews, each with one or two students, were conducted over eight days, and each interview was both audio and video recorded for later analysis. There were a number of common themes that emerged from the interviews, and the dialogue of the students was used to identify some of the Tools, and Workbench processes used during the test. Tools and Workbench are part of the framework developed by Rebello & Zollman (2004) to describe student answers in interviews. Here, the framework has been modified so that the External Inputs are limited to the test itself, while the Answer is a student’s written answers, as the framework is being used to identify what happened during the test, rather than during interviews, as it was designed for. It is still helpful to use it to model student thinking during the test, as the primary purpose of the framework is to describe student reasoning.

\(^9\)Constancy in the variance of the residual terms.

\(^{10}\)It is assumed that the residuals are random, normally distributed, variables with a mean of zero.
5.2.1 Themes

Relation between sections

The strongest theme that emerged from the interviews was that five out of seven students saw Section A of the test as a ‘warm-up’ for Section B. This included one of the students who had not been aware while taking the test that both sections contained the same mathematics, but in the interview he recognised that he may have been ‘warmed-up’ subconsciously. Of the remaining two students who did not verbalise this theme, one of them did not see the similarity, and the other simply did not make a comment about this, although he recognised similarities between the sections.

Expectations

There were also a variety of student expectations coming into the test, according to those interviewed. One student, Peter (all names have been changed to protect privacy), said that he treated the test like an exam:

“I sort of took it under exam kind of conditions where each question might not .. is probably not related. Right so you get the question, like in question 1 — in that, the parts may be related but not necessarily between .. question to question”

As far as having an exam mindset, Peter saw the two sections as separate and was not aware of the mathematical similarities between the sections while taking the test:

“I didn’t see any offhand, no. There may have been subtle ones but I didn’t recognize them”.

Another student, Christopher, stated that he was not in exam mode, and therefore was not thinking as clearly as he would have under exam conditions. Another student, Elijah, said that he was expecting there to be a mathematics section and then another section that used the same mathematics in a physical context. He considered this to be obvious from the recruiting process for the test—a concern held by the researcher prior to the test. However, Elijah was the only one interviewed to comment on this, and in discussions with other students at the time of testing there was no indication that students knew what to expect in the test. However, this does give the researcher something to consider in regard to promotion and recruiting for any future tests.

When interviewed, all of the students were asked (1) how they felt about the test, and (2) how well they thought they did. The answers fell into the following categories:

- Great \ Top marks
- Good \ High marks
- Not great \ Average marks
- Not good \ Low marks

When these expectations of achievement were compared with performance (rated by marks on both Sections and the Transfer Index), the students were generally quite close to reality (see Table 5.4). A few underestimated their performance, while a couple may have slightly over-estimated.
<table>
<thead>
<tr>
<th>Expectation of marks</th>
<th>Section A mark</th>
<th>Section B mark</th>
<th>Transfer Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>89</td>
<td>86</td>
<td>93</td>
</tr>
<tr>
<td>High</td>
<td>89</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>86</td>
<td>100</td>
</tr>
<tr>
<td>Average</td>
<td>67</td>
<td>57</td>
<td>79</td>
</tr>
<tr>
<td>Low</td>
<td>78</td>
<td>71</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>43</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 5.4: Student Expectations and Test Performance

**Blocking factors**

Another theme that emerged was the existence of additional factors that blocked or impeded the transfer process. The most frequently noted was the difficulty that students encountered in answering the graph-related questions:

“Section B was probably harder than Section A because you had to read it off the graph, instead of looking for extra information in the question”.

From examination of the test scripts, question 2(d) appeared to be more problematic than 2(a) & (b) in this regard, although Peter initially tried to numerically solve 2(b), and only answered it graphically as a last resort.

For two other students, the amount of information in Section B and the need to interpret it was a difficulty: literacy as a roadblock. There were two students that had taken a break of at least six months between Year 12 and university, and they both commented that they had difficulty in applying the maths to a new context. One of them, Igor, said that he was not sure what to do in Section B, although he knew the mathematics. He said that it was “another step of logic” to relate the mathematics to a new context, and that “remembering is different to understanding”.

The last blockage that emerged was slightly peculiar — the only female student interviewed seemed to find the mathematics harder in the pure mathematics context than in the physical context.

**5.2.2 Tools and Workbench**

From the interviews, a number of Tools and Workbench processes were identified. There are more that are thought to exist, but those given below emerged directly from verbal testimony of the students.

**Tools**

The Tools that students identified as cognitive resources used during the test were:

- Log laws
- Expectations
- Formulas developed in Section A
The first Tool was identified from statements such as “[the test] . . . required a bit of thinking and knowing your log laws as well”.

The last Tool listed here is an example of dynamic transfer — the construction of tools in situ that are used later in the test.

Workbench

The processes that students identified that they used while doing the test were:

- Use of log laws
- Analysing the test according to expectations
- Interpreting/translating the text in Section B
- Interpreting the graphs
- Familiarity with the mathematical concepts in Section B (exponential growth and decay)

The first two processes listed here are executions of the first two Tools listed above. The last Workbench process was identified from answers to the question if Section B looked familiar: “Definitely — with the exponential reduction thing . . . in the 3 Unit course last year”.

5.2.3 Activation of Resources

If applicable, the students were asked what prompted their recognition that the mathematics in Section B was the same as in Section A. The responses were:

- Seeing equations with a $10^{kt}$ form
- An exponentially decaying graph
- Having to solve Q.1 on Section B
- Seeing ‘logs’ in the questions

These prompts were identified as the activation\textsuperscript{11} of mathematical resources. According to Tuminaro (2004), such resources can be inactive, primed or active. The relationship of these prompts to the transfer process is discussed further in Section 6.1.2.

\textsuperscript{11}The level of activity of a neuron or set of neurons. A neuron can be in a variety of activation levels.
Chapter 6

Synthesis and Evaluation

*But what ... is it good for?* (IBM engineer commenting on the microchip in 1968)

This chapter discusses the quantitative and qualitative results from the previous chapter, and the relationship between them (Section 6.1.3), including integration with the specified theoretical frameworks. The relation of the project to the taxonomy of Barnett & Ceci is described in Section 6.1.5, and the implications of this study are discussed in Section 6.2. The chapter concludes with suggestions for future work.

6.1 Discussion of Results

Chapter 5 contained the results of both the statistical analysis of the project variables (Section 5.1) and the qualitative analysis of the interviews (Section 5.2). These two analyses were designed to inform each other (Section 6.1.3), with the interviews helping to gain understanding of the mental processes of students during the test.

6.1.1 Statistical results

Correlations

As mentioned in Section 5.1.1, statistical correlations cannot determine a causal relationship between variables. A correlation is not directional, so there must be other causes that provide direction to the relationship. The most statistically significant associations to arise from the correlations performed on the relevant variables are shown in Table 6.1.

<table>
<thead>
<tr>
<th>Variable category</th>
<th>Association</th>
<th>Spearman’s rho ($\rho_s$)</th>
<th>Sample size (N)</th>
<th>Significance level (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSC</td>
<td>$HSC_{Maths3/2} \leftrightarrow Section B$</td>
<td>0.92</td>
<td>11</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>$HSC_{Maths3/2} \leftrightarrow Graph$</td>
<td>0.79</td>
<td>11</td>
<td>0.01</td>
</tr>
<tr>
<td>University</td>
<td>$Uni_{Maths} \leftrightarrow Section B$</td>
<td>0.66</td>
<td>47</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>$Uni_{Science} \leftrightarrow Graph$</td>
<td>0.59</td>
<td>43</td>
<td>0.01</td>
</tr>
<tr>
<td>Test</td>
<td>$Transfer \leftrightarrow Graph$</td>
<td>0.72</td>
<td>49</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 6.1: Strongest correlations of various project variables with **Test** variables

There are two aspects to the discussion about the correlations — those correlations that are strong and significant, and those that are weak and insignificant. Firstly, the weaker and insignificant correlations are examined.
Of the HSC variables, HSCPhysics was notable for its lack of correlation with any of the Test variables, and HSCAvScience also had generally weak correlations. One possible explanation for the weakness of association between HSCAvScience and the Test variables is that HSCAvScience is not a well-constructed variable: in the attempt to create a broad measure of scientific ability, a general measure of nothing in particular has been created.

The lack of correlation of HSCPhysics is more surprising, and harder to explain. Following the discovery of a mediating variable for the 3 Unit Mathematics marks, the scatter plots of HSCPhysics were examined for a similar factor, but to no avail. The smaller size of the sample is not enough to explain the result either, considering that HSCMaths3/4 is smaller, yet still with significant correlations. An explanation relating to the nature of the HSC and the workload of students in Year 12 is given below.

With regard to the strong and significant correlations, one of the most surprising results was the very high association between HSCMaths3/2, and both Section B and Graph. Generally in social research, such a strong correlation is regarded as the result of the variables concerned being related — they are essentially measuring the same thing. If such variables are predictors in a regression model, the model has multicollinearity\(^1\). In this situation, the variables (either HSCMaths3/2 and Section B or HSCMaths3/2 and Graph) are not both predictors in the proposed multiple regression model Figure 5.1 (as they are in different categories of project variables), and as such the problem does not need resolution, but it does have an explanation worth telling.

The 2 Unit Mathematics syllabus contains the section “Applications of Calculus to the Physical World” which examines exponential growth and decay in a manner very similar to Section B of the test (Board of Studies NSW, 1997). Most of the students interviewed commented that they had seen a problem like Section B in high school mathematics, and clearly this was true. So why did Section B correlate so highly, while Section A, whose content is also covered in the same HSC course, did not?

The answer may lie in the context of the material. By definition, pure mathematics does not have a context in the same manner that, say, physical chemistry does. Pure mathematics (such as that in Section A) tends to be abstract, and not tied to a physical context. While this may make the concepts and skills more portable (i.e. transferable), it may also make these things harder to access, in terms of memory. The repetition that tends to be part of mathematics would enable cognitive resources such as log laws to enter long-term memory, but hard to recall once they have left working (short-term) memory. Conversely, the physical context of exponential growth and decay in which students learnt mathematical concepts related to logarithms and exponentials, may well provide a chain of association that makes it easier to access than the more abstract pure mathematical representations. From Redish (2003, p.12), “The activation of a particular resource in response to a presented stimulus can depend not only on the stimulus but on the context – the activation pattern existing in the brain when the stimulus is presented”.

So, it is thought that the completion of Section A primed and/or activated the resources associated with logarithms and exponentials, and that the primed/activated resources were triggered into a chain of association in Section B, by the prompts listed above.

Why, then, do the 3 Unit marks of the students that also chose 4 Unit mathematics (HSCMaths3/4) correlate with both Section A and Section B well, when students did not learn exponential and logarithmic concepts in the same physical context as described above for the 2 Unit course? The across-the-board strong correlations of HSCMaths3/4 suggest that these students have good higher-order cognitive skills, and thus would be expected to transfer well, regardless of the original learning context.

This argument can also be applied to the uniformity of UAI correlations with Test vari-

\(^1\)Exists when there is a strong connection between two or more predictors in a regression model. It is problematic as it violates one of the assumptions for regression analysis (Field, 2000, p. 131)
ables. As detailed earlier, the UAI is specifically designed to be an all-round measure of a student’s academic ability, and as such those that transfer well can be expected to attain a high UAI. It should then come as no surprise that UAI correlates well with measures of high order cognitive skills such as Transfer and Graph, as students with these skills are likely to attain a commensurate UAI, and similarly for those without these skills.

These correlations also show a significant relationship between Transfer and Graph that warrants further investigation, due to the strength of the association. Is there an underlying causal relationship, and if so, in which direction? The inclusion of Graph as a project variable is to investigate the graphicacy hypothesis — that the ability to do well on graphing problems is an indication of abstraction capability, and is thus a high order cognitive function. Transfer is generally thought to be a high order cognitive skill, related to one’s meta-cognitive abilities (Flavell, 1985). So if there are two high order cognitive processes at work, which comes first? It is something of a chicken-and-egg situation, as is the graphicacy hypothesis itself. Do good results in mathematics flow from abstraction skills developed through graph-reading related activities, or do good maths students have good abstraction ability and can thus perform well on graphing activities? The hypothesis for the relationship between Transfer and Graph is that Transfer will be a predictor of Graph — that graphicacy is a result of underlying cognitive abilities that are described by Transfer. This is due to graphicacy skills being at higher levels of Bloom’s taxonomy than transfer skills. However, there needs to be further carefully designed study to elicit the nature of these cognitive processes, and thus the relationship between these two factors.

The effect of the nature of the HSC on student learning

Overall, the Test and University variables had stronger associations than did the Test and HSC variables. The researcher suggests that this is a symptom of the nature of learning that is generated by the assessment of the HSC.

The HSC involves a high-pressure series of examinations at the end of Year 12, the results of which count for 50% of a student’s mark for the subject concerned. Many high school teachers report that they do not have sufficient time to cover the material in the syllabus, and that they are forced to ‘teach to the test’, rather than teaching for deep understanding (Vinson, 2002). Research in the USA has shown that external testing puts pressure on teachers to teach to the test, and that the time devoted to preparing for such assessment significantly reduces learning time (Smith, 1991; Haladyna et al., 1991). The researcher suggests that the nature of the HSC assessment leads to students having shallow understanding of the subjects due to the styles of learning adopted by students in response to the high-pressure external exams they face. This accords with the work of researchers such as Ramsden (1992) and Rigden & Tobias (1991), who report that the assessment of learning greatly affects the style and nature of learning by the student.

First semester university subjects share a lot of surface features with HSC subjects, but in addition require high order cognitive skills that students may not have learnt at high school. Transfer and Graph are measures of deep learning and abstraction abilities, which is why they correlate well with the University variables. The lack of correlation with HSC subjects is due to the lack of deep understanding measured, or possibly generated by the HSC. The exception for the HSC variables is UAI, which is designed to be an overall measure of students’ academic ability, and is thus expected to reflect high order cognitive abilities of students.

Multiple Regression Models

As mentioned in Section 5.1.2, an adequate model of causation must incorporate all possible independent variables, and account for the variance in the dependent variable. In this project,
there are two chronological gaps that may contain variation that has not been accounted for. These gaps are between high school and the time of the test, and the test and end of first semester. Significant factors that may account for results of the test and university subjects during these times include:

- the amount of time a student spends studying
- a change in living situation and/or social environment
- motivation levels of the student; and
- the learning styles and approaches of the student

Aside from the difficulty of adequately describing such factors numerically, the effort to gather such data would be enormous. Yet without this data, a model of causation is lacking in predictive power — the very situation that is found here. But despite the inadequacy of the models developed in Section 5.1.2, they can still give an indication of the reliability of the assumptions made about the nature of the relationship between the project variables.

Of the three multiple regression models (shown in Figures 5.1 and 5.2), one of them reduced to a bivariate\(^2\) model, with the other variables excluded on the basis of predictive significance. The remaining two models reduced to two predictors, as shown in Figures 5.3 and 5.4. This result will be discussed in two stages, corresponding to the two categories of models: HSC → Test and Test → University.

For the first category, HSC → Test, UAI and HSCMaths3/4 were found to be predictors of Transfer. This confirms the validity of the UAI as a measure of a student’s general academic ability, incorporating higher order cognitive skills, and also strengthens the above argument that HSCMaths3/4 is a similar measure. This is evidenced by the size of the β value of HSCMaths3/4 compared to that of UAI (0.50 to 0.21). It is likely that the variable HSCMaths3/4, which effectively gives a snapshot (or cross-section) of the achievement of some of the highest achieving students (those who attempt 4 Unit Mathematics), is an indicator of the overall ability of these students.

For the second category, Test → University, the Age and Gender variables proved to be insignificant, leaving Transfer as the only significant predictor of UniMaths, and both Transfer and Graph as the predictors of UniScience. Considering the nature of Transfer and Graph as measures of meta-cognition and abstraction, it is not surprising that these variables contribute significantly to predicting first semester university results. Both variables have a roughly equal contribution to the prediction of UniScience, with β values of 0.37 and 0.38. Is this an indication that meta-cognitive and abstraction capabilities are equally important in the study of science? Further study must be done to avoid speculation on this point.

Noting that the UniScience model has the highest \(R^2\) of the three regression models (0.48), further work should seek to incorporate other significant factors to increase the validity of this model, and to test changes in the variables.

The results of the multiple regression are as interesting for the variables that were excluded as those that were significant. In all three models, Age and Gender proved to be insignificant, as did Graph for predicting UniMaths. These omissions warrant some examination.

For Age, the mean was 18 years and 11 months, with a standard deviation of 14 months. This small standard deviation (6%) coupled with the nonparametric distribution of the data indicates that there is little spread in the variable, and so its predictive power is diminished. Meta-cognition, and therefore transfer, are thought to be related to age, but the range of ages represented by this cohort is not sufficient to reveal such relationships.

\(2\)Involving two variables, as opposed to many (multivariate).
In regard to Gender, there were only seven female students in the cohort of 49, which provides little variation. In one of the regression models, Gender could not be included due to there being no females in the students selected by that model, and in others the number of females was below seven due to the variables involved. Similarly to the age of students, the small variation in Gender weakens its predictive powers.

6.1.2 Interview results

Through analysis of the interviews, three Tools were identified, and six Workbench processes, with two of these processes being executions of two of the Tools. Additionally, four prompts were identified - things that the students said helped them to recognise the mathematics in Section B as being the same as in Section A. The themes that arose from the interviews were the view that Section A was a ‘warm-up’ for Section B; that students came into the test with different attitudes and expectations, as well as factors that students said impeded their ability to transfer. These factors were primarily related to graphiacy and literacy skills.

In his construction of a theoretical framework for analysis of students’ mathematical thinking in physics, Tuminaro (2004) identifies three different cognitive structures involved in mathematical thinking: resources, epistemic games and frames. In Section 2.4.1, these resources were identified with Tools, although the definition of Tools is broader and includes “meta-tools” that control the use of lower-order (cognitive) tools. Of the three Tools identified in this project, the first (Log laws) is a lower-order tool, or a mathematical resource. The second, expectations, is a meta-tool that controlled access to cognitive resources during the test, as evidenced by one student’s comment that he was not thinking as clearly as he would during an exam: his framing of the situation affected the availability of cognitive resources. The last tool identified (Formulas used in Section A) was a dynamic in situ construction that was used in Section B.

Thus, the Tools identified represent the three kinds of mental constructs outlined by Tuminaro — Log laws as mathematical resources; Formulas developed in Section A as epistemic games; and Expectations as frames.

In addition to the Tools and Workbench identification made from the interviews, information about the nature of the transfer process was gleaned through the themes and prompts that were identified. In fact, prompts can be seen as one of the themes — the recognising of Section A as assisting in performance on Section B of the test. The other two themes were expectations and blocking factors. These two themes can be seen to be important in the transfer process as framing and activation of resources. A student’s framing of a situation will determine their access to cognitive resources, and hindrances to the transfer process may interfere with the activation of resources.

A Special Case

One student, Peter, was unusual in that he did not recognize the relationship between the two sections of the test, yet he did very well (Transfer = 100). His interview suggested that during the test, he was not aware of connections between the two sections — there was no conscious priming or activation of resources between sections, yet he was still able to transfer well. This raises questions about the nature of transfer — is it a meta-cognitive process after all, or does it occur on a subconscious level? More research is required to be able to provide an answer to this question.

6.1.3 Linking the Statistical and the Interview results

The statistical results show that there is significant variation in the ability of students to transfer mathematical skills and knowledge to a new context. They also show that UAI is a significant
predictor of this ability (measured by Transfer), and that Transfer is a significant predictor of University results.

The interviews revealed a range of student awareness of their transfer process. A number of cognitive resources — the stuff that is actually transferred — were identified, as were processes that take place as part of transfer. Student expectations of their performance were generally accurate, but their awareness of transfer did not seem to affect its occurrence.

### 6.1.4 Other comments

The self-selecting nature of the cohort is a major issue when it comes to generalisation of the statistical findings of this project. The unusual nature of the cohort that participated in the project may be responsible for the anomaly found in the 3 Unit marks, and it is unknown what further effect the nature of the cohort has on the findings.

The nature of the Transfer Index and its validity as a measure of student’s ability to transfer, is something that requires consolidation with further research. From the quantitative results above, it appears to be an internally consistent measure that relates to the other project variables in a consistent manner. The strong association of the Transfer Index with the measure of graphacy (Graph) indicates a measure of predictive validity. However, external comparison with another measure of transfer would contribute to solidifying its validity. Unfortunately, to date the research team’s literature search has been unable to find such a measure.

### 6.1.5 Relation to the literature

The taxonomy of Barnett & Ceci (2002) was designed to allow transfer studies to be positioned along dimensions of content and context to enable constructive comparison of results and methodology (see Figure 2.1). Of the three content dimensions, memory demands is the most important in this project, as performance change is not being measured, and the nature of the learning skill is not of particular importance. For most of the students that took part in this project, the memory demands would have been “Recognize and execute”. However, for those students who had taken time off (at least six months) between Year 12 and university, the memory demands become “Recall, recognize and execute”. Aspects of the memory demands involved in transfer are illuminated by Redish (2003), who argues that recalling items from long-term memory is a non-trivial process that can take significant amounts of time. This was evidenced by the difficulty that two of the students who had taken time off between high school and university had in recalling how to use the mathematics that they knew.

In relation to the context dimensions for this project, the setting for transfer is between the two sections of the test, rather than from the original learning context to the test (which would be much further transfer) (see Figure 2.1). Clearly, all of the contexts except for Knowledge Domain are the same — same place, time, function, social context and modality. But how far along the knowledge dimension is microbiology from pure mathematics? The SUPER\(^3\) group attempted to position the test along this dimension, with no consensus. It is apparent that there needs to be more explicit criteria for the taxonomy in order to be able to satisfactorily position studies for comparison.

For the goal of measuring transfer, the situation of only having one non-near transfer dimension is a desirable situation, as only varying one of the possible six dimensions of transfer context enables a clearer understanding of what is going on in student’s minds, during the transfer process. Future work needs to focus on crystallising understanding of this process, in order to be able to ‘adjust’ the variables that affect transfer.

\(^3\)Sydney University Physics Education Research
6.2 Implications

This project has seen the development, refinement and implementation of a new measure of a student’s ability to transfer mathematical skills and knowledge to a new context — the Transfer Index (Equation 4.2). This Transfer variable was then statistically related to other measures of student achievement to test its validity and predictive power. The attempt to measure the degree of transfer is thought to be unique in transfer studies.

The mixed method approach of quantitative and qualitative data analysis in a study of transfer is also a new addition to the field. It has aided in understanding the transfer process in a deeper way by ‘getting inside’ the student’s heads, identifying cognitive resources and processes, and relating the findings to theoretical frameworks.

The discovery of a strong association between Transfer and Graph (as a by-product of testing the graphicacy hypothesis) has provided avenues for further study to determine the nature of the relationship between these two measures of higher order cognitive ability.

The results of the statistical analysis suggest that students who transfer well are more likely to attain high marks at high school, and thus lead to a correlation between their high school results (in particular UAI and HSCMaths3/4) and Transfer. There is also a suggestion that the nature of assessment of the HSC tends to encourage shallow learning techniques for students at high school, which is a cause for concern for educators and students alike.

6.3 Future Work

Questions that have arisen from this project that can guide future work are:

- Is awareness of transfer related to the ability to transfer?
- What is the relationship between Transfer and Graph?
- Does the assessment of the HSC encourage poor teaching and learning?

To be able to answer such questions, a future study requires a superior sampling technique to the current project. A high-response rate (>80%) in a large random sample is needed to allow the results of the study to be as generalisable as possible. A much more extensive qualitative analysis will also contribute to identifying more cognitive resources and processes involved in the transfer of mathematical skills and knowledge.

In future studies, further thought needs to be put toward the idea of having control groups, in order to eliminate the effect of priming and activation of cognitive resources by the content in Section A. The possibilities for this are to have groups that only do Section A, or Section B, and to compare the performance of these groups with the corresponding performance of those who do both sections; or to have half of the cohort attempt the sections in reverse order.

The connection between Graph and Transfer suggests a relationship between high order cognitive abilities, and future work should be designed to examine this relationship further.
Chapter 7

Conclusion

*I may not have gone where I intended to go, but I think I have ended up where I needed to be* (Douglas Adams)

The aim of this project was to quantitatively measure the ability of first year science students to transfer mathematics skills and knowledge to a different context. The two research questions that guided the work were:

- Can we quantitatively measure the transfer of mathematics skills and knowledge of first year science students?
- How do students see their transfer process?

A transfer instrument originally developed by the research team was modified for this project, and tested with 49 student volunteers. In order to overcome problems with the measure of transfer devised by Britton et al. (2004), the Transfer Index was developed, based on the concept of correlating displays of mathematics skills and knowledge on both sections of the test. Access to university records provided high school data for 36 students, and first semester results for the whole cohort. Statistical correlations and multiple regression were carried out with the variables developed from this data.

The statistical results suggest that the UAI is a good overall measure of a student’s high order cognition, and that students who take 4 Unit Mathematics have higher abstraction abilities than other students. The results also indicate that the nature of assessment of the HSC may lead students to take a surface approach to learning, evidenced by the general lack of correlation between Transfer and HSC variables.

The interviews provided qualitative data from which both cognitive resources (*Tools*) and processes (*Workbench*) could be identified. Other factors that influence the transfer process, such as student expectations and literacy skills, were also identified. The theoretical frameworks of Rebello & Zollman (2004) and Tuminaro (2004) were used in interpreting the qualitative data.

The possibilities for examining relationships between variables are plenty, and future studies with larger numbers of appropriately selected participants will yield a rich body of data to augment the present one. This project has laid a strong foundation for more exhaustive work and development in the future.
Bibliography


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Appendix A

Glossary

Activation – The level of activity of a neuron or set of neurons. A neuron can be in a variety of activation levels.

Epistemic Games – Coherent activities that use certain kinds of knowledge and associated processes to create new knowledge or solve a problem. These are equivalent to the Workbench.

Epistemological beliefs – Views about the nature of knowledge and learning.

Frame – An individual’s definition of a situation that guides interpretation. A frame helps to answer the question “What kind of activity is this?”

Graphicacy – An integrated understanding of graphs, possibly underlying higher order mathematical concepts.

HSC – The Higher School Certificate, awarded to students in NSW on completion of Year 12. 50% of a student’s mark for the HSC comes from the results of external examinations administered by the Board of Studies.

HSCMaths3/2 – The variable that represents the Mathematics Extension 1 (3 Unit Mathematics) marks for students who also undertook Mathematics (2 Unit).

HSCMaths3/4 – The variable that represents the Mathematics Extension 1 (3 Unit Mathematics) marks for students who also undertook Mathematics Extension 2 (4 Unit).

HSCAvScience – The average mark of science subjects taken in the HSC.

Homoscedasticity – The assumption that the variability in scores for one variable is roughly the same at all values of the other variable.

Kolmogorov-Smirnov test – A goodness-of-fit test that compares cumulative probabilities from the data set to the cumulative probabilities of the same values in a specified theoretical distribution.

Kolmogorov-Smirnov Z – The greatest difference in cumulative probabilities across the entire range of values.

Mathematical resources – Cognitive tools involved in mathematical thinking and problem solving. These resources can exist in inactive, primed and active states. These are equivalent to Tools.

Mediating variable – A variable that accounts for the relation between the predictor and the criterion to some degree.

Metacognition – Awareness and understanding one’s thinking and cognitive processes; thinking about thinking.

Multicollinearity – Exists when there is a strong connection between two or more predictors in a regression model. It is problematic as it violates one of the assumptions for regression analysis.

Nonparametric – Variables about which nothing is known concerning their distribution. Data is non-parametric when the normality of the distribution cannot be assumed.
Normality – The fitting of a Gaussian function to the peaks of an evenly-binned histogram.

Ontology – The description of a system in terms of the kinds of objects germane to its characteristics.

Priming – The partial or low-level activation of a set of resources by a particular input. Once resources are primed they are typically easier and quicker to access than if they are not primed.

Resource – A compiled cognitive element that appears irreducible to the user. Different levels of structure may be used as resources by different individuals. These are a generalisation of Tuminaro’s Mathematical Resources.

Spearmans’s rho – A nonparametric test of correlation. Spearmans test works by first ranking the data, and then applying Pearson’s equation to those ranks.

SPSS – A commercially available statistical analysis and data management system.

Tools – Cognitive resources and/or processes used in student reasoning. May be pre-existing, or created by the student during the activity. They include Frames and Epistemic games.

Transferability – The quality of being transferable or exchangeable; specifically a measure of a student’s ability to transfer the content under investigation.

UAI – The University Admissions Index awarded to students in NSW who complete the HSC. The UAI is a percentile ranking.

Workbench – Describes mental processes and decision-making by the student. These processes may utilise Tools.
Appendix B

Plots

Figure B.1: Distribution of the Transfer Index

Mean = 57.8776
Std. Dev. = 36.22478
N = 49
Figure B.2: Scatter plot of Section B and 3 Unit marks. The two groups of marks can be seen to the left and right of 50 (c.f. Figure B.3)

Figure B.3: Scatter plots of Section B with HSCMaths$3/2$ and HSCMaths$3/4$. Note the scales on the horizontal axes