UNIVERSITY LEVEL GENETICS STUDENTS' COMPETENCIES IN SELECTED SCIENCE PROCESS SKILLS

by

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Declaration

The experimental work described in this dissertation was carried out in the Department of Genetics, University of Pretoria, Pretoria, From January 2002 to December 2004 under the supervision of Professors John Rogan and Brenda Wingfield

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any other University. Where use has been made of the work of others it is duly acknowledged in the text.

Signed:
C. M. Aldous (candidate)

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There are unique circumstances that surround a student returning to formal study after many years away. This set of circumstances requires much scaffolding, support and understanding from all the people the student interacts with. Having found myself in these circumstances, I can testify to the truth of this statement. On reflecting on the years it took to get as far as handing in a masters thesis, I realise just how many people I have to be grateful to.

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Summary

Science process skills are essential for all practicing scientists. These skills include various practices that are needed to glean new knowledge as well as to represent existing knowledge. For example, an ability to use mathematics to represent relationships between variables is important in any scientific discipline. Furthermore, understanding scientific method is imperative in any research field. In addition, being literate with tabulated and graphical data is not only important for the scientist's understanding of data, but also for the representation of data in a coherent manner for peer review and knowledge dissemination. Unfortunately these skills are often not explicitly taught in science discipline courses, but instead many course designers assume that students already have these skills. Research has shown however, that this can be a wrong assumption as graduate students sometimes display a shortfall in science process skills.

The research presented in this thesis focused on assessing genetics student competencies in some of the science process skills required by practicing geneticists. The research questions sought to investigate the status of students' abilities in some science process skills, whether they improve throughout the undergraduate careers of the students and which factors might impact on student performance in the skills. The study is introduced in the first chapter with a rationale for the study along with a statement of the significance of the research goals. The term 'science process skills' is expounded and examples are given.

Chapter two contains a review of the literature on science process skills. The historical development of science and the inclusion of science process skills as an integral part of the scientific discipline are related in order to emphasise the importance of science process skills. The current status of the science process skills literature is examined and it is shown that there is a gap in the literature, pertaining to our understanding of the status of undergraduate and graduate student science process skills, which requires investigation by research.

The general research method and design developed for the study is explicated in chapter three. The nature of the study required that both quantitative and qualitative data be gleaned from a large number of students. The complexity of the study required many research processes to be carried out in a linear procedure, from interviewing experts, to designing and implementing a test instrument, to statistical and qualitative analysis of the student scores for the items in the instrument. All of these processes are

explained in chapter 3 while the development of the instrument is specifically dealt with in chapter four.

Chapters five to seven report on the specific methods used to address each research question, the results obtained and the implications of the study. Quantitative analysis of the items in the instrument was executed in order to get a snapshot of the student capacities in the science process skills tested (Chapter five). The results achieved for each group from first year through to honours were compared to infer whether students increase their skill level as they progress through the years (Chapter six). Data from student records were used in addition to their test scores in an effort to find indicators of performance (Chapter seven). Chapter seven includes a model for predicting student performances in science process skills. This model could prove useful when selecting students for admission into science courses

The final chapter provides an overall synthesis of the study with reflective critique and suggestions for further research. An important inference of the study was that in spite of their overall successful completion of the instrument, many students have some specific problems with some science process skills. Furthermore, it appears that students' abilities with science process skills improve significantly from first year through to honours.

This study was conducted in one department at a single university and therefore the results cannot be taken as indicative of all science departments nationally or internationally. However, the method designed and used for this work may be transferred in order to establish the status of students' similar skills at other department and institutions. It is also with this regard that the findings of this thesis may be useful in the future.

Samevatting

Wetenskaplike proses vaardighede is noodsaakilik vir alle praktiserende wetenskaplikes. Dié vaardighede sluit in verskeie praktyke wat nodig is om nuwe kennis te ontdek sowel as om huidige kennis voor te stel. By voorbeeld, die vermoë om wiskunde te gebruik om verhoudings tussen veranderlikes voor te stel is belangerik in enige wetenskaplike disipline. Verder, om wetenskaplike metode te verstaan, is net so belangerik in enige navorsingsgebied. Om tabel en grafiek data te lees en om tabelle an grafieke te gebruik is nie net belangerik vir die wetenskaplike se verstaan van data nie, maar ook om data voor te stel vir ewenaarsoorsig en nuwe kennis verspreiding. Ongelukkig is hierdie vaardighede nie openlik aan student voorgelê nie, maar dit is deur kursus ontwerpers aanvaar dat die studente wel in besit is van die vaardighede. Navorsing wys dat dié aanvaarding wel foutief is en dat gegradueerdes nie in beskik is van wetenskaplike proses vaardighede nie.

Die navorsing voorgele in hierdie tesis is gefokus op die assessering van genetika studente vaardighede in van die wetenskaplike proses vaardighede wat nodig is vir praktiserende genetikuste. Die navorsingsvrae is gemik op die studente se vlak van vaardigheid in van die wetenskaplike prosese, of hulle verbeter in hulle vaardigheidsvlak en op watter faktore mag impak he op die student se vaardigheidsvlak. Die studie is in die eerste hoofstuk voorgele saam met die rasionaal vir die studie en die betekenendheid van die navorsingsdoeleindes.

Hoofstuk twee sluit in ‘n oorsig van die literatuur op wetenskaplike proses vaardighede. Die historiese ontwikkeling van die wetenskap en die insluiting van wetenskaplike proses waardighede as ‘n geintegreerde deel van wetenskaplike disipline is weergegee om die belangerikheid van wetenskaplike proses vaardighede te beklemtoon. Die huidige stand van die literatuur op wetenskaplike proses vaardighede is ondersdoek en dit is gewys dat daar ‘n gaping is in verband met literatuur op die stand van ondergraadse en nagraadse student wetenskaplike proses vaardighede, wat verdure navorsing benodig.

Die algemene navorsingsmetode en ontwerp vir die studie is in hoofstuk drie uiteengesit. Die geaardheid van die studie het benodig dat beide kwalitatiwe en kwantitatiewe data van ‘n groot getal studente geeis moes wees. Die kompleksiteit van die studie het geeis dat verskeie navorsingsmetodes in ‘n liniere prosedure gelewer word, van onderhoude met deskundiges, tot die ontwerp en implementering van ‘n toestinstrument, tot statistiese en kwalitatiewe analise van studentetellings vir

items in die instrument. Al die proses is in hoofstuk drie verklaar terwyl die ontwikkeling van die instrument spesifiek in hoofstuk vier uiteengesit is.

Hoofstukke vyf tot sewe rapoorteer op die spesifieke metodes gebruik vir elke navorsingsvraag. Kwantitatiewe analise van die items in die toetsinstrument was gedoen om 'n blik te kry op studente bekwaamheid in die wetenskaplike proses vaardighede (Hoofstuk vyf). Die uitslae behaal vir elke jaar vanaf eerste jaar tot honeurs is vergelyk om te sien of studente bekwaamheid verhoog deur die jare van studie (Hoofstuk ses). Data vanaf studenterekords was gebruik saam met die toets punte om aanwysers te verkry vir student bekwaamheid (Hoofstuk sewe). Hoofstuk sewe sluit in 'n model vir voorspelling van student vaardigheidsvlak in wetenskaplike proses vaardighede. Die model mag van nut wees as studente selekteer moet wees vir opname in weteskap kursusse.

Die finale hoofstuk gee 'n sintese van die studie met oorpeinsende kritiek en voorstelle vir verder navorsing. 'n Belangerike vinding van die studie is dat alhoewel studente sukses behaal het in die toetsinstrument, ondervind hulle spesifieke probleme met van die wetenskaplike proses vaardighede.

Die studie is in een departement in een universitet uitgevoer en daarom kan die resultate nie as aanwysend geneem word vir alle wetenskap departemente nie, nasionaal of internasionaal. Nogtans, die metode wat ontwerp en gebruik is vir die studie, mag oorgedra word om die stand van studente se soortgelyke vaardighede in ander departemente en universiteite te studeer. Dit is ook in die opsig dat die bevindinge van hierdie tesis in die toekoms van nut mag wees.

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Chapter One: Introduction

1.1 General statement of the problem

A recent study investigating the needs of science-based employers with respect to certain skills required of their graduate employees (Duggan and Gott, 2002) indicated the need across several scientific disciplines for more preparation in some of the practices of science, principally in procedural understanding. Procedural knowledge includes both the understanding of the concepts of scientific inquiry (e.g. concept of a ‘hypothesis’ or a ‘control’) as well as the process skills required to implement these concepts. Some scientists commonly, although erroneously, describe such knowledge as *the* ‘scientific method’ (Lederman, 1998). Duggan and Gott (2002) looked particularly at the procedural knowledge required for functioning in a scientific workplace setting in a biotechnology company, a colourant company, an environmental analysis company and a pump company. Error and accuracy of measurement, followed by repeatability and calibration skills, were common needs across these industries, with each company showing a set of more specific requirements. For example, the biotechnology company identified the following procedural knowledge that it needs its employees to be competent in:

> Repeatability, error (instrument, human, inherent), appropriate accuracy, precision, fair test/controlled conditions, choice of instrument, sensitivity (the least quantity that can be differentiated from zero with confidence), specificity and calibration. (Duggan and Gott, 2002, p 669)

Duggan and Gott (2002) go on to point out that employers “… seemed surprised that new employees did not know how to make these decisions…” (p 670) with regard to the procedural knowledge they said required better skill preparation.

In a different study (Bowen and Bencze, 2002) that focused on pre-service teacher competency with scientific investigation practices it was found that “Having completed a B.Sc. degree was not, necessarily, a predictor of use of higher order practices…” (p 6) such as graphing skills and formulation of hypotheses. They cite numerous studies “…which suggest pre-service teachers have difficulty both with the general practices of science research and the specific practices around interpretation of inscriptions, as do most students.” (p 2). Two points come out of this statement. Firstly a B.Sc degree does not produce graduates with process skill competencies and secondly, since graduate teachers fall into this group, their competencies with process skills, which they are expected to teach, are questionable. Here in lies the root of the problem that in turn gives rise to the following three issues.

Firstly, how can school leavers be expected to gain the procedural knowledge required in the practice of science when the teachers themselves have limited abilities with the same procedural knowledge despite having completed undergraduate science courses? Both the Biology (Life Sciences) (National Curriculum Statement, 2002) and Physical Sciences (National Curriculum Statement, 2002) most recent subject statements stipulate that science process skills must be developed during the teaching of these subjects. But most teachers have difficulty with process skills (White, L. and Aldous, C.M., 2003) and therefore do not adequately impart these skills at the school level. Teachers are therefore required by policy to teach something they themselves have little competency in.

The second issue is how then do tertiary institutions cope with this inadequacy of basic procedural knowledge? In most tertiary academic teaching paradigms, it is assumed that students coming from school into first-year courses have a basic knowledge of process skills and that these will be practiced and nurtured through their undergraduate years to ensure a graduate who will have these capacities. However, the supposed learning of the basic skills in school followed by nurturing at the tertiary level seems to infrequently deliver, if the results of the studies by Bowen and Bencze as well as Dugan and Gott are to be generalised.

The third issue is whether existing university courses help students build on this basic knowledge and develop more advanced procedural knowledge? Many scientists involved in tertiary level education have not had procedural concepts/skills defined for them and either practice them unknowingly, passing them on to students without conscious effort, or omit them completely from their teaching, or assume the skills are acquired automatically by "osmosis". Good scientists who do use the process skills appropriately are often not aware of the need to pass them on to their students and with cluttered syllabi may not find time for their inclusion. This particular issue forms the research questions for this thesis.

Duggan and Gott (2002) further point out that the employers see the identified skills as "common sense" or "gut feeling". They do not see them as requisites in a science pre-service education/training program. It is the assumption that process skills need not be taught, that they are gathered through life experience alone, that has resulted in the inadequate preparation of scientists for the job-market. However, if certain knowledge is required to do a particular action, it has to be explicitly taught (Lederman, 1998).

Science students require an education that will prepare them for careers in a global society that has science and technology as a common currency. Because undergraduate education is central to the preparation of our future science knowledge workers, it is imperative that undergraduate education in science provides and develops all the skills required of a scientist in the work force in addition to the relevant content knowledge for the job.

1.2 Defining Scientific Process Skills

Padilla (1990) states "One of the most important and pervasive goals of schooling is to teach students to think…Science contributes its unique skills, with its emphasis on hypothesizing, manipulating the physical world and reasoning from data."(p1). The terms 'scientific method', 'scientific thinking' and 'critical thinking' have been used at various times to describe these science skills. Today the term 'science process skills' is commonly used. Popularised by Science – A Process Approach (SAPA), these skills are defined as a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behaviour of scientists. Scientific process skills form part of the procedural knowledge required by scientists to practice science. They can be defined more specifically as follows:

> "Scientific process skills are those skills involved in the process of doing science. These skills vary with the type of science being done, but almost always include working through the scientific method; whether it be the experimental or historical methodology." (Bishop and Marsh, 1995)

The researcher could find no single comprehensive and definitive list of all scientific process skills. Owing to the diversity of science as a discipline, and the fast pace of scientific development, it is not likely that one exists. A comprehensive list of all the skills would include skills specific to the disciplines as well as general skills. It is these general skills that are considered important inclusions in science curricula worldwide.

The International Biology Olympiad defines the following scientific process skills as important in its project:

Observation,

Measurement,

Grouping or classification,

Relationship finding,

Calculation,

Data organization and presentation: graphs, tables, charts, diagrams, photographs,

Prediction / projection,

Hypothesis formulation,

Operational definition: scope, condition, assumption,

Variable identification and control,

Experimentation: experimental design, experimenting, result/data recording, result interpretation and drawing conclusions, and

Representing numerical results with appropriate accuracy (correct number of digits).

These skills might arguably be accepted as general scientific process skills for most biological disciplines. Interestingly, the South African Revised National Curriculum Statement Grades R-9 for the Natural Sciences: Teachers Guide for the Development of Learning Programs (2003) quotes the same list almost verbatim; a point that might allow one to have confidence in the list above. In the limited literature available, scientific process skills have sometimes been divided into two groups viz. basic scientific process skills and integrated scientific process skills (Padilla, 1990;Saskatchewen Education). Although the basic process skills provide the basis for learning the integrated process skills, the line dividing these two groups is nebulous, as claimed in the following quote:

> "The scientifically literate person uses processes of science in solving problems, making decisions, and furthering understanding of society and the environment. Complex or integrated processes include those which are more basic. Intellectual skills

> are acquired and practised throughout life so that eventually some control over these processes can facilitate learning. This can provide information processing and problem solving abilities that go beyond any curriculum. Process skills such as accessing and processing information, applying knowledge of scientific principles to the analysis of issues, identifying value positions, and reaching consensus are believed to include the more basic processes of science." (Saskatchewan Education)

The basic scientific process skills include observing, communicating, classifying, measuring, inferring and predicting. Identifying variables, constructing a table of data, constructing a graph, describing a relationship between variables, acquiring and processing data, analysing investigations, constructing hypotheses, defining variables operationally, designing investigations and experimenting are seen as the integrated scientific process skills. It is this grouping that is used to expand and expound the scientific process skills in Tables 28 and 29 to be found in Appendix 1.

1.3 Significance of the study

The concerns raised by Duggan & Gott (2002) and Bowen & Bencze (2002) should be taken seriously by any university or college where undergraduate teaching takes place. That bachelor degrees in science might not be adequately preparing science graduates for the workplace is a criticism that should be taken seriously. The primary significance of this study therefore is that the Genetics Department at the University of Pretoria was in effect carrying out a self-assessment in allowing this study to take place. The results of the study, whatever the outcome, could be used to inform all the lecturers in the department of the capacities the students taking genetics had in terms of scientific process skills in general and, more specifically in which areas difficulties may occur. Such knowledge could inform future curriculum development if remediation is required. Inferences beyond the UP Genetics Department into the rest of the Faculty of Science and Agriculture at UP could be made with caution, but inferences beyond this faculty to other science faculties in universities in South Africa would be irresponsible unless all the variables affecting student performance in the instrument were known and were comparable across the board.

Of secondary importance could be the insights gained by looking at the performance of the students on the test instrument within their demographic contexts. It could be anticipated that the students' scores will lie in a continuum from a weak score to a high score. Although expected, outside factors such as gender, type of matric achieved, ability with mathematics might have some impact on the score achieved by different students in the instrument. Thus the results of the research embarked upon for this thesis should be of particular interest to the staff that teach these students but also to all science lecturers in general.

1.4 Research questions

In order to address the above research problems and issues, the following specific research questions were formulated:

A How do UP genetics students' perform in a test of their scientific process skills and do they experience any difficulties?

If they do have difficulties:

- What is the nature of these difficulties?
- What is the potential source of such difficulties?

B Do genetics students develop their scientific process skills throughout the undergraduate course in genetics?

C Can some factors be gleaned from information about the students (both demographic and from their performance in the instrument) that show they impact on the students' performance in the instrument or various sections of the instrument?

1.5 Outline of following chapters

The thesis for this study is laid out in eight chapters beginning with this introduction. The researcher has attempted to build the thesis up in a logical manner to ensure ease of reading. Subsequent to the current introductory chapter one, the literature is reviewed (chapter two). Chapter three explains the research methodology. Here the research design, context of the study and procedures are explained and justified. Chapter four covers the design of the test instrument and the data for each research question are presented in the subsequent four chapters (five to seven). The final chapter, chapter eight, includes interpretations of the results, discussion of the limitations of the study and implications for future research and practice.

Chapter Two: Review of the literature

2.1 Introduction

The literature read for background to this research covers different areas. In order to substantiate that scientific process skills are an integral part of science as a human endeavour, the history of science is called upon. Much has been written on the history of western science and because the science we practice in schools and universities in South Africa is western in origin, this literature is cited. In some cases the history of the scientific process skill itself is referred to.

Areas of current research into scientific process skills are defined. Much of the available literature in this area covers research on curricula. Science curricula have been rewritten often throughout the world during the last half-century with emphasis moving towards the development of skills and away from rote learning. A second area of research is that into specific scientific process skills. For example, much research has been carried out into studying student competencies in graphing skills and scientific method (Onwu, 1993). A third area of research is the competencies of students at different age levels. There is however, a dearth of literature in the area of identifying scientific process skill competencies that are important in the workplace – the central theme of this thesis.

2.1.1 Where do science process skills come from?

Science as human practice has evolved over millennia. Early man was able to work with and start fire, grow and gather food and make shelter…the beginning of science. This science likely grew out of observation of natural phenomena that was imitated for re-creation. The first basic scientific process skill had been exercised; that of observation. Observations probably led to knowledge and experimentation must have followed where observations were not made, but results anticipated on the basis of observations made previously. It is not clear however if these ancient people asked questions that could be likened to the research question we use as a matter of course today to define research projects (Lindberg, 1992). The communication of accumulated knowledge of scientific phenomena was encapsulated in oral traditions. Man was pre-literate at this point, and the use of oral recording traditions had its limitations.

As man became more society orientated, measuring time and goods became important in order to predict seasons for agriculture and to barter for value. The earliest Egyptian calendar was based on the moon's cycles. However on realising that Sirius, (a star in the constellation of Canis major) rose next to the sun every 365 days, about the time of the annual inundation of the Nile began, they devised a 365 day calendar. This apparently occurred in 4236 BCE (Before the Common Era), one of the earliest years recorded in history. (Steel, 2000)

In order to barter, yardsticks for the measurement of weight and length had to be found that meant the same thing to many people. For short lengths, the lengths of body parts formed the units of measurement: the foot being self-explanatory, the inch being the width of a man's thumb and the yard being the distance from the tip of a man's nose to the end of his outstretched arm. Originally these measures naturally varied from man to man. Clearly it was hugely beneficial to send a very tall man with big feet out to do the shopping or have a very small man as a shop assistant. Weight measurement required a balance, originally used to merely compare the masses of two objects. The Babylonians improved this system by devising the scheme of using standardised weights along with the balance, which provided a more enduring weight standard (Pappas, 1999). However, measurement evolved as a human practice (and a scientific process skill), with people adding more standardising elements through time, resulting in a build up of measuring standards and techniques.

Literacy set in motion the further development of science. Lindberg (1992) states that "…one of the critical contributions of writing, especially alphabetical writing, was to provide a means for the recording of oral traditions, thereby freezing what had hitherto been fluid, translating fleeting audible signals into enduring visible objects."(p12). Writing brought about the new capacity of being able to store information rather than commit it to memory for later recall that might not be accurate. Goody (1977) uses the analogy of an ancient individual's ability to plan a funeral (a complex task in some ancient civilizations) to explain the importance of writing:

> For an individual who is responsible for a funeral, the information about these contributions, which he will later need to return to in similar circumstances, comes to him sporadically during the course of a very busy and complicated burial performance lasting some three days. People arrive from here and there, in the middle of a particular rite, and make offerings that differ from individual to individual, depending upon specific factors such as the state of his granary, his chickens or his pocket, the state of his relationship with the deceased or his relatives, etc. To sort the information on contributions so that it can be retrieved for future action of a reciprocal kind is no easy matter and requires the application of intellectual skills which are only inadequately summarised under the heading of `memory' or `recall'. With writing, the information can be listed in an enduring form as it comes in a chronological order, 1, 2, 3 - possibly with the names and amounts… (p85)

The first forms of writing were limited in their diffusion by their difficulty and inefficiency. The forms used in the writing took a long time to reproduce and the materials used for writing also slowed the writing process down. One has to think only of the Rosetta Stone and imagine comparing the timing of its' creation with the time it takes to type the same verbal content into a computer today. As a result, literacy was under the ownership of the scholarly elite.

However, with the progress made in writing techniques in terms of ease, the number of people who had access to literacy increased along with the amount of information that became available in writing (stored knowledge). Now people were able to record data. Merely recording the data for later recall was not the only benefit however; data in magnitudes too large for memory could also be recorded. This advantage allowed man to infer from much more comprehensively represented evidence than he ever could before. By the sixth and fifth centuries BCE, as a result of these changes in the literacy of a society, as well as some other politically and socio-economically driven factors, the "Greek miracle" happened (Lindberg, 1992).

Pre-Socratic philosophers debated whether reason or sensory perception was the better source of knowledge. Clearly knowledge gained from observation is sensory and the first knowledge gained by man must have been through these means. One of the positive outcomes of this debate was the highlighting of "…rules of reasoning, argumentation, and theory assessment." (Lindberg, 1992. p 35). Plato defined the difference between knowledge gained from reasoning and that gained from observation in his work Phaedo (in Lindberg, 1992). He stated that the senses "…are chains that tie us down; the route to knowledge is through philosophical reflection."(p 38). The process skill of observation for science was now acknowledged and defined, along with its shortcomings.

It was however Plato's student, Aristotle, who is credited with putting the science thinking's house in order. He is credited with systematically defining many scientific disciplines that we still recognise as discrete today, ego physics, meteorology and astronomy. His was enormously influential in his time. His approach to science became dominant once again from the thirteenth century through the Renaissance. As Lindberg (1992) puts it, this success "… resulted not from intellectual subservience on the part of scholars during those periods or from interference on the part of the church, but from the overwhelming explanatory power of his philosophical and scientific system."(p 68).

In Europe during most of the Middle Ages (roughly 500 AD to 1500 AD), technological advancement virtually ceased. It is therefore assumed that the development of science process skills had remained static. It is likely however, that by 500AD, most of the commonly used science process skills were being practiced, after having been put in place by Aristotle and his scholarly predecessors.

Eco (1983) translated Adso of Melk's account of William of Baskerville's deciphering a situation from environmental clues that shows the depth of deductive thinking from observation that was in place in the fourteenth century. The account is interwoven with Eco's fiction and thus must be spuriously relied upon as a truthful indicator, but if it is then it is appropriate to relay the story here. In the account, Adso of Melk is astounded when his travelling companion, William of Baskerville is able to inform a search party in detail of the abbot's horses whereabouts after it had run from the monastery, without either of them having seen the horse. Later, Adso asks William to explain how he was able to do so. William's replies:

> "My good Adso," my master said, "during or whole journey I have been teaching you to recognize the evidence through which the world speaks to us like a great book. Alanus de Insulis said that
>
> *omnis mundi creatura*
> *quasi liber et pictura*
> *nobis est in speculum*
>
> and he was thinking of the endless array of symbols with which God, through His creatures, speaks to us of the eternal life. But the universe is even more talkative than Alanus thought, and it speaks not only of the ultimate things (which it does always in an obscure fashion) but also of closer things, and then it speaks quite clearly. I am almost embarrassed to repeat to you what you should know. At the crossroads, on the still-fresh snow, a horse's hoof prints stood out very neatly, heading for the path to our left. Neatly spaced, those marks said that the hoof was small and round, and the gallop quite regular —and so I deduced the nature of the horse, and the fact that it was not running wildly like a crazed animal. At the point where the pines formed a natural roof, some twigs had been freshly broken off at a height of five feet. One of the blackberry bushes where the animal must have turned to take the path to his right, proudly switching his handsome tail, still held some long black horsehairs in its brambles. You will not say, finally, that you do not know that path leads to the dung heap, because as we passed the lower curve we saw the spill of waste down the sheer cliff below the great east tower, staining the snow; and from the situation of the crossroads, the path could only lead in that direction." (p 23)

After 1500AD, science was very much a gentleman's pastime, and the author surmises that it was since then that recognised science practice became conditional upon the exercising of science process skills. The development of pedagogy in the teaching of science process skills remained to develop with education in general. It was only on entering the twentieth century that science as a school subject became accessible to the populace, albeit mainly to boys. After the Second World War and with the start of the space race, science curricula throughout the western world began to acknowledge a more inquiry-based approach to learning science. Many efforts to get inquiry into practice in the last half of the previous century were aborted early, as they were perceived to lack rigour (Ostlund, 1998).

2.1.2 Current status of the science process skills literature

In 1986, Padilla and Padilla embarked upon a literature review of the science process skills literature. Their work synthesized research related ostensibly to the teaching of science process skills. They described studies that evaluated the effect of various new science curricula. Research covering single process skills, process skill outcomes, and formal operational studies that focused on the ability to conduct experiments were also reviewed. The following review will similarly follow areas of science process skills research.

Studies on the effect of curricula on science process skill development in learners

Ostlund (1998) points out that research indicates that the process-approach programs of the sixties and seventies, Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS), and Science-A Process Approach (SAPA), were more effective in raising student performance and attitudes than the traditional programs. Data from meta-analyses by Shymansky et al. (1983) (quoted by Ostlund) on student performance across these activity-based programs, in terms of performance clusters (achievement, perceptions, and so on) and a composite performance measure, show that students in the hands-on programs outperformed their traditional elementary school counterparts by 9 percentile points. Students' perceptions of these science programs as well as performance on process skill measures were particularly positive, exceeding traditional students by 17 and 19 percentile points respectively. The data indicate that, in fact, these elementary science programs were more effective in enhancing student achievement and problem-solving s kills than were traditional programs.

Bredderman (1983) (cited in Ostlund, 1998) did quantitative research that showed clear evidence that students in process-approach programs learn more than do students in traditional textbook-based programs. Various other studies also have evaluated how well different science curricula edify basic process skills. Studies centred on the SCIS and SAPA indicated that elementary learners, when explicitly taught process skills learn to use them, and retain them for future use and transfer. After comparing SAPA learners to those who experienced a more traditional science program, researchers concluded that the success of SAPA lay in the area of improving process-oriented skills (Wideen, 1975; McGlathery, 1970). It seems reasonable to infer therefore that learners become better adept in the basic skills if they are considered an important objective of teaching.

Tasker (1979) put together a paper that looked into the problems and difficulties in several areas of the Learning in Science Project. He synthesised comments made during both structured and unstructured interviews from students, ex-students, teachers, headmasters, science advisers, and inspectors as well as observations made by project staff related to process skills. The presentation of these comments was intended to disclose problem issues with the transfer of science process skills along with problems in other areas of the project. He suggested direction for further study, covering such topics as the extent to which teachers are confused over the meaning of the term "process skills," and the identification and development of activities to enhance process skill development.

Zion et al. (2004) report on the Biomind curriculum developed in Israel to encourage inquiry in biology teaching and learning. An experienced biology teacher and colleagues developed this program in 2000. Zion states that "the programme offers an alternative conception and organisation of the biology inquiry process, in terms of teaching, learning and assessment."(p60). Although not clear on how they assessed the success of the program, Zion et al. (2004) report that the program does improve scientific thinking among the learners exposed to it.

Studies of learner competencies in science process skills

Padilla, Cronin, and Twiest (1985) carried out a survey of the basic process skills competencies of 700 middle school learners who had no specific process skill training. Even at the eighth grade level, only 10% of the learners scored over 90%. Similarly, Harlen et al. (1984) and Schofield et al. (1989) (both cited in Ogunniyi and Mikalsen, 2004) reported the poor understanding and low-order process skills displayed by 11-15 year olds students in performing cognitive tasks in science. Ogunniyi and Mikalsen (2004) compared a group of South African middle school learners with a similar group in Norway. They found that "…while the two groups of students might be familiar with the content of the VIIAB and the MIM [assessment instruments] and hold some valid ideas about acids, bases and magnetism, they were not always able to mobilise the necessary classification/conceptual process skills or the application/decision-making process skills in performing a number of cognitive tasks in a consistent manner, even after formal instruction." (p 153)

Padilla, Okey and Dillashaw (1983) as well as Brotherton and Preece (1995), demonstrated that experimenting abilities, and therefore by implication science process skills, are related to the formal thinking abilities described by Piaget. A correlation of 0.73 between the two sets of abilities (formal thinking and process skills) was found in the Padilla et al. study (1983). Most early adolescents and many young adults have not yet reached their full formal reasoning capacity (Chiapetta, 1976). Yeany (1984) in his research indicated that students might not be able to acquire certain scientific process abilities until prerequisite cognitive skills are developed. However, Allen (1973) found that third graders were able to identify variables if a simple context was provided. There is an apparent dichotomy in thoughts about when learners have the capacity to carry out advanced tasks; is Piaget right or can a context be developed where younger children will be able to develop skills before the age Piaget predicts?

Not only is there a relationship between cognitive maturity and abilities with science process skills but also with cognitive style. Research carried out by Nakayama (1988) found significant relationships (differences and correlations) between cognitive-style preferences and performance with integrated science process skills. Strauss and van Rooyen (1992) carried out an empirical assessment of the relationship between the cognitive styles of senior education science students. Their research indicated a positive correlation between some of the types of cognitive styles and students' mastery of integrated science-process skills.

Campbell and Martinez-Perez (1976), using Pearson's product-moment correlation coefficients, found that there were positive correlations between

- basic science process skills and integrated science process skills,
- basic science process skills and attitudes toward science,
- basic science process skills and self-concept,
- integrated science process skills and attitudes toward science,
- integrated process skills and self-concept,
- and attitudes toward science and self-concept.

They used the Moore and Sutman (1970) Scientific Attitude Inventory (SAI) to gather data about learner attitudes towards science; Fitts' (1964) Tennessee Self-Concept Scale (TSCS) was used to gather data on learner self-concept and a post-test The post-test items were constructed based on the Basic Science Process Skills (BSPS) and the integrated Science Process Skills (ISPS).

The importance of teaching science process skills

Thiel and George (1976) investigated the skill of prediction among third and fifth graders, and Tomera (1974) that of observation among seventh graders. The results of these studies showed that basic skills can be taught and that when learned, can be transferred to new situations (Tomera, 1974). This echoes Lederman's (1998) call for explicit teaching of science process skills. Colvill and Pattie (2003) elucidate the place of science process skills in a good science curriculum; that science process skills are inextricably linked to acquisition of new science knowledge. A study carried out by Flehinger in 1971 would support this statement. Two-by-two analysis of variance was performed comparing experimental and control groups with high and low process skill level groups. A significant positive correlation was identified between the level of process skills and level of knowledge acquisition for the experimental subjects. Students with a high level of process skill did significantly better in acquiring subject matter than did students with a low level of process skill.

The benefits of explicit teaching of science process skills goes beyond helping only school children. Radford et al. (1992) showed that elementary education students who had taken a science methods course had significantly more positive attitudes toward science and science teaching than did elementary education majors who had not yet taken a science methods class.

Studies on how science process skills should be taught

In 1984, Padilla, Okey and Garrard tested a manner of transferring science process skills in middle school. They integrated experimenting lessons into the science curriculum systematically. Two groups of learners were used in order to compare the learning. The first group of students was taught a two-week introductory unit on experimenting which focused on process skills. The second group experienced an additional process skill activity each week for a period of fourteen weeks after being taught the same experimenting unit the first group was given. The second group outscored the first group in a post-test, showing that process skills are not well learned through an independent teaching unit like that in which science content is commonly taught. Rather, experimenting abilities need to be introduced, practiced and entrenched over time.

Studies on teacher attitudes and training in science process skills

There have been several studies that looked into teacher attitudes and abilities with science process skills (White and Aldous, 2003 and Rambuda and Fraser, 2004). Many interventions have been developed for in-service training (e.g. Rowland et al., 1987) that are subsequently followed up by research into their efficacy (e.g. Norman, 1989). Norman concludes from his research on in-service training using a 'Resource book of Science Process Skills' that;

> "(1) they [teachers] can make significant gains in the mastery of science process skills from an inservice course emphasizing science process skills;
> (2) they can make significant gains in their logical thinking from an in-service course emphasizing science process skills; and
> (3) they may have great difficulty in learning instructional strategies for teaching their process skills to their students." (p 1)

Scholtz et al. (2004) show that there are other problems in the adoption of innovations such as science process skills. Their research indicated that "…rather than adopting a new curriculum or pedagogic strategy, teachers often adapt the strategy in response to an interaction between the new curriculum or pedagogic strategy and the situation in which they work."(p 51). It will be too simplistic therefore to assume that merely training the teachers in in-service situations will improve the teaching of science process skills across the board.

De Jager and Ferreira (2003) carried out a study of teachers' perceptions of problems in the teaching of science process skills. They identified 27 problems in the literature and then formulated a questionnaire to investigate the level of these problems as experienced by teachers. In some of the problems there was a difference in the perceptions of teachers from historically disadvantaged schools and those from historically advantaged schools. This highlights the problem that not all teachers will respond to an innovation in the same way. De Jager and Ferreira name the following issues as hampering the teaching of science process skills in some South African schools:

- Large classes
- A lengthy syllabus
- An inflexible and irrelevant biology curriculum
- A lack of clearly stated outcomes related to process skill development in curricula
- Additional demands on teachers as regards work load and lesson planning
- Lack of equipment and infrastructure particularly in historically disadvantaged schools
- Avoidance of inquiry activities such as field work, laboratory work and practicals
- Attitude of teachers
- The emphasis on examination results
- School management, particularly in historically disadvantaged schools
- Teacher centred teaching

Materials available for the development of science process skills

The literature contains much exemplary material for the development of science process skills in learners. Some activities are designed to develop single process skills while others develop a range of skills. The skill of sorting and classifying is the focus of activities designed by Moore (2003). In his paper he describes various activities designed to teach children how to sort and classify objects that contain more than one attribute using Venn diagrams. In the article the author describes how these skills can be transferred across curricula. Greene and

Greene (2001) encourage the use of amphibians and reptiles in the classroom to develop the skills of observation. To diagnose and remediate this skill of observation, Green developed a test instrument in 1994.

Esprivalo-Harrel and Bailer (2004) developed a novel set of science activities for developing general biological skills using mealworms. They focus on the students setting up and keeping of an observational journal which "…provides a framework to help students systematically organize their observations so they can make inferences, predictions, collect data, engage in analysis, and form conclusions about what they are experiencing. It enables them to construct understandings of how valuable science process skills are to understanding and making valid conclusions about science investigations." (p 34). Solano-Flores (2000) designed a "bubbles task" related to the concepts of force and motion in physics. The learners are required to design and conduct experiments to find out which one of three soapy solutions makes the longest- and which makes the shortest-lived bubbles. This is an open-ended activity that provides many opportunities for problem solving.

Wilson (1996) developed a fun-activity for middle school children aimed at teaching basic concepts that will enable the children to collect and analyse data, carry out necessary tests and develop a scientific approach to solving crimes. This activity forms part of a mystery festival (an inter-curricular activity between science and maths) where children learn to solve 'crimes' in their school while developing scientific process skills, learning to use basic science equipment, and developing their problem solving techniques and critical thinking.

Souchek and Meier (1997) designed an activity that was intended to concurrently and interdependently develop both science process skills and information skills. Their project, which was designed for undergraduates, was divided into four cumulative areas covering a semester: (a) information literacy and the scientific process, (b) the Paramecium experiment, (c) the cricket experiment, and (d) a student-developed, final mini-research project. They designed the activities to become more challenging and to culminate in a final project. Their informal assessment of the project showed favourable results.

There are also more sophisticated teaching aids in the literature. Weiner and Weiner (1996) "…describe an intelligent mentor for teaching the ability to think scientifically" (p 5) in the form of a virtual experimental environment. Their paper describes the use of the package, Biomatrix, as an intelligent tutor for advanced undergraduates and graduate students in scientific reasoning. In mentor mode, this system allows students to investigate research questions interactively by proposing and testing scientific hypotheses. Students are able to create a research project and proceed with it in real time, just as if it were a real research project.

Eidson and Simmons (1998) examined the effect of an educational genetics software program on students' science process skills and conceptual understanding of some genetics concepts. The students used CATLAB to solve problems by practicing process skills applications and testing basic genetic principles. The authors conclude "…The use of microcomputers and appropriate software (such as CATLAB) can result in significant learning and understanding of genetics concepts by students and enhance students' abilities to use specific process skills in problem-solving." (p 21)

2.2 Interpretive summary of the current state of knowledge

Much of the reported literature in this review does not have a direct bearing on the research questions for this thesis. The literature about science process skills in school education is abundant. This study was carried out at a tertiary institution. The importance of teaching science process skills actively is pronounced in much research. In this study, the skills are not explicitly taught, but the students do not experience problems with them. The driving force behind the implementation of teaching science process skills is curricula. Much literature reports on the degree of success of various curricula in the teaching of the skills. It is the learner who is the intended beneficiary of the acquisition of these skills, and research has been reported on that looks into the performance of learners from junior school through to college level.

Teachers' knowledge, perceptions and training are also often studied and reported. The pedagogy and pedagogic content knowledge required to teach science process skills are also, to a lesser degree, covered in the literature. There is an abundance of materials designed to help teachers and students develop science process skills. These materials are either focussed on the development of specific science process skills, or of a variety of skills concurrently.

There is a gap in the literature with regards the use of science process skills in practice beyond formal education. Many sources state the importance of science process skills as a form of life skill for a general population, but there is an inadequacy in research into what is required of scientists and technicians in the workplace. It is important to define other outcomes for science process skills education for this sector. In order to do this future research will have to be engaged in to find out what the important science process skills are for different scientific disciplines.

Chapter Three: Research method

3.1 Research design

Research methods are the range of approaches used in the collection, interpretation, explanation, prediction and inference of data (Cohen and Manion, 1994). In order for any research undertaken to make some contribution to already established knowledge it has to be valid. A valid research study is one where research frameworks that are understood by other researchers are used and where the research is adequately described so that other researchers may use it to extend the results to other studies (Phelps, 1994; McMillan & Schumacher, 1993).

In order to achieve such validity, well-established methods were chosen. This chapter expounds the conceptual and methodological frameworks employed in the research on which this thesis reports. The approach and range of methods that were used in this study to gather and interpret data on student capacities with some of the process skills required to practice as a scientist are discussed. The rationale for the design of certain probes and methods employed is dealt with explicitly. The limitations as well as the strengths of the methods used are considered where appropriate.

The nature of the knowledge to which this thesis contributes to education is descriptive. As descriptive research, it is aimed at producing statistical information about the genetics students' at the University of Pretoria competencies with selected scientific process skills. Specifically, this kind of study falls into the ambit of relationship research as it includes causal-comparative and correlational methods. In educational research this approach is important as it explicates the reality, a necessary precursor to causal inference research and the design of new instructional methods and curriculum design (Gall et al. 1996). According to Gall et al.,

> …the usual steps involved in quantitative research: formulate a research problem; state research hypotheses, question, or objectives; select an appropriate sample and measures; and collect and analyse the data. (p376).

It is this approach, which closely follows scientific method, that is pursued for this thesis.

Both quantitative and qualitative approaches were applied in this study. The quantitative methods were applied in analysing the entire sample of students test instruments. It is a positivist approach (Delamont, 1992) that makes the assumption that without changes in any variables, the results would be consistent over time. Matlou (2002) mentions that Cock (1986) criticizes the quantitative approach for its quantification of human experiences that in fact need contextual description and interpretation. The nature of the research for this study is such that an overall picture of the entire cohort of registered genetics students in 2003 was sought in order to answer the research questions. A statistical analysis of the students' performances is specifically required for this study and the psychometric feature of the quantitative approach has merit here.

The qualitative approach was taken when each student response of interest was analysed inductively. All the items in the instrument were accompanied by a request for the student to write down why they answered each question as they did, i.e. they were asked to justify their answers in their own terms. The focus was on understanding why the student made certain choices in their answers to the probes, making this part of the research phenomenological. One of the aims of the qualitative approach is to understand the personal experience of the student (Patton, 1990). This part of the research was interpretive in nature. This is a post-positivist approach which "…is grounded in the assumption that features of the social environment are constructed as interpretation by individuals and that these interpretations tend to be transitory and situational." (Gall et al., 1996).

Quantitative and qualitative approaches are often construed as dichotomous…a false dichotomy. The researcher is of the opinion that neither approach needs to be seen as mutually exclusive; that each can contribute, in an integrated way, to answering the overall research question. This argument echoes that of Biddle and Anderson (1986), who favour the complementary use of both approaches in the understanding of the educational context. In this study, the quantitative method was used to seek out general trends that were further analysed using the qualitative approach. Figure 1 below serves to clarify the structure of the study and the areas where various research methods were employed.

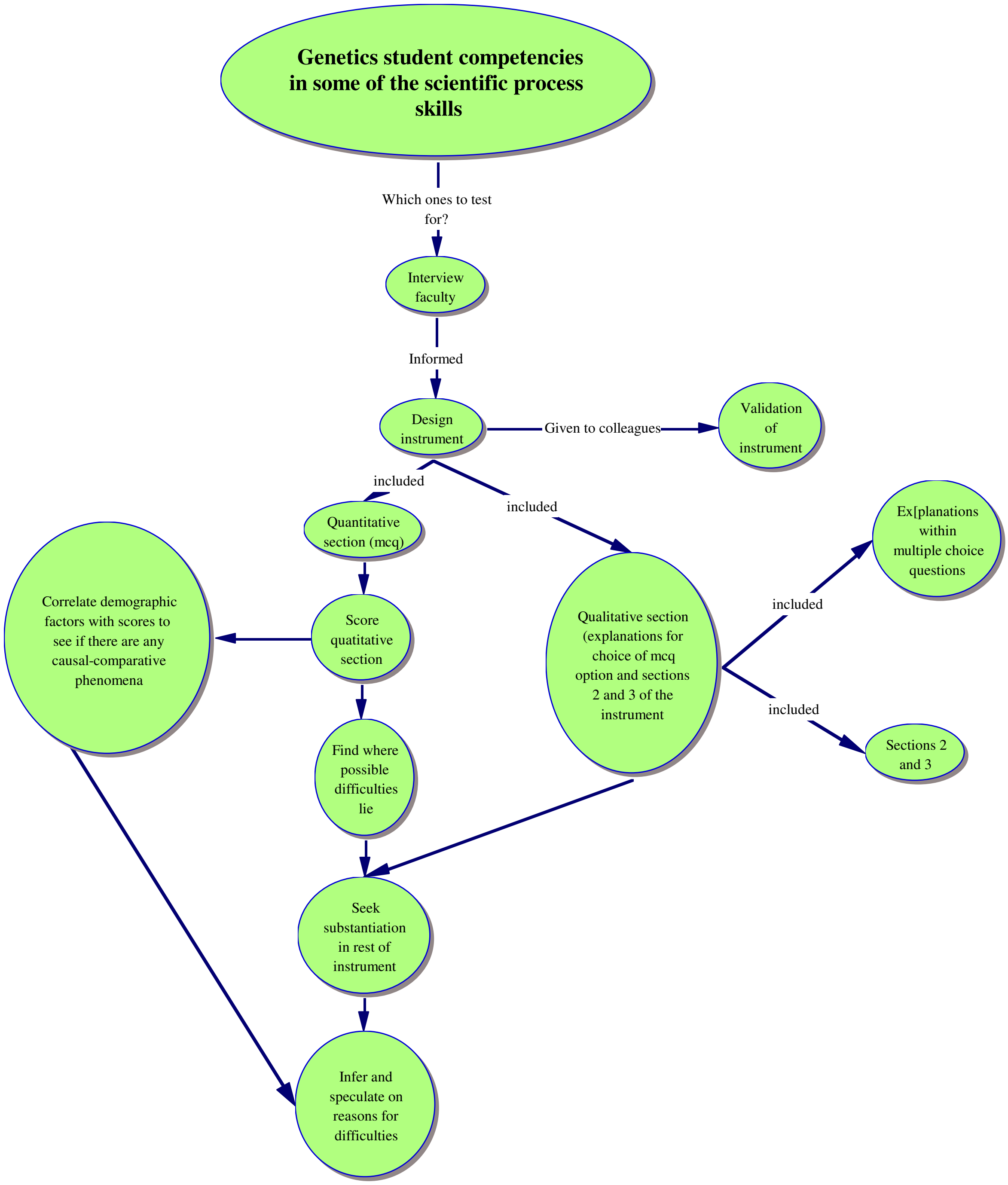


Figure 1: The structure of the study and the areas where various research methods were employed

3.1.1 Interviewing faculty

The term "scientific process skill" is one that is familiar to science educators. School curricula from around the world include inquiry and the associated process skills as necessary outcomes of an education in the sciences. Scientists practice the skills but are often not aware of the collective term for them. A seminar defining and exemplifying what is meant by scientific process skills was run as an information session for the genetics lecturing staff prior to commencing the research. It was deemed easier to determine a list of process skills specific to the field of genetics if an exemplary sample list was provided as a starting point. Presented in the seminar, showing the explanation with examples helped clarify to the scientists what the nature of the process skills might be for the practice of genetics. The International Biology Olympiad has such a list and this was presented as an exemplary list during the seminar.

In order to establish a list of scientific process skills required by geneticists, a semi-structured interview was subsequently conducted with genetics staff. The interviews were conducted on a one on one basis except for one interview where two colleagues were interviewed together. Appointments were made with each lecturer to suit their schedules. Data from the interviews were recorded on an interview sheet during the interview. A copy of the structured interview sheet is given in Appendix 2.

Ensuring a relaxed atmosphere and establishing a rapport with the interviewee during an interview are important prerequisites (White & Gunstone, 1992) to gathering data that are both reliable and valid, apart from the interviewer characteristics and his/her preparation. Since both the interviewer and interviewees were contemporaries in many cases, as well as colleagues in the same university, the contact was relaxed and positive. Also, the interviewer had completed an honours degree under many of the same lecturers during the previous year and a positive relationship had already been forged during this time.

Appropriate casual chat was engaged in with the interviewee in order to create a friendly and relaxed atmosphere (Lincoln & Guba, 1985, Schollum, 1983). The interviews were conducted in the their offices; another factor which contributed to the relaxed atmosphere of the interview. Various authors (e.g. Bell, 1999; Cohen & Manion, 1994) have stated that the respondent or interviewee may answer questions according to what they think the interviewer wants to hear. Owing to the relationship of mutual respect between the interviewer and interviewees the problem of pleasing the interviewer probably did not exist. At the start of the interview the lecturers were reminded of the aim of the study which they were told of during the seminar and were assured that the purpose of the interview was to gain greater insight into areas of possible difficulties so that more effective teaching strategies and approaches could be formulated, an approach also suggested by White & Gunstone, (1992).

The interview commenced with a single free-response type question, which allowed the interviewee to express his/her own thoughts on process skills, and the research embarked upon. This approach allowed the interviewer to assess the extent of the interviewee's familiarity with the science process skills s/he deemed important in order to practice as a geneticist. It also assisted the interviewer to make decisions whether to then use further probes to delve deeper or to guide the interview (Cohen & Manion, 1994). The use of both free-response and more structured probes in an interview increases objectivity and uniformity and also allowed for clarification and in-depth probing (McMillan & Schumacher, 1993).

In order to create a train of thought focused on scientific process skills during the interview, scientific method was used as a guide. It was thought that if the interviewee could place him/herself within a thought experiment in his/her field and think about the science process skills required at each point along the experimental process, a list of skills pertaining to that specific sub-discipline of genetics could be established. It was acknowledged that each thought experiment that a scientist could undertake might require different science process skills, and the list that would be formed after this interview would not be fully comprehensive. In addition the list would not be static over time, as new techniques that might require new skills are continually being added to the repertoire of protocols available to geneticists. However, it was envisaged that during the interviews, as comprehensive a list would be formed as possible which could include the most important and widely used scientific process skills. The combined list from all the interviewees would therefore still be useful in informing teaching of genetics in the future. The competence of students on the three most frequently mentioned process skills was tested.

3.1.2 Student Assessment instrument

The measure used to get data for the study was a diagnostic instrument specifically developed to test various scientific process skills. The choice of which scientific process skills to test was informed by information gathered through faculty member interviews. A performance test was sought with a focus on achievement in scientific process skills. No standardized instruments could be found by the researcher to test these specific science process skills, so the instrument was locally constructed. Gall et al (1996) set out seven major steps in developing a test that were followed in the design of the instrument. These are:

i) *Defining the constructs to be measured* – the three most numerously mentioned scientific process skills in the lecturer interviews defined the areas of questioning.

ii) *Defining the target population* – all the genetics students from first year through to postgraduate were asked to complete the instrument.

iii) *Reviewing related tests* – an extensive search was carried out to find existing standardized tests.

iv) *Developing a prototype* – using probes from other instruments and newly designed probes, an initial instrument was designed.

v) *Evaluating the prototype* – colleagues were asked to review the instrument.

vi) *Revising the test* – the comments received from the reviewers were evaluated and the instrument was altered accordingly.

vii) *Collecting data on validity and reliability* – an item analysis was carried out on the multiple-choice questions in Section One of the instrument.

The first part of the instrument contained probes that were designed primarily for quantitative analysis that would highlight the areas where students might show difficulties. Here the two-tier multiple-choice format was chosen (White & Gunstone, 1992). The first tier consists of an answer to the question through choosing the correct answer from a set of distracters. The second tier, a reason supporting the answer given. The effectiveness of this approach lies in its ability to diagnose the student's reasoning and the understanding of the knowledge required to make the answer.

The rest of the instrument provided the opportunity for limited qualitative analysis that would allow for some informed speculation on reasons for the difficulties if any were identified. The items required longer written answers that could be analysed for reasoning as well as requests to justify the answers.

The process skills tested were some to do with research design, use of mathematics to express scientific phenomena and the use of graphs and tables. Probes were sought from already validated tests available on the worldwide web. Some probes were found in the following sources and in some cases they were slightly altered to make them more appropriate for the level of the students:

- Regents Prep Living Environment: Multiple choice questions archive (Oswego City School District Regents Prep Exam Center)
- Regents High School Examinations (Oswego City School District Regents Prep Exam Center) and
- Collegiate Assessment of Academic Proficiency: Science reasoning sample passages and items.

Sufficient suitable probes were not found for the purposes of this instrument, so the researcher, with the assistance of a genetics lecturer, created additional appropriate probes to test for the skills.

Gall et al. (1996) identified five criteria that can be used to judge the quality of a test instrument for use in educational research. Each criterion is discussed below for the instrument designed for this research.

i) *Objectivity* – For the first section of the instrument, (which was designed specifically to do mass quantitative analysis on in order to glean initial findings that would inform later qualitative study), multiple choice questions (mcq's) were designed. In a mcq-based instrument, a memorandum is drawn up to score mcq's that all scorers' use and therefore many scorers will score identically. This ensures maximum objectivity. The rest of the instrument contained questions that were also factual in nature and therefore objective marking could be ensured. However, the explanations students were asked for to elucidate their responses in all the sections cannot be objectively marked. These items could be likened to self-report measure type items that are intended to give information unique to the student. These questions were intended for qualitative analysis.

ii) *Standard conditions of administration and scoring* – The instrument was administered by the researcher in all cases to ensure uniformity. Time was scheduled during the practical sessions for each group and no time limit to complete the test instrument was given to any group. The researcher carried out all the assessment after administration.

iii) *Normative data* – The purpose of this study is to estimate precisely the students' level of performance in three scientific process skills. The instrument is therefore criterion-referenced. In a criterion-referenced instrument, an individual's score is interpreted by comparing it with a professionally judged standard of performance. In this case, a full score (all the items correct) would be considered maximum capacity in the scientific process skills being examined. Criterion-referenced instruments aim at testing understanding of domain specific knowledge. The overriding aim of this research is to establish the students' level of capacity in the application of some of the process skills used in science – a good reason to choose a criterion-referenced type instrument. It is also an objectives-referenced measurement because it is aimed at finding out the abilities of the students to answer items measuring specific instructional objectives.

iv) Validity – Please find a more detailed discussion below.

v) Reliability – Please find a more detailed discussion below.

3.1.3 Validity and reliability of the instrument

A valid probe is one that tests what is supposed to be tested (Bell, 1999; Verma & Mallick, 1999; White and Gunstone, 1992). A reliable probe is one that will produce similar results on different occasions under constant conditions (Bell, 1999, & Verma & Mallick, 1999). A commendable aim of rigorous research is the solution of valuable and fundamental research questions through the use of techniques that are both reliable and valid (Verma and Mallick 1999; Hammersley, 1987). In order to collect data that were both reliable and valid, the probes given to the students in the study were critically assessed. The reviewing of probes by colleagues, as suggested by Bell (1999), was used to ensure that a degree of validity was attained. This type of validity is termed "face validity", ("…the apparent appropriateness of an experimental design in resolving the question it is intended to address, at a subjective level". (Usability First, 2002)) where an expert checks both the content and the construct validity of the instrument. Anastasi (1998) points out a criticism of this approach by stating:

> "Content validity should not be confused with face validity. The latter is not validity in the technical sense; it refers, not to what the test actually measures, but to what it appears superficially to measure. Face validity pertains to whether the test "looks valid" to the examinees who take it, the administrative personnel who decide on its use, and other technically untrained observers" (p.144).

For the purposes of this research, and considering its context, it was decided that face validity would provide an adequate measure of validity for the instrument.

Once the researcher had designed the instrument it was given to science education experts at the universities of Pretoria and KwaZulu Natal in South Africa and Miami University in Oxford, Ohio, USA. It was also given to a curriculum specialist at the University of Pretoria. Each expert checked all the probes for reliability, validity, ambiguity and correct questioning technique. The entire expert input was taken into account before finalizing the instrument. Owing to the limited time available to implement the study with the students, the instrument was not piloted. Retrospectively, the high results achieved by the students in the test further assured the researcher of the validity and fairness of the instrument.

An Item analysis was run on the mcq's in order to find a standard error of measurement. This statistical test provides in indication of reliability as above, where the test is not applied more than once.

3.1.4 Quantitative analysis

An item analysis was carried out on the results of the multiple-choice section of the test. The item analysis evaluates the quality of the item as well as concepts that the students might have difficulty with (Zurawski, 1998). There are three statistics that can be derived through an item analysis viz. item difficulty index, item discrimination and distracter power.

The item difficulty index is merely the proportion of test takers who took the test who selected the correct answer. As a proportion, the statistic can range from 0 if no one got the correct answer and 1 where all everyone got the correct answer. The only information given by this statistic is indicative of the number of students answering a question correctly. No rationale for the statistic is gleaned at all.

The item discrimination index adds a more informative dimension to the item analysis. It gives an indication of the item's ability to differentiate between test takers who did well in the test over all and those who did not. Zurawski (1998) states, "The item discrimination index tests the test in the hope of keeping the correlation between knowledge and exam performance as close as it can be…" To calculate the item discrimination index two groups of test takers have to be differentiated. This can be done in many ways as long as there is a differentiation between the stronger and the weaker performers in the test. Either the top 20% and bottom 20% (or any other percentage below 50%) of learners are taken, or all the learners scoring above the median and all those scoring below the median are grouped. The item difficulty index for each of the two groups is calculated. Subtracting the lower groups difficulty index from that of the higher group then arrives at the item discrimination index. According to Zurawski (1998), discrimination values of 0.30 and above are good discriminators and items with these figures are worthy of consideration.

The item distracter analysis is applicable only to multiple choice type questions and is a useful diagnostic tool here. It looks at the number of test takers who select each incorrect distracter. Distracters might be designed for different reasons. The primary reason in an ordinary test is to see if the test taker can discern the correct answer from a group of possible answers. Good incorrect distracters must have a level of plausibility in order for the item to be valid.

However, distracters may be designed to show common misconceptions. If a particular incorrect answer is selected at a high frequency, it may indicate a common misconception. An examiner may wish to determine how prevalent a well-known misconception is in a group. To do so a distracter designed to show the misconception or common understanding difficulty is included with the correct one and others in the item. It was with this intention that some of the items were designed for the instrument.

The questionnaires were scrutinized in order to identify and classify student difficulties. The results of the test indicated strengths and weaknesses in the students' ability to apply the process skills for which the instrument tests. There could be several reasons why students may have difficulties with using procedural knowledge other than lack of adequate exposure.

3.1.5 Qualitative analysis

Each multiple-choice question was accompanied by a request for the student to provide a reason behind the choice of distracter made. Several lines were provided on the questionnaire where the student was required to write an explanation of reasoning behind the choice. These written reasons were scrutinised in cases where the incorrect distracter was chosen. The responses were grouped into clusters of similar rationales. Where these clusters contained a large number of student responses, they were considered to be common misconceptions. It was this basic form of quantitative analysis that was used to speculate on reasons for possible student difficulties.

3.2 Sample selection

Permission to administer the instrument to all the genetics students at the University of Pretoria was negotiated with the Head of Department and the lecturers. All the students from first year through to the Honours year were asked to complete the instrument during a practical session timetabled in their schedules. By using these sessions, maximum population validity could be achieved for inference specific to the University of Pretoria. The cohort of students at UP for genetics is among the largest in South Africa; therefore, although further comparative research would have to be carried out, the data might be generalisable to other genetics students in South Africa. Purposeful sampling for the qualitative analysis for possible reasons for student difficulties was subsequently carried out after identification of possible difficulties.

The study was carried out only once and can therefore not be considered a longitudinal study. However, because each year of study is an academic progression on a previous year, some inferences are made as if the study were a longitudinal study.

3.3 Instrument administration

The instrument was administered in the genetics department facilities during practical sessions timetabled on the routine schedule for each academic year from first to third year. Honours students were scheduled specifically to complete the instrument in consultation with the Honours co-coordinator. All the students completed the instrument over a three-day period in six sessions; two first year, two second year, one third year group and the honours group. The researcher attended all the administration sessions, handing out the papers and explaining the purpose of the research to all the students as well as ensuring the confidentiality of each completed instrument. This was done in order to encourage maximum cooperation from the students. All the sessions occurred in the practical laboratories allocated for the particular sessions. No time limit was given to the students to complete the instrument, but no student took longer than an hour to complete it. As students completed the instrument they handed it to the researcher and were allowed to leave the venue. The masters and doctoral students were given the instrument to complete in their own time without supervision.

3.4 Other procedures

Various other statistical procedures were used in the analysis of the data. These are expanded upon in the relevant results chapter where they can be explained in context.

3.5 Time line

The main part of the research was completed in 2003. Table 1 shows the time allocated for each of the steps in the research.

Table 1: Time line indicating progress of the research project

March 2003	Found assistance in the form of interviews from Genetics Department staff to customize the list for genetics practice.
March 2003	Designed an instrument to test for the three scientific process skills most frequently mentioned in the lecturers interviews as important for genetics students.
April 2003	Tested the instrument for validity/reliability using colleague review.
April 2003	Made necessary revisions to the instrument.
	Research question A
May 2003	Administered the instrument to all genetics students.
June 2003	Processed data.
	Research question B
June 2003	Analysed data and identified and classified student difficulties.
2004 - 2005	Consolidated findings and wrote up results in the form of a thesis.

Chapter Four: Development of the instrument

The background to the development of the instrument is set out in detail in Chapter 3. Over a period of three days all the lecturing staff in the UP Genetics Department were interviewed as experts in the area of scientific process skills required for geneticists. Data from the interviews with lecturers was recorded on the interview sheet (Appendix 2). The skills mentioned by each lecturer are recorded below in Table 2.

Table 2: Table of expert suggestions of student difficulties with science process scores

Lecturer	Skills students have difficulty with
Expert 1:Dr Bloomer	Graphing skills Designing an investigation Making inferences from data Using mathematics (particularly grasping statistical procedures)
Expert 2:Dr Fick	Interpretation of data Synthesis of data in the context of a problem Use of graphs for communication Understanding long questions
Expert 3:Dr Greeff	Using numbers and mathematical formulae Seeing mathematical models in a real life context Relating mathematics to problems Understanding the concept of 'hypothesis' Defining variables operationally Interpretation of data and making inferences Synthesis of data Communication, writing in English is problematical
Expert 4:Ms. Herman	Using mathematics (particularly with respect to measurement) Designing investigations Integration of information Identifying variables Interpretation of graphs Understanding the concept of 'hypothesis'

Lecturer	Skills students have difficulty with
Expert 5:Prof. Huismans	Prediction Understanding of the scientific method in general Interpretation of results
Expert 6:Prof. Oberholzer	Using mathematics Synthesis of information Interpretation of graphs Understanding the concept of 'hypothesis' Interpretation of data Formulating a problem
Expert 7:Dr van Staden	Prediction from data
Expert 8:Prof. Wingfield	Using mathematics Logical thinking Communication

The data from the interviews indicated that the most commonly mentioned process skills that genetics students have problems with are:

- Understanding the concepts of scientific inquiry (mentioned six times in different contexts);
- Using mathematics (mentioned 5 times);
- Reading graphs and interpreting data (mentioned 5 times).

The design of the student instrument (see Appendix 3) was informed by these findings. The instrument had four discrete sections, each with a view to covering different skills and different types of assessment. The first section tested for all three skills in the form of multiple-choice questions. The scores for this section could be quantitatively analysed. Reasons for each answer selected were requested and these student statements were aimed at gaining an insight into student difficulties if they arose. The other three sections focussed on understanding the concepts of scientific inquiry. The aim with the different sections was to assess Section One first and if any severe difficulties were diagnosed specifically with the skills of understanding the concepts of scientific inquiry, further analysis of parts of the rest of the instrument would be carried out. The resulting structure of the questionnaire is given in Table 3 below.

Table 3: Structure of the test instrument

Section	**Number of items in the question**	**Process Skill tested for**
Section 1	6 items – MCQ with explanations required 4 items – MCQ with explanations required 6 items – MCQ with explanations required	Understanding concepts of scientific inquiry Using mathematics Reading graphs and tables
Section 2	7 items – 1 one word answer and 6 MCQ with explanations required	Understanding concepts of scientific inquiry
Section 3	5 items – Short answers some with explanations required	Designing a fair experiment
Section 4	3 items – long questions	Designing a fair experiment

The results of Section One were used to answer the research questions for this study. Each of the following chapters deals with a single research question, showing the results with brief discussions. The rest of the test instrument items were to be used for further research beyond this thesis.

Chapter Five: University of Pretoria Genetics students' performance on the test instrument

The first research question driving this study is: *How do UP genetics students' perform in a test of their scientific process skills and do they experience any difficulties?*

Within this question there are two other related questions:

If they do have difficulties:

- *What is the nature of these difficulties?*
- *What is the potential source of such difficulties?*

In order to address all the facets of this research question, it is broken down into two parts and the two related questions. Each part is addressed separately below.

5.1 How do UP genetics students' perform when their abilities in scientific process skills are tested?

Only Section One of the instrument was analysed in order to answer this question. All the questionnaires were scored against a memorandum for Section One and the student's choices for each question were recorded. The data were captured electronically for further analysis using the SASS (Statistical Analysis for the Social Sciences) package. The average percentage score for the three skills and the instrument total for all the participants for each year are given in Table 4 below.

Table 4: Average Scores in percentages for all the years of study for the entire instrument and the sub-sections of the instrument

	Science process	**Mathematics**	**Graphs and tables**	**Instrument total**
First year	81.78	80.71	80.58	81.07
Second year	85.62	79.54	79.89	81.93
Third year	92.20	78.30	84.26	85.37
Honours	92.42	80.00	89.09	87.5
Masters and PhD	94.44	91.11	93.33	93.06

The results for the instrument are high on average, indicating that the short answer to the research question on how students do in a test of process skills is, 'very well'. The students performed well in all three of the skills tested.

Table 5 below contains the data for each item (V2 to V32). The frequencies for each distracter are given under the columns A, B, C and D as percentages. The correct answer is indicated in bold for each question in the frequency columns. The discrimination index was calculated using the Itemman statistical package. The difficulty index is also shown.

The results for each item once again support the fact that most of the students could get the correct answer for the questions. Over 90% of the students chose the correct distracter in six of the sixteen items. In only four of the items (25% of the items), fewer than 70% of the students chose the correct answer. Item V10 is the only item where under 60% of the students chose the correct distracter; 59% chose the correct option.

Table 5: Item difficulty, discrimination and distracter analysis

Variable	A	B	C	D	Item difficulty index (*p*)	Discrimination index (*D*)
V2	8	2	16	**72**	0.72	0.34*
V4	1	0	0	**98**	0.98	0.05
V6	0	1	**96**	1	0.96	0.07
V8	1	**77**	15	4	0.77	0.17
V10	11	5	**59**	14	0.59	0.31*
V12	1	4	3	**92**	0.92	0.14
V14	1	1	**93**	3	0.93	0.11
V16	13	**66**	11	7	0.66	0.45*
V18	**91**	2	4	1	0.91	0.24
V20	4	3	2	**86**	0.86	0.28
V22	4	22	3	**67**	0.67	0.51*
V24	5	1	**89**	3	0.89	0.22
V26	**71**	8	7	8	0.71	0.42*
V28	2	6	18	**68**	0.68	0.5*
V30	2	3	**93**	0	0.98	0.10
V32	10	**80**	1	7	0.80	0.33*

In the table above, the seven items that showed a discrimination index of over 0.3 are highlighted with an asterisk. The difficulty indices demonstrate that none of the items were experienced by the students as particularly difficult. However, where the item discrimination index is high (over 0.3 for this study) and the difficulty index low (under 0.75 for this study i.e. over 25% of the group did not give the correct answer) for a particular item, common conceptual problems might be discerned for some students by looking at the choice of distracters that they made.

5.2 Do the students experience any difficulties as a result of possible prior experience or misconceptions gained otherwise?

Having scrutinised the item difficulty and discrimination index for the items in Section One, the following items were selected as candidates for analysis for possible reasoning difficulty: V2, V10, V16, V22, V26 and V28. These items had a difficulty index of under 0.75 and a discrimination index of at least 0.3. Difficulties may therefore exist in understanding the importance of repeatability in scientific experimentation, making inferences from data, using mathematics in the context of biological problems and reading data from graphs and tables.

5.3 What is the nature of these difficulties?

The distracter analyses for the following items indicate that some students over the four years of study may possibly have some common difficulties in their understanding and thinking. The choices of alternative distracters allude at times to the possible nature of the difficulties. Each item is set out below showing the frequencies for each distracter. Where more than 10% of the students chose an incorrect distracter that distracter was considered for a possible common understanding difficulty.

V2	A biologist reported success in breeding a tiger with a lion, producing healthy offspring. Under what conditions will other biologists accept this report?
A	Research shows that other animals can be cross-bred.
	(1st year, 8; 2nd year, 10; 3rd year, 0; Honours, 0)
B	The offspring are given a scientific name.
	(1st year, 2; 2nd year, 1; 3rd year, 0; Honours, 0)
C	The biologist included a control in the experiment.
	(1st year, 17; 2nd year, 17; 3rd year, 9; Honours, 10)
D	The other researchers can replicate the experiment.
	(1st year, 74; 2nd year, 73; 3rd year, 91; Honours, 90)

Item V2 was designed to test whether a student could identify the importance of repeatability in science experimentation before generalisation of findings can be made – a necessity in science methodology when it comes to accepting new scientific knowledge. Most students (72%) indicate through their answers that they were aware of this point. Some students (16%) however indicated that they thought that having a control in the experiment was more important. The importance of a control experiment is emphasised when taught at school level as well at tertiary level so it is not surprising that some students chose this distracter. Very few students chose distracters A and B, indicating that these distracters do not show possible common understanding difficulties.

V10	Based on the fact that a watermelon contains many seeds, what can be inferred about the normal flower of the watermelon plant? It contains…	
A	many sepals and petals	(1st year, 13; 2nd year, 5; 3rd year, 5; Honours, 0)
B	very large anthers	(1st year, 6; 2nd year, 4; 3rd year, 0; Honours, 9)
C	a large number of ovules	(1st year, 66; 2nd year, 85; 3rd year, 91; Honours, 91)
D	a large number of stamens	(1st year, 16; 2nd year, 6; 3rd year, 5; Honours, 0)

Basic understanding of flower anatomy is required in order to make an inference in V10. The anatomy of the flower is taught in the general science syllabus in South Africa and under the previous syllabus (prior to the introduction of C2005) it was covered several times. The only background knowledge required to make the inference is that seeds develop from fertilised ovules – a fact one would assume all biologists would have as propositional knowledge. They should also know that the stigma, style and ovary together make up the female parts of the flower which give rise to seeds and the anthers and stamens make up the male flower parts. Equally common knowledge should be the fact that petals and sepals are not sexual organs but ancillary parts of the flower. Also it should be understood that one flower generally gives rise to a single fruit and that a single fertilised ovule gives rise to a single seed. With this knowledge, and the cues given in the distracters, it is surprising that so many students chose the incorrect distracters. They were required to infer that with many seeds in a single fruit, which originates from a single flower, there would have to be many ovules. Only 59% of the students chose the correct distracter – C. 14% and 11% of the students selected distracters D and A respectively. These two distracters therefore may point to common understanding difficulties. Too few students selected distracter B for it to be considered indicative of a common understanding difficulty.

V16	For several years, the blue whale population off Antarctica has grown by 2,5% per year. If the population is 1000 this year, which of the following formulae would you use to calculate the number of blue whales next year?	
A	1000 x 0.25	(1st year, 13; 2nd year, 16; 3rd year, 24; Honours, 9)
B	1000 x 1.025	(1st year, 69; 2nd year, 66; 3rd year, 61; Honours, 55)
C	1000 x 1.25	(1st year, 12; 2nd year, 10; 3rd year, 4; Honours, 18)
D	1000 x 2.5	(1st year, 6; 2nd year, 7; 3rd year, 11; Honours, 18)

The incorrect distracter choices for V16 clearly show problems with mathematical reasoning. Had the students merely checked their choices by working out answers, they might have realised their own difficulties. 66% of the students got the question correct while 13% and 11% of them selected incorrect distracters A and C respectively.

V22	Which of the following statements is correct given the following equation? $y = 2 + (10/x) - (z/3)$	
A	y will increase as x increases	(1st year, 4; 2nd year, 3; 3rd year, 0; Honours, 0)
B	y will increase as z increases	(1st year, 23; 2nd year, 23; 3rd year, 27; Honours, 9)
C	z will increase as x increases	(1st year, 3; 2nd year, 2; 3rd year, 0; Honours, 0)
D	y will increase as z decreases	(1st year, 71; 2nd year, 72; 3rd year, 73; Honours, 91)

V22 required the student to work in the abstract and understand the relationship between the numbers and operations in the equation – a complex mathematical skill. However, by simply substituting values into the equation, the students could have worked out the answer. While 67% of the students selected the correct distracter, 22% selected the incorrect distracter B. Distracter B is seen as having strong potential in this particular study for showing a common mathematical reasoning difficulty.

The following two questions are based on the information and data in the tables below. In addition to requiring a level of mathematical reasoning ability, they also require that data are interpreted.

A scientist investigated the factors that affect seed mass in the plant species ***Desnodium poniculatum***. Some results of this study are summarized in the tables below.

Table 1

Daylight hours	**Other variable**	**Average seed mass (in mg) of plants raised at:**	
		23°C	**29°C**
14	-	7.10	5.63
14	Leaves removed	7.15	6.11
14	Reduced water	4.81	5.81
8	-	6.12	-

Table 2

A. Number of seeds per fruit	Average seed mass (mg)
1	6.62
2	6.28
3	5.97
4	6.00
5	5.59
B. Position of seed in fruit*	Average seed mass (mg)
1 (closest to stem)	5.98
2	6.06
3	5.96
4	5.82
5 (farthest from stem)	5.27
Note: Seeds closest to the stem mature first and are released first.	

V26 Which of the following conclusions is **NOT** consistent with the data presented in **Table 2**?

A The last seed released from the plant will have a greater mass than the first seed released.

(1st year, 76; 2nd year, 73; 3rd year, 93; Honours, 100)

B The first seed released from the plant will have a greater mass than the last seed released.

(1st year, 9; 2nd year, 13; 3rd year, 0; Honours, 0)

C The last seed released from the plant's fruit is the farthest from the stem.

(1st year, 7; 2nd year, 8; 3rd year, 5; Honours, 0)

D Seeds of the smallest mass are located farthest from the plant's stem.

(1st year, 8; 2nd year, 6; 3rd year, 2; Honours, 0)

The students who did not choose the correct answer for V26 did not all choose a single alternative; their choices were distributed between the alternatives. 71% of the students selected the correct distracter, while fewer the 10% chose each of the three incorrect distracters. For this study these types of results are not considered indicative of common understanding difficulties.

V28	Suppose some of the plants in the study had been exposed to 8 hours of sunlight and a temperature of 29°C. If no other variables were introduced, which of the following would be the most reasonable prediction of the average mass of the seed(s) produced under those circumstances?	
A	8.30 mg	(1st year, 2; 2nd year, 2; 3rd year, 2; Honours, 0)
B	7.10 mg	(1st year, 6; 2nd year, 5; 3rd year, 12; Honours, 0)
C	6.50 mg	(1st year, 19; 2nd year, 16; 3rd year, 16; Honours, 9)
D	4.85 mg	(1st year, 73; 2nd year, 77; 3rd year, 70; Honours, 91)

With no other variable being brought in for this question, one would look at the experiment in the table that had no other variable too. The inference that would be made therefore is that at a higher temperature, the seed mass would be lower. Therefore the mass of the seed in the question would have to be lower than 6.12 mg.

5.4 What is the potential source of such difficulties?

It is possible only to speculate on reasons for the difficulties based on inferences made from the reasons students gave for making the choices of incorrect distracters.

Item V2

For V2 the answer required that the student have some knowledge about the philosophy and nature of science; the question did not test any reasoning ability per se. All of the distracters report correct procedures in the scientific process, however they all have different importance and relevance to the question. The importance of a control experiment in scientific research is given emphasis in science teaching along with repeatability of the experiments. It appears that some students may not have the knowledge of what priorities exist in science methodology –

that repeatability is given higher priority in acceptance of experimental results over the inclusion of a control experiment.

Item V10

In item V10, students answer that it is because it contains a large number of stamens that the watermelon flower produces a fruit that contains many seeds. 55 students gave a reason for selecting distracter D. Their answers are grouped as follows in Table 6.

Table 6: Student difficulties shown in item V10 having chosen distracter D

Category of difficulty	Sub-category of question	No. of students with difficulty
Student did not understand the question	Admits no knowledge of topic in English	3
	Afrikaans student admitting problems with English terminology	3
	Afrikaans student admitting problems with knowledge on topic	1
	Afrikaans student showing problems with translation of terminology	4
Student confused between male and female plant anatomy terminology	Stamens develop into seeds or carry seeds	15
	Stamens are seeds	1
Students saw a directly proportional relationship between the number of stamens in the flower and the number of seeds produced in the fruit	The amount of pollen produced is proportional to the number of seeds	5
	The number of stamens present is proportional to the number of seeds	14
Miscellaneous difficulties shown by single students		9

Eleven student responses could not be judged for possible misconceptions because they did not fully grasp the question either because they had a language problem (not being first language English speakers) or because they were unfamiliar with the terminology. Nine students showed unique difficulties that are not expanded on here because the aim of this research is to seek out common misconceptions. It appears from the inductive analysis that the biggest problem students had was in erroneously inferring a proportional relationship.

The question for item V10 is phrased in such a way that there is an implied numerical relationship between the number of seeds in a watermelon and the factors given in the distracters. It is natural to answer the question therefore, showing such a relationship. Fourteen students stated that there was a directly proportional relationship between the number of stamens present and the number of seeds formed. The following student responses support this conjecture:

> "…because the flower has a very large number of stamens, more seeds are present in the watermelon."
>
> "The more stamens present, the greater the amount of watermelon seeds."
>
> "I would say that the amount of stamens of the flower determines the amount [number] of seeds in the fruit which in turn will determine how successfully the plant will reproduce."

Five students said the relationship existed because if there were many seeds there had to be a lot of pollen produced so therefore the number of stamens had to be plentiful in order to produce the high amount of pollen for all the seeds. The following student reasons support this argument:

> "A large amount of pollen must be collected to fertilise [the large number of seeds]"
>
> "Die blom behoort 'n groot hoeveelheid stampers te bevat; meer stuifmeel kan dan op stampers beland en sort doende voortplanting te verberter." [A flower has a large number of stigmas; more pollen can land on the stigmas [if there are many stamens] thus improving reproduction.]

Sixteen students indicated confusion between the terminology for male and female flower parts. In most cases the students confused stamens with the ovary. Students in their reasons made statements such as the following:

> "Stamens produce seeds."

"The seeds in the plant come from the female organ/part called the stamen."

"Stamens develop into seeds when the flower develops into the fruit."

In item V10, some students (11%) answer that it is because it contains a large number of sepals and petals that the watermelon flower produces a fruit that contains many seeds. 39 students gave a reason for selecting distracter A. As for the inductive analysis for distracter D above, some students responses were not analysed for possible misconceptions or understanding difficulties. Students' answers are grouped as follows in Table 7 below:

Table 7: Student difficulties shown in item V10 having chosen distracter A

Category of difficulty	Sub-category of question	No. of students with difficulty
Student did not understand the question	Admits no knowledge of topic in English	7
	Afrikaans student admitting problems with English terminology	3
	Afrikaans student admitting problems with knowledge on topic	1
	Afrikaans student showing problems with translation of terminology	1
Students shows difficulties in understanding the relationship between the role of the flower in reproduction and numbers of seeds in the fruit	Number of flowers, size of the flower and number of sepals and petals determine reproductive success	4
	The number of petals and sepals is seen as a function of the number of flowers and / or the number of seeds produced in the flower	3
Students saw a directly proportional relationship between the number of sepals and petals in the flower and the number of seeds produced in the fruit	No sub-categories	8
Students confused with terminology	No sub-categories	4
Miscellaneous difficulties shown by single students	No sub-categories	8

Seven students linked the flower to the reproductive success implied the number of seeds. The sepals and petals make up the most visible part of the flower, the corolla. The corolla usually plays a large role in attracting organisms to assist in fertilisation.

Student reasons such as:

> "It is a vine plant and flowers should be large to attract insects that pollinate the flowers," and
>
> "The greater the anther of the flower, the greater the flower, the more seeds,"

suggest that this may be the case.

Three students see the number of petals and sepals as a function of the number of flowers and/or the number of seeds produced in the flower. The following statement illustrates the reasons these students give:

> "Watermelons contain many seeds, because it contains many sepals and petals which allow fertilisation and pollination to be very much higher."

Eight students created a linear relationship between the number of petals and sepals and the number of seeds in the fruit. Most of their reasons were nonsensical but the following student quotes clearly show the proportionality thinking:

> "The more seeds the more sepals and petals [there are]."
>
> "The more sepals and petals you have the more fruit are generated by that plant."
>
> "The more sepals and petals [there are] the more seeds produced."

Four students showed in their reasons that are confused with the terminology. The sepals and petals were confused with ovules and ovaries as shown in the following quotes:

> "The more petals to be pollinated the more seeds will be produced."
>
> "Sepals and petals are the parts of the plants that are most likely to contain seeds…"

<u>Item V16</u>

For itemV16, 86 students who selected the incorrect distracter A gave reasons for their choice. In all the cases where a numerical explanation was offered, the students equated 2,5% with the decimal fraction 0.25. They came about this conclusion in different ways. The following sample of quotes expresses their thinking:

> "2,5% = 2.5/100 = 0.25"
>
> "100 x 2.5/100 = answer, therefore 2.5/100%"
>
> "100 is a 10th of 1000 therefore 2.5/10 = 0.25"
>
> "2.5% of 1000 is 0.25"

The difficulty shown by the students is the conversion of 2.5% to a decimal fraction. These students did not see the link many take for granted between 0.25 and one quarter and realise that 2.5% is smaller than 25% or 0.25.

Most students who chose distracter C gave a similar reason, but they realised that to keep the original number of whales in the equation they would need to multiply by 1. The following students' reasons show this thinking:

> "100 x 0.25= the amount of whales added to the pop +1000 (already existing pop) thus =1000 x 1.25"
>
> "1000 x 0.25 = next years increase but must add this year's to this number therefore 1000 x 1.25"
>
> "It is 25% of the current population + the previous population therefore 1000 + 1000 X 0.25 therefore 1000 x 1.25"

Of the 52 students who wrote down reasons for their choice of distracter C, 46 students explained their thinking in the same way as these students quoted above. The other 6 students provided only written responses where the mathematical reasoning was impossible to discern objectively.

Item V22

In this item students are required to discern a relationship between two variables in the equation y = 2 + (10/x) – (z/3). Twenty two percent of the students chose the incorrect distracter B, which states that y will increase as z increases. One hundred and twenty students gave written reasons for their selection. Many of the reasons given for this choice referred to proportionality, for example:

> "Hoe groter z word, hoe groter word die breuk z/3 dus verhoog y.As z kleiner word word y ook kleiner" [The bigger z becomes, the bigger the fraction z/3 becomes, thus y increases. If z is smaller then y will also become smaller]
>
> "y and z are directly proportional"
>
> "y is directly proportional to z but inversely proportional to x"

Sixty-six of the students' reasons were that they saw y was directly proportional to z in the equation. The rest of the reasons were illegible, nonsensical or were not understandable through their numerical representation. No other common understanding difficulty was gleaned from the student responses.

Many of the students worked out that as z increased, z/3 would also increase. However not a single response considered that this increasing value was actually being subtracted in the equation. It seems the students assumed that if a value on the right side of the equation increased, so the left side (y) would also increase. The following student statements support this conjecture:

> "y is the numerator therefore if z increases then the value of z/3 increases which in turn makes y increase"
>
> "[The] denominator stays the same as the numerator increases therefore resulting in increased y value as z increases"
>
> "z is the numerator and as that increases so does the other side of the equation, which is y"

It appears for most students who chose this distracter that their consideration of the solution to the question fell short of looking at and considering all the operations within the equation.

Item V28

This item required that students reason with given data to make an inference on a hypothetical situation. The logical steps in the reasoning were:

- Find a similar situation
- Observe the changes that occur within the parameters of the hypothetical situation
- Create a mental model of what occurs in the similar situation
- Apply the model to the hypothetical situation
- Make the inference

In this example the most similar situation is where the plants are exposed to 14 hours of daylight with no other variables. In that experiment the mass of the seeds was lower at the higher temperature. By transferring knowledge from this observation to make the inference for the 8-hour exposure, one would assume that the mass of the seeds would be lower than 6.12 mg. Most students who made the incorrect choice chose distracter C, 6.50 mg.

Seventy-three students wrote down reasons for their choice of distracter C. Some students sought a value slightly higher than 6.12 mg because they reasoned only with the inappropriate data in the row above this experiment in the data. Immediately above is an experiment where there is an increase in mass with increased temperature as a result of water reduction. It is the only experiment in the table where seeds are heavier at 29ºC than at 23ºC. According to the logical steps in the reasoning given above, these students did not get as far in their reasoning as finding a similar situation. Twenty-nine students' reasons indicate this lack in reasoning. The following student reasons point to this trend:

> "At 23ºC and 8 hours of sunlight, the seed weighs 6.12 mg, therefore for 29ºC the seeds will most likely be 6,50 mg"
>
> "Due [Owing] to constant variables (such as water) the seeds mass would increase"
>
> "Followed trends"
>
> "Relationship between two columns"

Another nineteen students looked at the averages in the data in the columns. They did not read that the table represented four different experiments where different variables impacted on each experiment. It is likely that the assumption made by these students was that the table represented a single experiment with only a single variable and therefore the data in the temperature columns were related. The answers offered by distracters A, B and D fell obviously outside the average of these figures, so the choice of 6.50 mg was made as it fell closest to the average. The following student reasons suggest this may be the case:

> "It is closer to the other values given…"
>
> "…an average of given data"

The rest of the reasons were illegible, nonsensical, not understandable in their presentation, or unique to particular students.

5.5 Concluding remarks

The data suggest that there are some difficulties that occur with numbers among students. The results show the difficulties, the choice of distracter shows possible understanding or reasoning difficulty and the reasons students gave for their choices of distracter provides a basis on which the origin of the possible difficulties might be speculated upon. It is this type of information that should be taken to account when science process skills are to be taught.

Chapter Six: Tracking development of skills from first year through to post-graduate level

The second research question addressed by this thesis is: Does the performance of genetics students in scientific process skills develop (on average) throughout the undergraduate course in genetics? This is an important point to know for curriculum designers so that they may pitch any remediation accurately with respect to the students' abilities.

6.1 Comparison of instrument scores for all the years of study

The box plot in Figure: 3 - illustrates a comparison of results for each year of study. Box plots are useful in comparing data sets when they contain large numbers of data points. The key below in Figure: 2 is referred to in order to read the data in the box plot. Each whisker represents the distribution of the top and bottom quartiles, while the box represents the middle two quartiles. Outliers are indicated outside of the quartiles. The lowest value is taken as the lowest value after the outliers have been discounted.

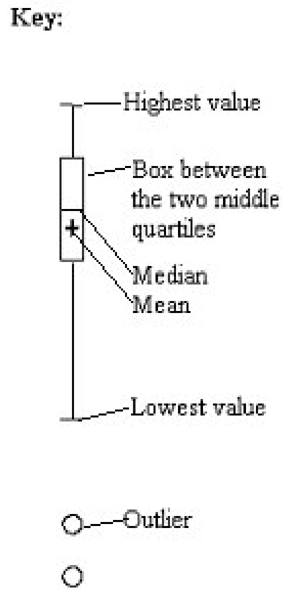


Figure 2: Key to Box Plot

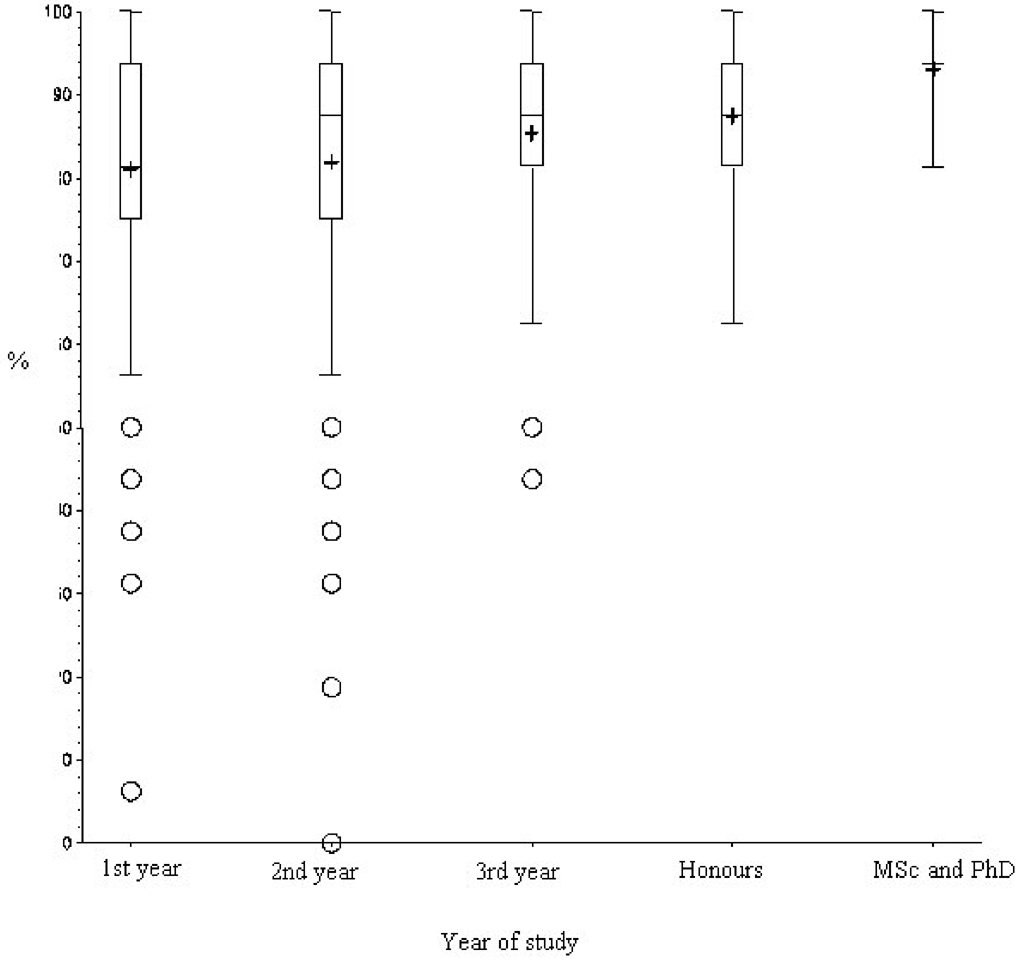


Figure 3: Box plot showing instrument scores in percentages for all the years of study

Figure: 3 is a visual representation of the differences in performance for all the academic years from first year through to MSc and PhD level. The mean score in the test for each year is indicated by a '+'. In the figure the '+' indicates a higher percentage for each year. At a glance, one can see that student performance does improve from first year through to post-graduate level. From the second year level upwards, the number of outliers decreases and the range of the two middle quartiles decreases. This implies that the group of students moving through the years becomes more uniform and better in their ability with the scientific process skills tested for in the instrument. Table 8 below shows the numerical data that support the box-plot.

Table 8: Instrument scores with means, standard deviations and variance for all the years of study

Year	N	Mean	Std Dev	Variance	Minimum	Maximum
First	467	81	14.47	210	6	100
Second	181	82	15.27	233	0	100
Third	48	86	13.15	173	44	100
Honours	11	88	11.18	125	63	100
MSc and PhD	10	93	5	24	81	100

Students mean scores increased over the years from 81% to 93% and the standard deviation and variance decreased. These results support the above suggestion that students' abilities in the three process skills tested for do improve from first year to postgraduate years. However, the statistical significance has to be sought in order to infer this suggestion as true, especially since the sample sizes for each year diminishes rapidly through the years.

A chi-square goodness of fit test was carried out on the data. The hypothesis tested with chi-square is whether the groups of students in each years performance is different enough in order that we can generalize that there is a statistical difference between the years. The chi-square value is 12.82 with a probability of < 0.05 (0.046), suggesting that the score is dependent on years of experience. A Kruskall-Wallis one-way analysis of variance was carried out on the same data to get a more detailed idea of where the differences might lie. The Kruskall-Wallis test compares rank of 3 or more different groups of data. It was found that the means between the first year level and the MSc/PhD level were significant at the 5% level ($\mu_1 < \mu_5$ at the 5% level) and the means between the second year level and the MSc/PhD level were significant at the 10% level ($\mu_2 < \mu_5$ at the 10% level).

6.2 Comparison of sub-scores for the three process skills tested for all the years of study

The instrument had items that tested for three different science process skills. The total scores for the instrument were split into three scores, one for each of the science process skills areas. The results are shown in Table 4 in Chapter 5.

For the processes of science, there is a clear trend towards improvement across the years, from 82% in the first year to 94% at MSc/PhD level. However, in using mathematics in biology there is an odd regression in ability until the honours year. First years scored higher on average than all the other undergraduate years and the honours year. For reading tables and graphs, but for the slight dip from first to second year there is a trend towards better performance, with a 12% rise in average from first year through to MSc/PhD level.

A chi-square goodness of fit test was carried out on the same data. The results are shown in Table 9 below. For understanding the methods of science the chi-square value is 40.89 with a probability of <0.05, suggesting that the score is dependent on years of experience for this particular process skill. However, students' performance in the other process skills was not dependant on the year of study.

Table 9: Chi-square statistics for the three sections of the instrument

	Chi-square statistic	**Probability**	**Dependence on year of study**
Processes of science	40.89	< 0.0001	Dependent
Using mathematics	4.12	0.85	Independent
Data reading and interpretation	10.98	0.20	Independent

A Kruskal-Wallis one-way analysis of variance was also carried out on the same data. For the skill of understanding the methods of science there is a significant improvement from first year to second year and then from second year to third year. There was no significance in the improvement in the mean score beyond that ($\mu_1 < \mu_2 < \mu_3 = \mu_4 = \mu_5$ at the 10% level). For the skills of using mathematics in biology and also reading graphs and tables, there is no significance in the increased means ($\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$). There is no significant difference in the performance of students from first year through to postgraduate studies in these two process skills.

6.3 Concluding Remarks

Each consecutive academic year results indicated that students' abilities generally do improve over the period of study from first year though to the postgraduate years. Students, whose abilities fall outside the range of the group, are excluded for postgraduate study. The skills of using mathematics and reading graphs and tables are not dependant on the year of study, suggesting that the students may already have their skill ability when they enter university and that these sills are practiced without being further developed. However, with the processes of science, there is an indication that there is development in the skills as the number of years of study increases.

Chapter Seven: Indicators of student performance in the instrument

Can some factors be gleaned from information about the students (both demographic and from their performance in the instrument) that show they impact on the students' performance in the instrument or various sections of the instrument?

7.1 Indicators from student performance within the instrument

The scores for all students for the three sub-test scores were correlated in order to establish whether there is a relationship between the performances in each of the three skills. The Pearson correlations were calculated for first, second, and third years. The Spearman coefficients were calculated for the honours and postgraduate student group because these sample sizes were small. Tables 9 to 14 below indicate these results. Table 9 shows the results for the entire group and Tables 10-14 show the results for each year of study.

Table 9: Pearson correlation of different skills for all the years of study (n=693)

	Understanding concepts of inquiry	**Using mathematics**
Understanding concepts of inquiry		
Using mathematics	0.26 p>0.0001	
Reading graphs and tables	0.29 p>0.0001	0.35 p>0.0001

Overall, there is a significant correlation between student performances in each of the three skills. A common thread to the three skills is the need to reason logically and clearly. If a student therefore has the ability to reason well, then he or she will be able to do well in all three skills. The scores will thus be expected to correlate highly.

Table 10: Pearson correlation of different skills for first years (n=451)

	Understanding concepts of inquiry	Using mathematics
Understanding concepts of inquiry		
Using mathematics	0.25 p>0.0001	
Reading graphs and tables	0.23 p>0.0001	0.41 p>0.0001

The first and second year group echo the results of the entire group. There is a strong correlation between their performances in the three different skills.

Table 11: Pearson correlation of different skills for second years (n=175)

	Understanding concepts of inquiry	Using mathematics
Understanding concepts of inquiry		
Using mathematics	0.28 p=0.0002	
Reading graphs and tables	0.39 p>0.0001	0.29 p>0.0001

Table 12: Pearson correlation of different skills for third years (n=47)

	Understanding concepts of inquiry	Using mathematics
Understanding concepts of inquiry		
Using mathematics	0.48 p=0.0006	
Reading graphs and tables	0.36 p=0.0140	0.12 p=0.441

At the third year level, there is no significant correlation between the skill of using maths and reading graphs and tables.

Table 13: Spearman correlation of different skills for honours year (n=11)

	Understanding concepts of inquiry	**Using mathematics**
Understanding concepts of inquiry		
Using mathematics	0.28 p=0.41	
Reading graphs and tables	0.30 p=0.37	0.26 p=0.45

Table 14: Spearman correlation of different skills for MSc and PhD (n=9)

	Understanding concepts of inquiry	**Using mathematics**
Understanding concepts of inquiry		
Using mathematics	-0.16 p=0.68	
Reading graphs and tables	0.0 p=1.0	-0.16 p=0.68

For postgraduate students, there is no significant difference in their performance in the three different areas of science process skills.

7.2 Indicators from information gleaned from student application forms

The students provide information about themselves on their application forms when entering study at the university. Some of this information was requested from the university administration in order to explore possible outside factors that might influence student performance in the test instrument. Tests were carried out using the variables for gender, home language and type of matric written by the students with the total score they achieved in the instrument.

7.2.1 Impact of gender on score

T-Tests were carried out for the whole sample using the pooled method with gender as the class variable, the scores for the maths score, the score for graphs and tables and the test total. The results are set out in Table 17 below.

Table 15: Impact of gender on scores

Score	Male (n=204)	Female (n=469)	t-value	Pr > |t|
Maths	84	79	2.82	0.0049
Graphs and tables	83	83	0.23	0.8185
Total	84	82	1.53	0.1256

In terms of the total score and with graphing and tabling skills, there is no significant difference between the performances of male and female students. However, male students significantly outperformed their female colleagues in the maths section of the instrument.

7.2.2 Impact of type of matric on score

A non-parametric one-way ANOVA was used to compare the scores in the test between students who had written the Independent Examination Board (IEB) matric and those who had written the state matriculation exam. Fifty-nine students had written the IEB matric and 614 had written the state matric. Those students unaccounted for here were from out of the country. The mean score achieved by the IEB students in the maths section of the test instrument was 84% and that achieved by the state qualifiers was 80%. However the F-value was 1.83 with a probability of 0.18, rendering the difference statistically insignificant. Similarly for the scores for the test total, IEB students scored 85% and the state qualifiers scored 82%. The F-value was 1.7 with a probability of 0,19; once again indicating a lack of statistical significance.

7.2.3 Impact of home language on score

The students in the sample came from many home-language backgrounds. They are grouped for analysis purposes into Afrikaans (n=365), English (n=237) and other (n=71). 'Other' includes South African languages other than English and Afrikaans and languages from beyond the borders. The test was administered in English; therefore an impact on test score was explored to see if students were disadvantaged through writing the test in a language other than their own. Kruskall-Wallis multiple comparisons were used to investigate. The results for each language group for parts of the test and the test total are given in Table 16 below.

Table 16: Mean scores in percentage for different language groups for sections of the test and test total

	Mean - maths score	Mean - rest of test	Mean for test total
Afrikaans speakers	82	83	83
English speakers	83	87	85
'Other' speakers	68	74	72

When it came to the maths score there was a statistically significant difference between scores of the Afrikaans speaker and other speakers and the English speakers and the other speakers (Kruskall-Wallis test statistic = 26.81 and P-value= 0.0).

With the rest of the test (processes and graphs and tables) and with the test total there were significant differences between all of the groups. (For processes and graphs and tables: Kruskall-Wallis test statistic = 51.06 and P-value= 0.0 and for the test total: Kruskall-Wallis test statistic = 51.07 and P-value= 0.0).

7.3 Indicators from the Matriculation scores:

Matriculation (matric) scores were made available by the Universities administration. Scores relevant to science performance were selected and Kruskall-Wallis tests run against the scores in the instrument for the entire sample of students. This was done in order to see if matric scores could be used as indicators of student performance on the instrument.

7.3.1 Matriculation mathematics as an indicator

Grade

The matriculation mathematics exam is written at higher grade and standard grade level. The higher-grade exam paper contains content of a more complex nature than the standard grade paper. It is therefore safe to assume that the highest performers in the higher-grade paper are the best performers in maths in general. In order to see if higher grade and standard grade matric maths students performed in the instrument differently, the plot of instrument score total against math mark by grade was drawn, see Figure 4 below.

From the plot the inference can be made that higher-grade maths students performed better in the instrument than the standard grade students did. Also, as the student matric maths score increased, regardless of grade, so their performance in the instrument increased. The top standard grade students and the lower higher-grade students appear to perform equally well.

One way ANOVA's were carried out with the matric maths mark by grade. The matric maths scores were grouped into 2 categories for the multiple comparisons as follows: 1 = Higher Grade (601 candidates), 2 = Standard Grade (46 candidates). No comparisons were made since only two groups were tested.

Kruskall-Wallis test statistic = 16.81 P-value = 0.0000

Mann-Whitney test statistic = 18762.00 P-value = 0.0000 using normal two-tail approximation.

This data supports the inferences made from the plot in Figure 4.

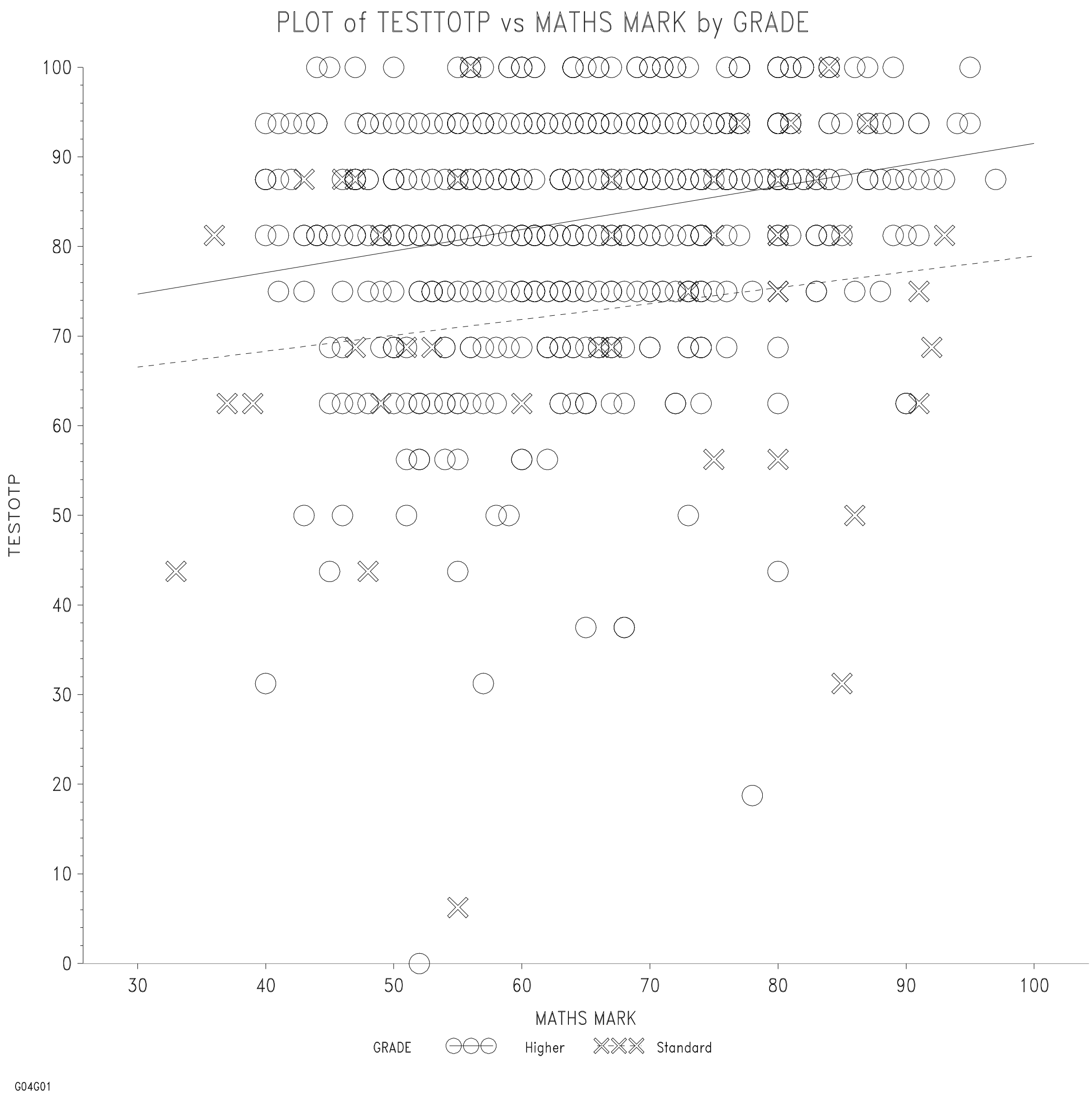


Figure 4: Plot of instrument score (TESTOTP) total against math mark (in %) by grade

Matric scores

Kruskall-Wallis tests were carried out with the matric maths mark and the score the students got in the instrument as well as each of the three sections of the instrument. The matric maths scores were grouped into eight categories for the multiple comparisons as follows:

Table 17: Splits for categories for higher-grade and standard-grade matric maths scores

Category	Grade	Score range
1	higher	scores less than or equal to 56%
2	standard	scores less than or equal to 49%,
3	higher	scores from 57% to 64%
4	standard	scores from 50% to 73%,
5	higher	scores from 65% to 74%
6	standard	scores from 73% to 81%,
7	higher	scores over 74%
8	standard	scores over 81%

The higher-grade and standard grade refers to a level of matriculation examination. Higher-grade curricula contain more complex content. The splits for the two groups were made in order that the categories would be comparable in terms of numbers. 601 students were higher-grade and 46 were standard-grade.

The critical Z values are 2.91 (*) for overall alpha of 0.10 and 3.12 (**) for overall alpha of 0.05 for all the tests run with the matric maths mark.

Table 18: Kruskall-Wallis test results showing significant difference between categories for matric mathematics

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
Instrument total	59.64	0.0000	1	7	6.29**
			2	7	4.19**
			3	7	4.94**
			4	7	3.73**
			5	7	3.66**
			7	8	3.03*
Maths total	71.31	0.0000	1	7	5.75**
			2	7	3.26**
			3	7	5.48**
			4	5	3.54**
			4	7	4.70**
			5	7	3.12*
			5	8	3.05*
			6	7	4.03**
Process total	16.83	0.0185	1	7	3.29*
Tables and graphs	28.82	0.0002	1	7	3.66**
			2	3	2.93*
			2	7	3.57**
			4	7	2.97*

Table 18 shows data which indicate that the top higher-grade maths students outperform all the other higher-grade students significantly. However, in the test total, the top standard-grade students outperform the top higher-grade students. Students who got higher scores in matric maths performed better in the instrument than their counterparts who achieved lower scores in matric maths. However, an interesting anomaly occurs where the second higher grade maths group (scores from 65% to 74%) performs significantly lower than the top standard grade group (scores over 81%) in the maths score.

The data in Table 18 suggest that there is a significant difference in the performance of students with lower matric mathematics scores and those with higher scores across both grades in reading tables and graphs. The top higher-grade students significantly outperformed the weakest higher-grade students as well as the weaker standard-grade students.

7.3.2 Matriculation physical science as an indicator

Kruskall-Wallis tests were carried out with the matric general science mark and the score the students got in the instrument as well as each of the three sections of the instrument. The matric physical science scores were grouped into eight categories for the multiple comparisons as follows:

Table 19: Splits for categories for higher-grade and standard-grade matric physical science scores

Category	Grade	Score range
1	higher	scores less than or equal to 58%
2	standard	scores less than or equal to 49%,
3	higher	scores from 57% to 66%
4	standard	scores from 50% to 63%,
5	higher	scores from 67% to 74%
6	standard	scores from 64% to 77%,
7	higher	scores over 74%
8	standard	scores over 77%

The critical Z values are 2.91 (*) for overall alpha of 0.10 and 3.12 (**) for overall alpha of 0.05.

Table 20: Kruskall-Wallis test results showing significant difference between categories for matric science

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
Instrument total	51.76	0.0002	1	5	3.72*
			1	7	6.17**
			3	7	5.24**
Maths total	51.76	0.0002	1	5	3.23**
			1	7	5.69**
			3	5	3.46**
			3	7	5.95**
Science process	8.33	8.33	-	-	-
Tables and graphs	36.90	0.0000	1	5	3.80**
			1	7	4.71**

The data from Table 20 suggest that the students who achieved higher scores in matric physical science at the higher-grade level performed better in the instrument than the lower performing groups. No significance occurs between standard-grade groups or between higher-grade and standard-grade groups. There are no significant comparisons between any of the categories for science process. Clearly therefore one cannot predict a student's achievement in science process based on his or her score in the matric physical science examination.

7.3.3 Matriculation biology score as an indicator

Kruskall-Wallis tests were carried out with the matric biology mark. The matric biology scores were grouped into 6 categories for the multiple comparisons as follows:

Table 21: Splits for categories for higher-grade and standard-grade matric biology scores

Category	Grade	Score range
1	higher	scores less than or equal to 67%
2	standard	scores less than or equal to 55%,
3	higher	scores from 68% to 76%
4	standard	scores from 56% to 85%,
5	higher	scores from 77% to 82%
7	higher	scores over 82%

The critical Z values are 2.71 for overall alpha of 0.10 (*) and 2.94 for overall alpha of 0.05 (**).

Table 22: Kruskall-Wallis test results showing significant difference between categories for matric biology

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
Instrument total	33.08	0.0000	1	3	3.48**
			1	5	4.71**
			1	7	4.86**
Maths total	22.14	0.0005	1	5	2.81*
			1	7	4.50**
Science process	6.59	0.2528	-	-	-
Tables and graphs	39.65	0.0000	1	3	3.74**
			1	5	5.25**
			1	7	5.06**

From Table 22 it can be seen that the weakest higher-grade biology students performed significantly lower than their counterparts in the higher categories for most of the comparisons. The predictive value in this data is therefore that the weakest students in higher-grade biology will not cope as well with science process skills as stronger students will. There is no significant difference between any of the 6 categories for science process scores.

7.3.4 Matriculation Afrikaans score as an indicator

Kruskall-Wallis tests were carried out with the matric Afrikaans mark. Only higher grade is offered in both English and Afrikaans at matric level. The matric Afrikaans scores were grouped into 4 categories for the multiple comparisons as follows:

Table 23: Splits for categories for higher-grade and standard-grade matric Afrikaans scores

Category	Score range
1	scores less than or equal to 67%
3	scores from 68% to 76%
5	scores from 77% to 82%
7	scores over 82%

The critical Z values are 2.39 for overall alpha of 0.10 (*) and 2.64 for overall alpha of 0.05 (**).

Table 24: Kruskall-Wallis test results showing significant difference between categories for matric Afrikaans

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
Instrument total	23.76	0.0000	1	3	2.71**
			1	5	3.81**
			1	7	4.46**
Maths total	11.55	0.0091	1	7	3.20**
			3	7	2.50*
			5	7	2.47*
Science process	10.73	0.0133	1	5	3.21**
Tables and graphs	24.83	0.0000	1	3	3.22**
			1	5	3.99**
			1	7	4.42**

Again the data in Table 24 show that the students from the strongest higher-grade category outperform their peers significantly and that the weakest are significantly poorer in the scientific process skills than their peers.

7.3.5 Matriculation English score as an indicator

Kruskall-Wallis tests were carried out with the matric English mark. The matric English scores were grouped into 5 categories for the multiple comparisons as follows:

Table 25: Splits for categories for higher-grade and standard-grade matric English scores

Category	Score range
1	scores less than or equal to 70%
3	scores from 71% to 78%
5	scores from 78% to 83%
7	scores over 83%

The critical Z values are 2.58* for overall alpha of 0.10 and 2.81** for overall alpha of 0.05.

Table 26: Kruskall-Wallis test results showing significant difference between categories for matric English

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
Instrument total	14.62	0.0056	1	7	3.76**
Maths total	12.72	0.0127	1	7	3.46**
Science process	5.41	0.2480	-	-	-
Tables and	16.21	0.0027	1	5	3.09**

Score used	Kruskall-Wallis test statistic	P-value	Category	Category	Z-statistic
graphs			1	7	3.28**

The data in Table 26 indicates that the top English students significantly outperformed the lower scorers. This shows the dependence of excellence in science on language ability.

7.3.6 Regression model

The following variables were used in a stepwise selection process in order to determine a model for prediction for student scores for the instrument total: gender, type of matric (ie IEB or Government or ex DET), home language, matric mathematics mark, matric general science mark, matric Afrikaans mark and matric English mark. The following model was derived:

Step	Variable entered	Model R-square	F Value	Pr > F
1	Matric General Science Mark	0.0689	40.32	< 0.0001
2	Home language	0.1143	27.88	< 0.0001
3	Gender	0.1218	4.63	0.0319
4	Afrikaans mark	0.1301	5.17	0.0233
5	Matric mathematics mark	0.1353	3.30	0.0697

All variables left in the model are significant at the 0.1500 levels. No other variable met the 0.1500 significance level for entry into the model.

7.4 Using the MLB (**M**o**L**ecular **B**iology) mark as an indicator

The MLB course is introductory to the fields of genetics, biochemistry and microbiology and is compulsory in the first year of study. A Pearson correlation was carried out between the scores the students got for the instrument as well as their scores for MLB. The Pearson correlation coefficient was 0.19686 with a probability of 0.0015, showing a significant correlation. Both scores were available for only 259 students out of the total sample. Figure 5 below shows this relationship visually.

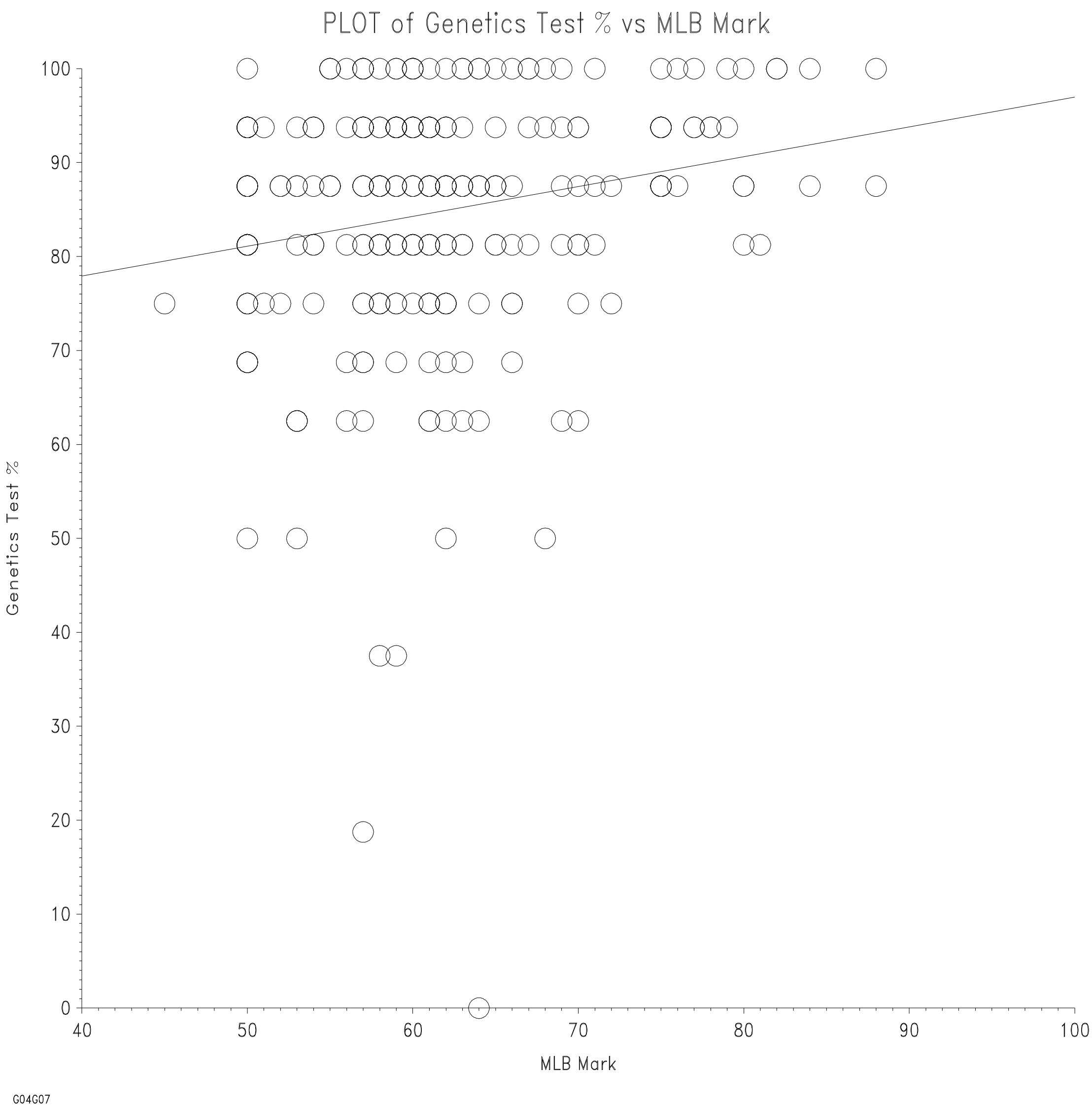


Figure 5: Plot of the instrument total (in %) and the score students achieved in the MLB examination

7.5 Concluding remarks

There are various factors which impact upon student performance on the science process skills tested for. The different skills are predictive of performance in each other in the early years. If a student does well in one skill, one can predict that they will be competent in the other skills. With regards gender, type of matric and home language there is evidence of problems that should be noted. Gender is not an important issue and statistically, neither is type of matric. However, it seems that the language problem is an issue. There is clear evidence from the data that students are at an advantage if they are tested in their home language.

It is also possible to predict student performance in the test from the scores they received in the subjects they took for matric. Higher-grade maths students outperform their standard grade counterparts. Students with higher maths scores in matric significantly outperformed lower scoring students in the test instrument. The same holds for physical science, biology, Afrikaans and English.

In a model for predicting student performance in the test instrument, the matric physical science mark came out as the strongest indicator. Home language, gender, matric Afrikaans and matric mathematics were other factors that contributed to the model in the given order respectively. Another significant indicator is the performance of the students in the MLB course.

Chapter Eight: Discussion

8.1 Interpretation of results

There were three research questions that drove this study. Each question required its own methods in the endeavour to answer them. The approaches delivered answers to the questions and these results are discussed below.

8.1.1 On the question of students general performance

The mean score achieved by the entire sample was high, suggesting that most, if not all, of the students already have a good command of the three science process skills that were investigated. The distracter analysis showed that no item proved difficult for the group as a whole. Nine of the sixteen items did not discriminate at all between low and high achievers in the instrument, and with the scores being so high in each item the suggestion is that these questions proved easy for all the students, regardless of their general overall ability. The difficulty indices for each item supports the statement that the students in this study in general performed very well in the instrument and therefore do not have a problem with science process skills.

Closer inspection of the split scores, i.e. those for the three different sections of Question One, highlighted that the students performed better in some areas than in others. The average score was highest in those items dealing with science process. Dealing with tables and graphs provided more challenge and using maths in biology provided the biggest challenge. Although the scores for the instrument were high, one might infer that the science process skill students are most likely to find more difficult is that of using maths in science.

Having said that the students in the sample in general had no problem with the science process skills tested for, the instrument results offered the opportunity to study where some students had difficulties in some areas. Six items were selected based on their item difficulty and discrimination index to study possible understanding difficulties that some students might have. These items showed that poorer students were less capable of answering them correctly than their stronger counterparts. It is these weaker students responses that provide opportunities to seek common understanding difficulties. The six items were spread through the three science process skills tested for in the instrument.

The possible sources of the understanding difficulties were merely speculated. They were based on the inductive analysis of reasons students gave for choosing the particular incorrect distracter. It appears that students might know the processes of science but may not be familiar with the priority required for different processes. This speculation is based on the fact that students chose to ensure a control for an experiment to be more indicative of acceptable and generalisable research than repeatability of the experiment. A control experiment is an important part of the design of an experiment and this point is taught throughout the school curriculum. However, repeatability of an experiment is far more important in accepting new science. An experiment that is not repeatable may have had a control.

Making an inference based on given information also provided some student with difficulty. However, in this particular case, it may not be the inability to make an inference that is the difficulty. It appeared through the inductive analysis that the students' difficulty was likely to lie more with not understanding the terminology because of a language problem or because they lacked the background knowledge required before the inference could be made.

Two items showed that students had difficulty with maths. One of the difficulties was clearly exposed as being an inability to convert percentages into decimals correctly in order to do calculations. Two types of difficulty are evident from the distracter analysis, but on inspection the understanding difficulty was the same; many students equated 2,5% with 0.25. Percentages and decimal fractions are commonly used in all research to express relationships such as growth or reduction in a sample as a result of a particular variable. It is imperative that a scientist therefore be able to understand the relationship between percentages, decimals and whole numbers without any problem. With 24% of the students in this study showing a problem with this item, it is necessary to consider some sort of remediation strategy, either in selection of students for science courses or in the provision of extra mathematical training.

The second maths problem was an algebraic one with several different sources shown in the reasons students gave for choosing the incorrect distracter. However for many students the difficulty lay with understanding the functions of signs in equations. Most students saw the relationship between the denominator and numerator and how the value of the fraction would change with changes in these values, but they did not recognise the function of the fraction in the equation, in this case subtraction. There could be several reasons for this problem which were not delved into for this study, but it is speculated that the students did not spend the time required on the question to go beyond the first problem that needed to be solved, that of working out the value of a fraction.

Two items showed a difficulty some students might have with reading data from graphs. This skill is also a form of maths literacy but is knitted in with other science process skills such as making inferences and drawing conclusions. One of the items did not expose a common reasoning difficulty. The complex reasoning required to answer the item on making an inference from data provided in the table, makes it difficult to pin point a single source for this difficulty. It appears that for many students, embarking on the complexity of the reasoning was the problem. They did not get as far as looking for a similar situation to the hypothetical situation before trying to complete the reasoning process.

To conclude the results of the investigation into the students' abilities in the science process skills the following assumptions are made:

- As a group this sample of students do not show any severe difficulties.
- Some students in the group have some difficulty with all of the process skills in the instrument, but the skill that poses the biggest challenge is that of using maths in science. Reading graphs and tables, which is also partly a skill of maths literacy follows closely.
- The sources of the difficulties appear to be, difficulties with language, understanding some of the science and its terminology, the interrelationship between percentages and decimal fractions, relationships within equations, and embarking upon complex reasoning processes.

8.1.2 On the question of progress and development of process skills through the years of study

The students' performance from first year through to masters and doctorate level improves in a staggered fashion, with the mean scores each group achieved in the instrument increasing from first year upwards. There is very little increase from first year to second year, but between second year and honours year there is a marked leap in the mean score. However it must be born in mind that the number of students in each year decreases from first year onwards, so such a comparison may not hold water.

From first year to second year the improvement is smallest. As expected, the improvement from first year to MSc and PhD is the most marked. This is an imprudent inference because the masters and PhD students completed the instruments without supervision and therefore their data were excluded. However if one looks at the comparisons of the undergraduate scores with those of the honours group, a similar inference can be made. It appears that the largest leap within the undergraduate group is between the second and third year. To conclude the results of the investigation of progress made in the development of science process skills through the years of study, the following assumptions are made:

- There is a small increase in ability from first year to second year.
- There is a marked increase between the second and third year.

8.1.3 On the question of indicators of student achievement in science process skills

Various strategies were investigated in order to find a predictive strategy for student performance in science process skills. These strategies were sought within the test scores as well as from scores achieved in other subjects completed at undergraduate level, matric scores and some demographic information.

The abilities students have with any one of the three science process skills tested for correlates with that they have in any of the other skills. The highest correlation is between using maths in science and reading tables and graphs. This is not surprising given the mathematical nature of reading data from graphs and tables. The correlation between the two mathematically biased skills and that of science process can only be explained by the fact that mathematically strong students are likely to achieve well in almost any academic pursuit because they have good reasoning abilities.

By the second year, the correlation between using maths and science and understanding concepts of inquiry is statistically insignificant. From third year upwards, there is no statistical significance at all for any of the correlations between the three scores. Although the correlations are statistically strong for the whole group and for first years, there is no evidence from this research that these areas can be used as indicators of performance. It is merely safe to say that in general, if a student is mathematically strong, they are likely to have no problem with other science process skills in the first year. It would be irresponsible to use the predictive value of these scores in first year to select students for further study.

Although male students do better in the use of maths in science than female students, overall there is no significant difference in their abilities with science process skills. There have been several studies in science education which have looked at gender issues, particularly at the fact that females were previously disadvantaged. There is no evidence of this in this study, in fact female students significantly outnumber male students in genetics at the University of Pretoria and they certainly show they are equals on the discipline's playing field.

Matric scores in various subjects proved to be useful indicators of performance. It is clearly evident from the data that the top higher-grade students in any of the matric subjects used in the Kruskall-Wallis tests, performed in the instrument significantly stronger than their counterparts. When physical science, biology, Afrikaans and English were used for the same tests, the weakest higher-grade group were distinguished i.e. they were shown to perform significantly poorer than their counterparts. The value in these correlations is in predicting who will achieve the lowest score in the instrument in the event that selection of students might have to take place.

The MLB score achieved in first year has some predictive value but insufficient to use for selection procedures. It will only be an accurate predictor for about 20% of all cases.

The regression model provides another predictive instrument for student selection. This model contains three of the matric scores and two demographic factors; home language and gender. Although home language and gender did not show any significant impact on student performance in the instrument (and therefore have not been expanded upon in this thesis), they are included in the model. The value of the regression model is questionable as it includes two variables that in independent tests show no significant contribution to the student performance.

No single, simple predictive factor or reliable model could be found which could be used to predict student performance. Almost every factor tested for predictive value had some merit, but not sufficient on which one could rely to make best choices for student selection.

8.2 Limitations of the study

In retrospect and on inspection, this study has several drawbacks that curtail wide generalizations of the findings. Some have to do with the choice of the sample and others with the research design. Those negative aspects identified by the researcher are expanded upon below.

Limitations in the design of the research

On reflection, it is evident that the research questions were answered for this study. However the questions and the design could be improved. In finding which skills to test for, it might not be ideal to ask lecturers for their inputs. The skills they require are those for scientists involved in research at the university. Those skills that were sought in the studies that motivated this research were those required in the work place. There may be little commonality in the requirements of academia and industry in terms science process skills required in their employees.

The study was completed only in one department at one university. Departments and Universities have their own characters, strengths and weakness. The academic environment as a result will differ from department to department and university to university. It is therefore ill considered to say that the findings of this study will definitely apply at any other department or university locally or worldwide. The more another department or university's environment has in common with that in which this study was carried out, the more their results will resemble these if the study were to be carried out there.

It is reckless to state that the students' abilities improve from first year through to post-graduate level. Although this is a possibility, no variables in the form of interventions for science process skill improvement were identified or studied in this research, so it is not possible to link the improved scores to anything other than experience. The next flaw is that students' experience and growth were not studied. This was not a longitudinal study where students could be monitored from first year through to their post-graduate years and individuals' abilities assessed for improvement. It is not unlikely that the improvement in scores observed across the years is due to elimination of students with lower abilities as the course develops through the years. Only academically strong students, who are likely to have more of an aptitude in science process skills, are selected for the honours course.

The sample sizes from first year through to the honours year decrease drastically, making it difficult to make generalizations from comparisons between the years. The first year group is by far the largest with 451 students, accounting for more than half the entire sample. This discrepancy could skew the results, making statements about the whole group spurious at times. However, the statistics consultants for this study accommodated this problem through their suggestions for statistical procedures. For example, for large groups a Pearson correlation coefficient was used to correlate the sub-scores for each year and a Spearman correlation was carried out for the smaller groups. A similar problem occurred where the higher-grade and standard-grade groups were distinguished for the Kruskall-Wallis tests run with the matric marks. The majority of students completed their matric subjects on the higher-grade level, leaving a very small group on standard-grade.

Limitations of the instrument

The high score achieved by the group as a whole suggests that the test might not have been pitched correctly. Only seven of the sixteen items had a discrimination index of over 0.3 suggesting that nine items were easy for the group as a whole. Some of the items did not test for the process skill exclusively; there were embedded alternate tests that were not anticipated by the researcher. This was particularly evident in the case where the students were required to infer a conclusion from information about a flower and seeds. It appears that the students who had difficulty with this item had difficulty with the language or the terminology in which the question was couched. It is therefore imprudent to infer that students performed badly in this item because they lack the skill of being able to infer a conclusion from given data. The item requiring insight into equations had a similar fault. It might have only tested students' staying power in order to solve a problem rather than whether or not they are capable of seeing relationships between values in and equation.

A significant limitation was that of language. The test instrument was given to the students in English when fewer than half the students were first language English speakers. The statistics showed that English speakers performed better in the test instrument than Afrikaans or other speakers. The genetics courses are delivered in English and all assessment is carried out in English. It is worth noting thus that students' performance in current assessments may not be a true reflection of their abilities.

Limitations in research process

The masters and PhD students were given the test to compete in their own time – without supervision. This approach was taken for logistical reasons. Their results therefore cannot be used for some of the inferences because the test conditions for them were vastly different from those for the rest of the sample. By looking at the data, these students did 'fall into line' and complete the instrument in the spirit of the research, so for some inferences it has been judged satisfactory to use their data.

8.3 Implications for future research

In this study a few understanding difficulties were identified and speculated upon as to their source. Each of these problems, in particular those in mathematics can be studied in more depth in order to devise better remediation strategies for future teaching. The instrument used in this study had few items that tested each skill. It is proposed that even more understanding difficulties will be uncovered if a more comprehensive instrument was designed to test each skill, particularly that of maths literacy for science.

8.4 Implications for practice

The good scores achieved by the students in the instrument, particularly in those students at the postgraduate level, means that little can be suggested to improve students' performance in science process skills. As a remediation strategy outcome of this study however, it might be recommended that science students either be tested for their literacy in the maths required in understanding and communicating good science prior to acceptance into the course, or a specific course should be designed where basic maths for science is covered in first year level. Reading data from tables is also a skill of mathematical literacy and should be included in such a course.

An unexpected outcome of this research has been the statistical evidence that students who wrote the test in their home language achieved better results. Many institutions of higher learning in South Africa teach in English, the language common as a second language to its students. This is the only real solution in a country with almost as many tertiary institutions as there are official languages and dialects thereof. In the first world, most students learn in their home language, so the students are able to achieve their full potential. It might be a solution in South Africa to, with further research, calculate a model that would factor in the language problem so that a truer reflection of non-English student abilities can be achieved.

List of References

Allen, L. (1973). An examination of the ability of third grade children from the Science Curriculum Improvement Study to identify experimental variables and to recognise change. *Science Education, 57,* 123-151.

American Association for the advancement of science. (1964). *Science, a process approach.* Washington DC, USA.

Anastasi, A. (1988). *Psychological testing*. Macmillan, New York.

Bell, J. (1999). *Doing your research project: a guide for first-time researchers in education and social science*, 3rd edn. Buckingham: Open University Press.

Biddle, B.J. & Anderson, D.S. (1986). *Theory, methods, knowledge and research in teaching.* Macmillan. New York.

Bishop, G.A. & Marsh, N.B. (1995). *The St Catherine's Sea Turtle Conservation Program.* [On-line] USA: Available: http://seaturtle.sdsmt.edu/055scimt.html. Accessed: 3 November 2004.

Bowen, G.M., & Bencze, J.L. (2002). Developing student teacher competency with the practices of science through long-term inquiry projects. *Paper presented at the annual American Educational Research Association Conference, April 1-5, 2002; New Orleans, LA.*

Brotherton, P.N. & Preece, P.F.W. (1995). Science Process Skills: Their Nature and Interrelationships. *Research in Science and Technological Education, 13,* 5-ll.

Campbell, R.L., & Martinez-Perez, L.A. (1976). A Study of Relationships of Science Attitudes, Achievement and Self-Concept of Pre-Service Teachers. ED125898.

Chiapetta, E. (1976). A review of Piagetian studies relevant to science instruction at the secondary and college level. *Science Education, 60,* 253-261.

Cohen, L. and Manion, L. (1994). *Research Methods in Education*, 4th edn. New York, Routledge.

Collegiate Assessment of Academic Proficiency. *Science sample passages and items.* (2003). [On-line] USA. Available: http://www.act.org/caap/sample/science.html. Accessed: 3 November 2004.

Colvill, M. & Pattie, I. (2003) Science Skills: The Building Blocks for Scientific Literacy. *Investigating, 9,* 21-23.

Criteria for the 15 skill areas, IEB working group pilot document, 1998. (unpublished workshop handout).

De Jager, T. & Ferreira, J.G. (2003). Factors preventing the development of process skills of biology secondary school learners in South Africa. *Educare, 32,* 186-198.

Delamont, S. (1992). Fieldwork in educational settings: Methods, pitfalls and perspectives. Falmer Press, London

Duggan, S., & Gott, R. (2002). What sort of science education do we really need? *International Journal of Science Education*, *24* , 661-679.

Eco, U. (1983). *The name of the rose*. Italy. Harcourt Inc. (Original work published in 1980).

Eidson, S., & Simmons, P.E. (1998). Microcomputer simulation graphic and alphanumeric modes: Examining students' process skills and conceptual understanding. *The Journal of Computers in Mathematics and Science teaching, 17,* 21-61.

Esprivalo-Harrell, P. & Bailer, J. (2004). Pass the mealworms, Please: Using mealworms to develop science process skills. *Science Activities, 41,* 33-36.

Fitts, W.H. (1964). *The Tennessee self-concept scale.* Nashville, Tennessee. Counselor recordings and tests.

Flehinger, L.E. (1971). Science Process Skill as a Predictor of Acquisition of Knowledge Among Preservice Teachers. ED087613

Gall, M. D., Borg, W. R. and Gall, J. P. (1996). *Educational Research: An Introduction.* 6th edn. White Plains, Longman.

Goody, J.R. (1977). *The domestication of the savage mind.* Great Britain.Cambridge University Press.

Green, R.D. (1994). Diagnosing and remediating observation process skill in integrated science pupils. *Studies in Educational Evaluation, 20,* 231-233.

Greene, J.S. & Greene, B.D. (2001). Using amphibians and reptiles to learn the process of science. *Science Activities, 37,* 29-32.

Hammersley, M. (1987). Some notes on the terms 'validity' and 'reliability'. *British Educational Research Journal*, *13,* 73-81.

The International Biology Olympiad. (2003) *Basic skills for the practical part of the IBO.* [On-line] Belgium: Available: www.kbinirsnb.be/ibo/program_pract.htm. Accessed: 3 November 2004.

Lederman, N. (1998). The state of science education: Subject matter without context. *Electronic Journal of Science Education, 3*. Editorial. Retrieved August 12, 2002, from www.ric.edu/ptiskus/Science_Education_Lederman.htm

Lincoln, Y. S. and Guba, E. G. (1985). *Naturalistic Inquiry.* SAGE Publications, Inc. London.

Lindberg, D.C. (1992). *The beginnings of western science.* University of Chicago Press. Chicago.

Matlou, M.D. (2002). *Tutors' perceptions about students' prior knowledge in genetics: a case study of teaching and learning in an academic development program at university.* Unpublished Masters thesis, University of the Witwatersrand, Johannesburg.

McGlathery, G. (1970). An assessment of science achievement of five and six-year-old students of contrasting socio-economic background. *Research and Curriculum Development in Science Education, 7023,*76-83.

McMillan, J. H. and Schumacher, S. (1993). *Research in Education: A Conceptual Introduction*, 3rd edn. New York, Harper Collins College Publishers.

Moore, J.E. (2003). The art of sorting: Using Venn diagrams to Learn Science Process Skills. *Science Activities, 39,* 17-21.

Moore, R.W. & Sutman, F.X. (1970). The development, field test and validation of an inventory of scientific attitudes. *Journal of Research in Science Teaching, 7.* 85-94.

Nakayama, G. (1988).A Study of the Relationship between Cognitive Styles and Integrated Science Process Skills. ED291592.

National Curriculum Statement For Grades 10-12 (Schools) Physical Sciences, Second Draft Subject Statement, (2002). Department of Education. Republic of South Africa.

Norman, J.T. (1989). The Effect of a Middle School Teacher Inservice Course Emphasizing Science Process Skills on the Development of Integrated Process Skills and Logical Thinking. ED306089

Ogunniyi, M. & Mikalsen, O. (2004). Ideas and process skills used by South African and Norwegian students to perform cognitive tasks on acids, bases and magnetism. *African Journal of Reasearch in Science, Mathematics and Technology Education, 8.* 151-164.

Onwu, G.O.M. (1993). Line graphing ability of some Nigerian secondary science students. *International Journal of Mathematics Education and Technology, 24,* 385-390.

Ostlund, K. (1998). What the Research says about Science Process Skills. *Electronic Journal for Science Education, 2, 4* . [On-line] Available: http://unr.edu/homepage/jcannon/ejse/ostlund.html. Accessed: 10 November 2004.

Oswego City School District Regents Prep Exam Center (1999) *Living Environment* [On-line] USA. Available: http://regentsprep.org/Regents/biology/biology.cfm. Accessed: 3 November 2004.

Padilla, M.J. Okey, J. & Dillashaw, F. (1983). The relationship between science process skills and formal thinking abilities. *Journal of Research in Science Teaching, 20.*

Padilla, M.J. Okey, J. & Garrard, G. (1984). The effects of instruction on integrated science process skill achievement. *Journal of Research in Science Teaching, 21,* 277-87.

Padilla, M.J., Cronin, L. & Tweist, M. (1985). The development and validation of the test of basic process skills. *Paper presented at the annual meeting of the national Association for research in Science Teaching,* French Lick, Indiana. USA.

Padilla, M.J. & Padilla, R.K. (1986). Thinking in Science: The Science Process Skills. ED 277549.

Padilla, M.J. (1990). The Science Process Skills. *Research Matters – to the Science Teacher*. No.9004. Available: http://www.educ.sfu.ca/narstsite/publications/research/skill.htm. Accessed: 10 November, 2004.

Pappas, T. (1991). *Mathematical footprints: discovering mathematical impressions all around us.* San Carlos, USA. Wide World Publishing/Tetra. 134.

Patton, M.Q. (1990). *Qualitative evaluation and research methods.* Sage Publications, London.

Phelps, A. J. (1994). Qualitative methodologies in chemical education research. *Journal of Chemical Education*, *71,* 191-194.

Radford, D.L. (1992). A Preliminary Assessment of Science Process Skills Achievement of Pre-service ementary Teachers. ED354145.

Rambuda, A. & Fraser, W. (2004). Perceptions of teachers of the application of science process skills in the teaching of geography in secondary schools in the Free State Province. *South African journal of education, 24,* 10-17.

Revised National Curriculum Statement Grades R-9 (Schools). (2003) *Teachers Guide for the Development of learning programmes: Natural Sciences.* [On-line] South Africa: Available: http://education.pwv.gov.za/content/documents/560.pdf. Accessed: 3 November 2004.

Rowland, P. (1987). Basic Science Process Skills. An Inservice Workshop Kit: A Workshop Manual. ED282773

Saskatchewan Education. (1992). Science: A Curriculum Guide for the Secondary Level Physics 20/30 [On-line] Canada: Available: http://www.sasked.gov.sk.ca/docs/physics/copyright.html. Accessed: 3 November 2004.

Schollum, B. (1983). Arrows in science diagrams: help or hindrance for pupils? *Research In Science Education*, *13*, 45-59.

Scholtz, Z., Watson, R. & Amosun, O. (2004). Investigating science teachers' response to curriculum innovation. *African Journal of Research in Science, Mathematics and Technology Education. 8*, 41-52.

Solano-Flores, G. (2000). Teaching and assessing science process skills in physics: The "bubbles" task. *Science Activities 37,* 31-37.

Steel, D. (2000). *Marking time: The epic quest to invent the perfect calendar*. John Wiley and Sons, Inc. New York, USA.

Strauss, J. & van Rooyen, H.G. (1992). Verband tussen studente se kognitiewe styl en geintegreerde natuurwetenskapprosesvaardighede. *South African journal of education, 12*, 191-193.

Soucheck, R. & Meier, M. (1997). Teaching information literacy and Scientifc Process Skills: An integrated Approach. *College teaching. 45,* p128-31.

Tasker, R. (1979). *Focus on Process Skills, Learning in Science Project.* Working Paper No. 7. ED 235017.

Theil, R. & George, D. K. (1976). Some factors affecting the use of the science process skill of prediction by elementary school children. *Journal of Research in Science Teaching.13,* 155-166.

Tomera, A. (1974) Transfer and retention of transfer of the science processes of observation and comparison in junor high school students. *Science Education,* 58, 195-203.

Usability First. (2002). *Usability Glossary*. [On-line] USA. Available: http://www.usabilityfirst.com/glossary/term_976.txl. Accessed: 3 November 2004.

Verma, G. and Mallick, K. (1999). *Researching Education: Perspectives and Techniques*. London, Falmer Press.

Weiner, D. & Weiner, J. (1996). Resource mentor: a tool to aid in the training of scientific investigators. *British Journal of Educational Technology. 27.* 5-14.

White, L. & Aldous, C.M. (2003). *Process Skills: Are teachers equipped and ready to implement.* In: B Putsoa, M Dlamini, B Dlamini & V Kelly (Eds). Proceedings of the 11th annual conference of the Southern African Association for Research in Mathematics, Science and Technology, Mbabane, Swaziland, 763-769.

White, R. and Gunstone, R. (1992). *Probing Understanding*. London, Falmer Press.

Wideen, M. (1975). Comparison of student outcomes for Science – A Process Approach and traditional science teaching for third, fourth, fifth, and sixth grade classes: A product evaluation. *Journal of Research in Science Teaching, 12,* 31-39.

Wilson, C. (1996). A Classroom Who-dunnit to sharpen science skills. *Teaching PreK-8, 26,* 52-54.

Yeany, R.H. (1984). Hierarchical Relationships among Modes of Cognitive Reasoning and Integrated Science Process Skills. ED244803.

Zion, M., Shapira, D., Slezak, M., Link, E., Bashan, N., Brumer, M., Orian, T., Nussinovitch, R., Agrest, A., Mendelovici, R. (2004) Biomind – A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education, 38,* 59-67.

Zurawski, R.M. (1998). Making the most of exams: Procedures for item analysis. *The National Teaching and Learning Forum,* 7, 1-4.

Appendices

Appendix 1: Basic and integrated science process skills

Table 27: Basic science process skills

Basic Scientific Process Skill	**Explanation**	**Examples**
Observation	This is the most basic process of science. The senses are used to obtain information about the environment.	During an investigation, a student writes a paragraph recording the progress of a chemical reaction between hot copper metal and sulphur vapour Examples of what this skill allows a scientist to do: Identify changes in colours that indicate chemical changes eg Iodine test for starch, and other food tests or acid, neutral and alkaline substances with various indicators. Observe and describe changes in colour, consistency, shape, levels of solutions, and changes in unknown situations. Match objects and make comparisons (similarities and differences) Identify objects from given information Classify objects using keys Observe details of features of objects/solutions/chemicals in known and unknown situations.
Communication	Communicating is any one of several procedures for transmitting information from one person to another.	Writing reports, or participating in discussions in class are examples of communicating." Examples of what this skill allows a scientist to do: [(5)] *Written or spoken descriptions* Record results and information Make a written or spoken summary of some information Make a formal written description of apparatus, materials and procedures, as in the write-up before or after an experiment or investigation *Diagrams and drawings* Know the difference between a drawing and a diagram. Know when a drawing or a diagram best models the information required to be communicated
Classification	Classifying is a systematic procedure used to impose order on collections of objects or events.	Grouping animals into their phyla or arranging the elements into the periodic table are examples of classifying.

Basic Scientific Process Skill	**Explanation**	**Examples**
Working cooperatively	This involves an individual working productively as a member of a team for the benefit of the team's goals.	Students should share responsibilities in the completion of an experiment.
Measurement	An instrument is used to obtain a quantitative value associated with some characteristic of an object or an event.	The length of a metal bar can be determined to the nearest millimetre with an appropriate measuring device. Examples of what this skill allows a scientist to do: Measure accurately and express results in the correct units Use measuring apparatus effectively (includes reading a meniscus accurately) Use grid to estimate areas Make rough estimates of mass, time, length etc Make valid measurements of variables, repeating measurements to obtain an average where appropriate
Questioning	It is the ability to raise problems or points for investigation or discussion.	A student should be able to create directed questions about observed events. When migratory birds are observed, questions such as, "Why do birds flock to migrate?", "Do some birds migrate singly?", and "How do birds know where to go?" should direct further inquiry.
Using numbers	This involves counting or measuring to express ideas, observations, or relationships, often as a complement to the use of words.	1 litre contains 1 000 millilitres.

Basic Scientific Process Skill	Explanation	Examples
Inferring	It is explaining an observation in terms of previous experience.	After noticing that saline sloughs have a different insect population than fresher sloughs, one might infer that small changes in an environment can affect populations. Examples of what this skill allows a scientist to do: Recognise patterns in data, extract information from results Interpret the results and observations which have been made in experiments or diagrams with correct scientific knowledge being used Make generalizations from observations Discuss anomalous results Make full conclusions with reference to data and results
Predicting	This involves determining future outcomes on the basis of previous information.	Given the results of the hourly population counts in a yeast culture over a 4 hour period, one could attempt to predict the population after 5 hours.

Table 28: Integrated science process skills

Integrated scientific process skills	Expected capacity
Note: the following six scientific process skills all have to do with the acquisition and processing of data.	
Constructing a table of data	Know the correct format of a table
Constructing a graph	• Select the most suitable means of recording data on the graph i.e. choose the most appropriate form from line graph, histogram, bar graph, pie chart, scattergram etc. • Know the correct axes for the dependant and independent variables • Set the axes to suit the data
Identifying variables	• Identify the independent variable and alter over a suitable range • Identify the dependant variable and measure it • Identify other relevant variables and suggest ways to control them • Collect relevant data and select an appropriate form for the presentation of results

Integrated scientific process skills	**Expected capacity**
Controlling variables (Describing a relationship between variables)	Controlling variables is based on identifying and managing the conditions that may influence a situation or event. Examples: If all other factors that may be important in plant growth are identified and made similar (controlled), the effect of gibberellic acid can be observed. In order to test the effect of fertilizer on plant growth, all other factors that may be important in plant growth must be identified and controlled so that the effect of the fertilizer can be determined.
Constructing and working with hypotheses	Hypothesizing is stating a tentative generalization which may be used to explain a relatively large number of events. It is subject to immediate or eventual testing by experiments. Example: Making predictions about the importance of various components of a pendulum which may influence its period is an example of hypothesizing. Examples of what this skill allows a scientist to do: • Formulate reasonable hypotheses from observations and results • Make deductions from hypotheses • Use observations to confirm or refute existing hypotheses • Modify hypotheses to accommodate new observations
Defining variables operationally	It is producing a definition of a thing or event by giving a physical description or the results of a given procedure. Example: An acid turns blue litmus paper red and tastes sour.
Note: The following scientific process skills have to do with designing investigations.	
Interpreting data	This important process is based on finding a pattern in a collection of data. It leads to a generalization. Example: Concluding that the mass of the pendulum bob does not affect the period of a pendulum might be based on the similarity of periods of 100 g, 200 g, and 300 g pendulums.

Integrated scientific process skills	**Expected capacity**
Formulating models	Models are used to represent an object, event, or process. Example: Vector descriptions of how forces interact are models.
Problem solving	Scientific knowledge is generated by, and used for, asking questions concerning the natural world. Quantitative methods are frequently employed. Example: A knowledge of genetics and the techniques of recombinant DNA are used to create bacteria which produce insulin.
Analyzing	It is examining scientific ideas and concepts to determine their essence or meaning. Examples: Determining whether a hypothesis is tenable requires analysis. Determining which amino acid sequence produces insulin requires analysis.
Designing experiments	Designing experiments involves planning a series of data-gathering operations which will provide a basis for testing a hypothesis or answering a question. Example: Automobile manufacturers test seat belt performance in crash tests. Examples of what this skill allows a scientist to do: • Identify aspects of a problem • Suggest a strategy to adopt in an investigation • State the aim of an investigation • Identify an appropriate procedure and select suitable apparatus and/or scale of suitable range to measure effectively • Plan a suitable procedure to test a hypothesis taking into account all the variables to be controlled

Integrated scientific process skills	**Expected capacity**
Carry out experiments	Use apparatus and techniques confidently and correctly with appropriate fine motor control
Using mathematics	When using mathematics, numeric or spatial relationships are expressed in abstract terms. Example: Projectile trajectories can be predicted using mathematics
Using time-space relationships	These are the two criteria used to describe the location of things or events. Example: Describe the migratory paths of the barren lands caribou.
Consensus making	Consensus making is reaching an agreement when a diversity of opinions exists. Examples: A discussion of the disposal of toxic waste, based on research, gives a group of students the opportunity to develop a position they will be using in a debate. Scientists were initially divided regarding the cold fusion debate. They held conferences but were still unable to agree on this issue. Further experimental results were needed.
Synthesising	Synthesizing involves combining parts into a complex whole. Examples: Polymers can be produced through the combination of simpler monomers. A student essay may involve the synthesis of a wide variety of knowledge, skills, attitudes, and processes.

Appendix 2: Lecturer interview sheet

Semi structured interview for Genetics Lecturers

Name of interviewee: ____

- **Interviewer defines process skills**
- **Interviewer defines the scope of the research**
- **Ask the open ended question "Do any process skills immediately strike you as problematic with genetics students?"**
- **If inadequate information is gleaned from the above question, go through the basic and then the integrated skills asking the questions.**
- **Courses taught to:**
- *Current 2nd years*
- *Current 3rd years*
- *Current honours students*
- **Is it possible to get copies of the practical manuals for these courses?**

Appendix 3: Test Instrument

Test for Scientific Investigation Skills in Genetics Students

Genetics Department
University of Pretoria

Dear Student

This test is aimed at identifying the increasing capacities in exercising scientific process skills amongst undergraduate and Honours students of genetics. There is much research going on world wide as to how science graduates accumulate skills often not explicitly taught. It is the aim of the study overseeing this test to show the change in abilities with these skills occurs in the Genetics Department at the University of Pretoria.

It is with the permission of your lecturers that I request that you complete the following questionnaire. The general findings will be forwarded to the Department. Your student numbers only are required in order for sampling procedures to be correctly carried out, but individual scores against your student numbers will not be made and individual scores will not be made available to anyone in the department.

In many cases there is not only one correct answer. The aim of such questions is to determine the most common perceptions and degree of in depth perception of certain concepts. Please fill in the test honestly and with an open mind in the knowledge that you will be contributing to science education research.

Thank you

Colleen Aldous

Please enter your student number into the shaded blocks below.

V1

1

SECTION 1 Below are a number of multiple-choice questions. Please indicate your choice of answer by drawing a **circle** around either **A** or **B** or **C** or **D** below. Please supply a brief reason for, or explanation of, your answer.

Example:

The Quagga is an extinct type of zebra which only has stripes on the front part of its body. Breeders have been trying to breed Quaggas from zebras which have lighter stripes on their backs. Which methods are most likely used?

A Artificial selection and inbreeding.
B Grafting and hybridization.
C Regeneration and incubation.
D Vegetative propagation and binary fission.

The correct answer is "A"

Explanation: *The Quagga was possibly an isolated population of zebras which due to genetic drift or selection lost the stripes on their backs. Continual breeding and inbreeding will allow for the selection of zebras with fewer and fewer stripes but will not bring the quagga back.*

1.1 A biologist reported success in breeding a tiger with a lion, producing healthy offspring. Under what conditions will other biologists accept this report?

A Research shows that other animals can be crossbred. V2 [ ] 9
B The offspring are given a scientific name.
C The biologist included a control in the experiment.
D The other researchers can replicate the experiment.

1.2 Please explain your choice of answer briefly.

V3 [|] 10

1.3 Which of the following statements could **best** be tested by experimentation?

A Blue is a far better colour than red generally speaking. V4 [ ] 12
B Robbie Williams is a better singer than Britney Spears.
C There is a ghost that walks through the Union Buildings at night.
D Water boils faster when you add salt to it.

1.4 Please explain your choice of answer briefly.

V5 13

1.5 When you are carrying out scientific research, how should you arrive at your conclusions? By ...

A saying what will be accepted by the general public. V6 15
B listening to the opinions of more experienced scientists.
C using the data you have collected in your experiments.
D asking more senior people what is correct.

1.6 Please explain your choice of answer briefly.

V7 16

1.7 As a scientific researcher what should you do once you have completed your experiments and acquired all the data you aimed to get?

A Discard the data that does not support your hypothesis. V8 18
B Test to see if your data supports your hypothesis.
C Change your hypothesis to suit the data you acquired.
D Repeat the experiments until the results support the hypothesis.

1.8 Please explain your choice of answer briefly.

V9 19

1.9 Based on the fact that a watermelon contains many seeds, what can be inferred about the normal flower of a watermelon plant? It contains ...

A many sepals and petals. V10 21
B very large anthers.
C a large number of ovules.
D a large number of stamens.

1.10 Please explain your choice of answer briefly.

V11 22

1.11 Scientific studies have indicated that there is a higher percentage of allergies in babies fed formula containing cow's milk than in breast-fed babies. Which statement represents a valid inference made from these studies?

V12 24

A Milk from cows causes allergic reactions in all infants.
B Breast-feeding prevents all allergies from occurring.
C There is no relationship between drinking cow's milk and having allergies.
D Breast milk most likely contains fewer substances that trigger allergies.

1.12 Please explain your choice of answer briefly.

V13 25

1.13 The diameter of a human hair is 0.1 millimeter. The diameter of this human hair in microns is ... (There 1000µm in 1 mm)

V14 27

A 1 µm
B 10 µm
C 100 µm
D 1 000 µm

1.14 Please show your calculation.

V15 28

1.15 For several years, the blue whale population off Antartica has grown by 2.5% per year. If the population is 1000 this year, which of the following formulae would you use to calculate the number of blue whales next year?

A 1000 x 0.25 V16 ☐ 30
B 1000 x 1.025
C 1000 x 1.25
D 1000 x 2.5

1.16 Please explain your choice of answer briefly.

V17 ☐☐ 31

1.17 A protocol for mixing the correct amount of an enzyme requires that 10 units of enzyme be added to every 100 ml of distilled water. The enzyme is in a powdered form and there is 1 unit of enzyme in every 2 grams of powder. How many grams of enzyme powder do you need to add to make 100 ml of solution?

A 20 grams V18 ☐ 33
B 10 grams
C 5 grams
D 2 grams

1.18 Please explain your choice of answer briefly.

V19 ☐☐ 34

1.19 In the same protocol as in **Question 1.17**, how many grams of enzyme powder would you add to make 5 ml of solution?

A 10 grams V20 ☐ 36
B 5 grams
C 2 grams
D 1 gram

1.20 Please explain your choice of answer briefly.

V21 37

1.21 Which one of the following statements is correct given the equation?

$$y = 2 + (10/x) - (z/3)$$

V22 39

A y will increase as x increases.
B y will increase as z increases.
C z will increase as x increases.
D y will increse as z decreases.

1.22 Please explain your choice of answer briefly.

V23 40

The following three questions are based on the data in the tables below:

A scientist investigated the factors that affect seed mass in the plant species ***Desnodium poniculatum***. Some results of this study are summarized in the tables below.

Table 1

Daylight hours	Other variable	Average seed mass (in mg) of plants raised at:	
		23°C	29°C
14	-	7.10	5.63
14	Leaves removed	7.15	6.11
14	Reduced water	4.81	5.81
8	-	6.12	-

Table 2

A. Number of seeds per fruit	Average seed mass (mg)
1	6.62
2	6.28
3	5.97
4	6.00
5	5.59
B. Position of seed in fruit*	Average seed mass (mg)
1 (closest to stem)	5.98
2	6.06
3	5.96
4	5.82
5 (farthest from stem)	5.27
*Seeds closest to the stem mature first and are released first.	

1.23 Which of the following conditions would result in the greatest seed masses?

V24 [ ] 42

A 8 hours of light, adequate water supply, and 23°C.
B 8 hours of light, decreased water supply, and 23°C.
C 14 hours of light, adequate water supply, and 23°C.
D 14 hours of light, decreased water supply, and 29°C.

1.24 Please explain your choice of answer briefly.

V25 [|] 43

1.25 Which of the following conclusions is **NOT** consistent with the data presented in **Table 2**?

V26 [ ] 45

A The last seed released from the plant will have a greater mass than the first seed released.
B The first seed released from the plant will have a greater mass than the last seed released.
C The last seed released from the plant's fruit is the farthest from the stem.
D Seeds of the smallest mass are located farthest from the plant's stem.

1.26 Please explain your choice of answer briefly.

V27 [|] 46

1.27 Suppose some of the plants in the study had been exposed to 8 hours of sunlight and a temperature of 29°C. If no other variables were introduced, which of the following would be the most reasonable prediction of the average mass of the seed(s) produced under those circumstances?

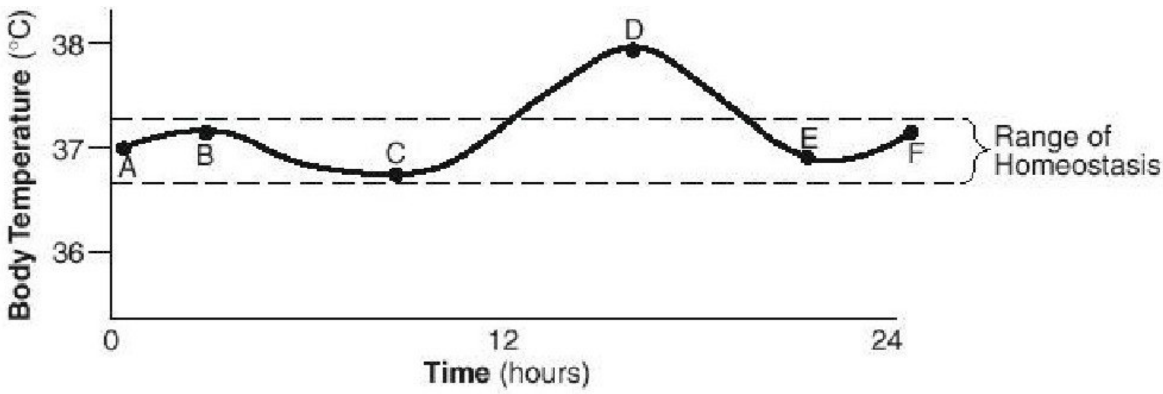
V28 ☐ 48

A 8.30 mg
B 7.10 mg
C 6.50 mg
D 4.85 mg

1.28 Please explain your choice of answer briefly.

V29 ☐☐ 49

1.29 The data in the graph below show evidence of disease in the human body.



A disruption in dynamic equilibrium is indicated by the temperature change between points ...

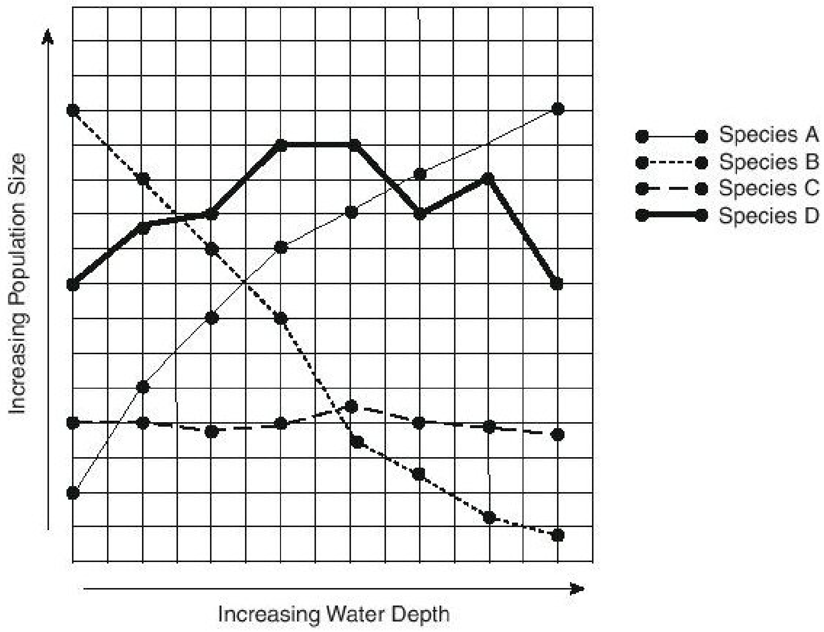
V30 ☐ 51

A A and B
B B and C
C C and D
D E and F

1.30 Please explain your choice of answer briefly.

V31 ☐☐ 52

1.31 As the depth of the ocean increases, the amount of light that penetrates decreases. At about a depth of 200m little if any light is present. The graph below illustrates the population size of 4 different species at different water depths.



Which species most likely performs photosynthesis?

A A
B B
C C
D D

V32 54

1.32 Please explain your choice of answer briefly.

V33 55

SECTION 2 Within the scientific endeavour, research methods followed will invariably make use of **observation**, **inference**, **prediction** and **hypothesis**.

2.1 What is an hypothesis? (Write your answer into the shaded space below)

V34 57

Read each of the statements below and decide whether each is an **observation**, **inference**, **prediction** or **hypothesis**. Please indicate your choice of answer by drawing a circle around either **A** or **B** or **C** or **D** below

2.2 "A rubber ball dropped from different heights rebounded 20cm when dropped from a height of 40cm, and rebounded 30cm when dropped from 60cm."

A Observation
B Inference
C Prediction
D Hypothesis

V35 59

2.3 Please give a brief reason for your answer.

V36 60

2.4 "Based on a graph of collected data, if the ball were to be dropped from a height of 110cm, it should bounce to a height of 55cm."

A Observation
B Inference
C Prediction
D Hypothesis

V37 62

2.5 Please give a brief reason for your answer.

V38 63

2.6 "The steeper the slope of a ramp, the further a film can at the base of the ramp will be moved by a toy car rolling down the ramp."

A Observation V39 65
B Inference
C Prediction
D Hypothesis

2.7 Please give a brief reason for your answer.

V40 66

2.8 "Water heaped up above the rim of a cup because of the bonding of water particles."

A Observation V41 68
B Inference
C Prediction
D Hypothesis

2.9 Please give a brief reason for your answer.

V42 69

2.10 "The surface of the water was above the rim of the cup."

A Observation V43 71
B Inference
C Prediction
D Hypothesis

2.11 Please give a brief reason for your answer.

V44 72

2.12 "If water is warmer, then more salt will dissolve in it."

A Observation V45 74
B Inference
C Prediction
D Hypothesis

SECTION 3 A group of students was studying the stretch of a condom when lead pellets was added. This was part of an AIDS awareness campaign where the misconceptions about the fragility of condoms were to be addressed. They added units of 20g of lead pellets to the condom that was fixed to the edge of a table and measured the total stretch of the condom using a ruler.

3.1 What was the **manipulated** variable in this experiment?

V46 75

3.2 Please give a brief explanation of your answer.

V47 77

3.3 What was the **responding** variable in the above experiment?

V48 79

3.4 Please give a brief explanation of your answer.

V49 81

3.5 What variables should be controlled in the investigation if it is to be a "fair" test of the hypotheses?

V50 83

3.6 Please give a brief explanation of your answer.

V51 85

3.7 Write down an appropriate hypothesis to guide the student's investigation?

V52 87

3.8 What would you do if your data does not support your hypothesis?

V53 89

SECTION 4

4.1 In Gauteng, researchers gave a cholesterol reducing drug to 2 335 people and a placebo to 2 081. After 5 years, 97 people who had been getting the placebo had suffered heart attacks compared to only 57 who had received the actual drug. The researchers are recommending that to help prevent heart attacks, all people take these cholesterol-reducing drugs.

In addition to the information above, what other information must the researchers have before support for the recommendation can be justified?

V54 91

4.2 A student formulated an opinion that cotton will grow larger bolls (pods) if magnesium is added to the soil. The student has two experimental fields of cotton, one with magnesium and the other one without.

Which data should be collected to support this opinion?

V55 | | | 93

4.3 In an area in Africa, temporary pools form where rivers flow during the rainy months. Some fish have developed the ability to use their ventral fins as "feet" to travel on land from one of these temporary pools to another. Other fish in these pools die when the pools dry up.

What can be expected to happen in this area after 5000 years?

V56 | | | 95

Thank you for your co-operation